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SUSTAINABILITY MODELING AND ASSESSMENT OF PRODUCT RECOVERY SYSTEMS - AN ENGINEERING APPROACH TO A SUSTAINABLE FUTURE

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SUSTAINABILITY MODELING AND ASSESSMENT OF PRODUCT RECOVERY SYSTEMS - AN ENGINEERING APPROACH TO A SUSTAINABLE FUTURE -

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ABSTRACT

Sustainability is defined as “meeting the needs of the present generation without compromising the ability of future generations to meet their own needs.” (WCED ,1987). This is a concept that was developed to counteract the negative consequences of the culture of disposability and consumption based economy on the environment. Many policy makers have the perception that pursuing policies that embrace sustainability would compromise countries economic prosperity. Therefore, this dissertation introduces the new index of sustainable prosperity. This is a novel multi-attribute measure that comprehensively assesses sustainable prosperity (SPI) for systems such as countries, hospitals, and products…etc. This index ensures that adapted policy contribute to progress toward sustainable development and equally important maintain the wealth of the system. Herein, we demonstrated its utility by applying it on the country case represented by the G-20 group.

We investigated the drivers for culture of disposability and made recommendation on expanding the definition of disposable products to better define its contribution to GDP. Furthermore, the major sustainability indices that act as tools in the assessment of sustainability were investigated. The goal is to identify a viable index to comprehensively assess sustainability and the key attributes for a good measure. While valid, each index had its own disadvantages that limited their use. A list of attributes that should be considered to develop an index that successfully measures the progress of nations toward sustainable development was developed (Table 4.6). These attributes were used as a frame of reference for the SPI index and the selection of the domains and sub-domains that are mapped to systems investigated.

The analytical methodology of SPI index is based on the use of Principle Components Analysis (PCA) combined with Data Envelopment Analysis (DEA) (PCA-DEA). This approach discriminates among systems i.e. G-20 countries investigated. It identifies the ones that are sustainable. It incorporates the use of inputs and outputs to calculate the efficiency score of each system investigated i.e. SPI. A total of 44 inputs (Chapters 6 and 7) were mapped to the domains and sub-domains of the framework. In addition, a total of 10 outputs were selected to capture the wealth of the nations, which is based on the maintenance of capital, or keeping capital stock least unchanged as proposed by Dasgupta (Dasgupta 2010). Initially, conventional DEA was implemented to calculate countries SPI. Since there was a large number of inputs and outputs utilized (a total of 54 variables) relative to the number of countries investigated (20 DMUs), this methodology fell short of discriminating among the G-20 countries. Indeed, all countries were sustainable and acquired an SPI score of 1. Therefore, PCA was used to reduce the number of variables and transform the original inputs and outputs into principle components with minimal loss of information (capturing most of the original variance of the original data). PCA reduced the number of combined inputs and outputs to a total of 17 variables while maintaining around (80-85%) of the total cumulative variation. Interestingly, this PCA-DEA methodology provides a similar impact to that of weight restrictions addition. Still countries discrimination was not satisfactory using this methodology (Table 8.7). To overcome this shortcoming, we used various combinations of PCA inputs and outputs to improve discrimination among G-20 countries. The impact of different case scenarios of the number PCA inputs and outputs used and their combinations for the years of 1990-

2012 was investigated (Table 8.9). Consistent with the literature reports, the use of one PCA from each dimension in the inputs and outputs provided the best differentiation among the G-20 group. This ensured that the SPI measure comprehensively assesses the progress toward attaining sustainable prosperity from the four dimensions, which is a key attribute of our novel index that many global indices lack. For robustness analysis, a Spearman Correlation Test (SCT) was performed to evaluate the relationships involved in the ranking of the G-20 countries using different PCA-DEA combinations. It was observed that there is high correlation between the countries ranking among different PCA-DEA combinations. Although the variability of the information has been reduced by integrating smaller number of PCA in the analysis, still we have effectively increased the discrimination among countries investigated. Collectively, the use of SCT was effective in demonstrating the validity of this methodology, consistent with literature reports.

Developed countries among the G-20 group had higher average SPI scores compared to developing countries over the period investigated. However, between 2008 to 2012, developed countries realized a reduction in the overall average SPI scores from ≈0.8 to 0.6. This trend was not clearly observed for the developing countries. This is the time period that followed the 2008 financial meltdown, which threatened the total collapse of large financial institutions and was prevented by the bailout of banks by national governments. Interestingly, the GDP growth in 2009 was limited to the developing countries, while developed countries had poor GDP growth if any.

A comparison between SPI results and key sustainability indices (GDP, EPI, and HDI) of the G-20 countries was determined. There is no link between GDP and SPI scores. The same trend was observed for HDI and EPI. The poor correlation observed between SPI and these indices is not unexpected since they assess only one aspect of sustainability considered, while SPI is a comprehensive sustainability index that integrates the three aspects of sustainability; environmental, economic, and social; in addition to the overall wealth as part of its assessment.

In summary, there continues to be a quest to build an index that enables policy makers to assess progress toward achieving sustainable development. Despite, the scientific research that was conducted, there is no general consensus on a sustainability index that would replace GDP. This is partially attributed to the fact that sustainability is a complex system that incorporates many dimensions. This research started with identifying the attributes that should be considered when building a comprehensive index that assesses progress toward sustainable development. Unlike other indices, our proposed index has a key advantage, which include among others, its ability not only to comprehensively measure sustainable development, but also to ensure that adapted policies contribute to maintaining the wealth of the system. In addition to countries, this novel index can also be used to assess and compare other systems such as hospitals, products, and manufacturing facilities to name a few. This research is far more than an academic investigation; it is rather a response for unmet need to present sustainability in a form that makes it more appealing for policy makers to make the investment in maintaining wealth while demonstrating progress toward sustainability.

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Abbreviations

Abbreviation	Definition
AHP	Analytic Hierarchy Process
BEA	Bureau of Economic Analysis
BRICS	Brazil, Russia, India, China, and South Africa
CDC	Centers for Disease Control and Prevention
CERES	Coalition for Environmentally Responsible Economics
CF	Carbon Footprint
CO_2	Carbon Dioxide
DEA	Data Envelopment Analysis
DEFRA	Department for Environment Food & Rural Affairs
DOE	Department of Energy
DMUs	Decision Making Units
EDF	Environmental Defense Fund
EF	Ecological Footprint
EDGAR	The Emissions Database for Global Atmospheric Research
EIA	U.S. Energy Information Administration
EIO	Environmental Input-Output
EPA	Environmental Protection Agency
EPI	Environmental Performance Index
ES	Environmental Space
ESI	Environmental Sustainability Index
ESS	European Social Survey
EVS	European Values Survey
EWI	Ecosystem Wellbeing Index
FA	Factor Analysis

FAO	The Food and Agriculture Organization of the United Nations
G-20	The Group of Twenty
GATT	The General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GNH	Gross National Happiness
GNI	Gross National Income
GPI	Genuine Progress Indicator
GRI	Global Reporting Initiative
GS	Genuine Savings
GWP	Gallup World Poll
HDI	Human Development Index
HPI	Happiness Index
HWI	Human Wellbeing Index
IDRC	The International Development Research Centre
IEA	The International Energy Agency
IEP	Institute for Economics and Peace
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
ISEW	Index of Sustainable Economic Welfare
ISO	International Organization for Standardization
JRC	Joint Research Centre
LCA	Life Cycle Assessment
MCMC	Markov Chain Monte Carlo
MDGs	Millennium Development Goals
MEW	Measure of Economic Welfare
MSW	Municipal Solid Waste

NGOs	Non-governmental organizations
OECD	The Organization for Economic Co-operation and Development
PCA	Principal components analysis
PI	Profitability Index
QUEST	Quality Utilizing Employee Suggestions and Teamwork
R&D	Research and Development
SA	Sensitivity analysis
SI	Sustainable Index
SNA	System of National Accounts
SNBI	Sustainable Net Benefit Index
SPI	Sustainable Prosperity Index
TCR	The Climate Registry
TSE	Towards Sustainable Europe
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNEP	The United Nations Environment Programme
UNESCO	The United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
WB	World Bank
W.Biocapacity	Globally Available Biocapacity per Capita
WBCSD	The World Business Council for Sustainable Development
WCED	World Commission on Environment and Development
WDI	World Development Indicators
WI	Well-being Index
WIPO	World Intellectual Property Organization

WHO	World Health Organization
WRI	World Resources Institute
WSI	Wellbeing/Stress Index
WVS	World Values Survey
WWF	World Wildlife Fund
ZEG	zero economic growth

CHAPTER 1: Introduction

1.1 Introduction

In 1776, Adam Smith "father of modern economics," published his prominent book "The Wealth of Nations", which played a key role in influencing economic thought at that era. It was based on that nation economic activity is based on boosting the stream of its goods and services. This led to the industrial revolution that was successful in establishing the standard industrial paradigm in the form of a linear manufacture-consume-dispose industrial system. This linear model is the first type of industrial eco-system[1] that is based on the sequence of raw material extraction, and then labor and technology are used to transform raw materials into final products that create profit (Graedel & Allenby, 1995). After a relatively short lifetime, these products are disposed of and become waste at the end of their life cycle. In essence, this model assumes an infinite supply of natural resources and sinks, which our planet cannot satisfy with our current rate of aggravated extraction, use, and disposal. Indeed, this era marked a significant increase in the generation of waste. For example, the per capita waste generation increased from 2.68 to 4.43 lbs/person/day and the Municipal Solid Waste (MSW) in USA was increased from 88.1 to 249.9 million tons from 1960 to 2010, (EPA 2011).

It should be emphasized that the economic activity fundamentals of this linear system are based on production and consumption. In this linear paradigm, the nation's economic progress is measured by making the manufacturing industry more efficient

[1] To attain industrial sustainability; the evolution of the industrial system is recognized in three possible stages that changes from type I a linear system to a more cyclic system Type III, like that of Mother Nature. This is a pivotal concept to industrial ecology (Graedel & Allenby, 1995).

thus producing more products. This results in the growth of the Gross Domestic Product "GDP", which fundamentally measures the production activity of a nation. Consequently, countries progress and development was driven by their ability to accelerate growth measured by GDP. It was generally believed that it is a good measure of prosperity. This has led societies to continue with their unsustainable consumption in their everyday life despite continuous losses of 'natural capital' that takes place around the planet. It is interesting to note that recent technological and scientific advances led to major transformation in the industry and manufacturing approaches in response to the excessive use of natural resource and to meet population needs. They significantly reduced material intensity to reduce natural resource extraction. While these efforts are relevant, they did not affect the bottom-line and natural resources continued to increase at a rate comparable to GDP as depicted by Figure 1.1. It is well established that this industrial revolution was associated with debilitating impact on our planet. Although increase in GDP leads to increase in countries wealth, it was clear that GDP methodology fells short from taking into consideration the potential debilitating impact on social welfare and environment. This led to the reinvigoration in the call for sustainable development. It should be emphasized that the historical roots of the concept of sustainability are traced back to the 1713 publication by Von Carlowitz. He published a technical book titled "Sylvicultura Oeconomicathe". Von Carlowitz was responsible for the forest and mines of Erzgebirge of Saxony and realized the horrendous impact of forest

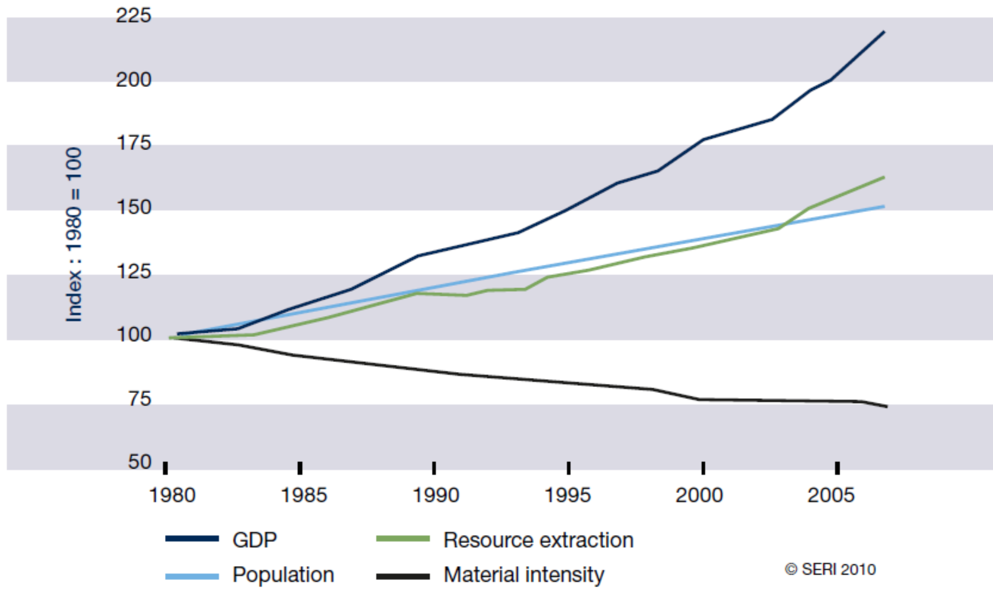

Figure 1.1: Trends in global resource extraction, population, GDP, and material intensity (Krantz, Shellaby et al. 2011).

destruction and overuse of wood for ore smelting during that era. He called for more responsible use of woods and forest to ensure long-term supply of wood. Von Carlowitz was a pioneer who was the first to use the term "nachhaltende Nutzung", which means "sustainable use" in English. In 19th century, the principles that were advocated for by Von Carlowitz to realize sustainability were followed and extrapolated to other economic sectors. It was originated in Germany during the late 18th and 19th centuries. At that time, forests upon which Germany was dependent for wood to support its rapidly growing economy were declining while the population and economy continued to increase. They started to search for a solution for the national forest resource depletion and its harmful consequences. This resulted in a rise of the sustainability concept that was viewed as a mechanism to ensure prosperity through ongoing economic growth [Zovanyi 1998]. Recently, different debates concerning the exploitation of the commons and the impact of the current industrial eco-system on the environment took place in the 1970s and 1980s. The basis of these discussions was Meadows *et al.* alarming report "The Club of Rome's": "The Limits to Growth", which raised the concerns of the devastating impact of exponential increase of human population that is estimated to reach 9 billion people by 2025 and consumption on the environment (Meadows & Meadows, 1972). They predicted that this trend would undermine the ecological carrying capacity of Mother Nature. The report called for a new era of economic growth that leads to a better life for inter and intra-generations, and thought of as sustainable economic development that focuses on living qualitatively rather than quantitatively (Goodland, 2009). It calls for an era that is not founded on mass consumption, production and disposal of masses of waste. Indeed, the concept of sustainable development became well known after 1987 the Brundtland Report by the United Nation's World Commission on Environment and Development (WCED) known as "Our Common Future" in 1987. This concept was defined as "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Moreover, a series of Earth Summits, were held 1992, 2000, and 2012 by United Nations Conference on Environment and Development (UNCED) with the theme that focuses on various aspects of sustainable development. Furthermore, world leaders showed their dissatisfaction and concerns about GDP as an effective tool to assess progress, since economic growth does not usually translate into both human and ecological wellbeing (United Nations, 1992). This led policy makers to urge researchers to develop sustainable progress indicators that would monitor progress and assess their actions toward achieving their goals on sustainable development.

1.2 Objectives and Scope of Investigation

My research interests have three objectives:

First, to review how disposability and disposable products are commonly defined, and discuss the correlation between GDP with the culture of disposability, and its impact on the environment.

Second, to review and discuss the most widely used sustainability indicators in particular the ones used to progress measurements, in term of their methodology, advantages and limitations, that are used to replace the economic indicator i.e. gross domestic product "GDP" as this indicator was criticized for its evaluation of the nation's economic activity but does not measure the citizens' social and ecological health.

Third, to define and model a novel multi-attribute sustainability measure that would assess the impact of economic strategies that foster green practices and minimize the extent of disposability, to enable general public to be more cognizant of current practices, their impact on the environment, and more importantly will encourage green manufacturing and technology without compromising economic progress. Finally, this indicator will be universal and applicable on different systems that include and not limited to: hospitals, manufacturing facilities and processes, universities, countries.

Finally, to study the results of the analysis and make recommendations for future studies and research.

1.3 Outline of the Dissertation

Following the introduction and objective of this dissertation introduced in Chapter 1 of this thesis, Chapter 2 presents the correlation between GDP and the culture of disposability. The negative impact of the current paradigm on the environment is summarized. An outline of the waste generation throughout the product life cycle in the linear model is presented, and finally the question of how we can shrink waste generation and call for a shift in the paradigm has been raised.

Chapter 3 introduces the antecedents of the concept of sustainability, then it covers the review of related literature to first assist in the understanding the various concepts and related topics in the area of sustainability and sustainable development, and second is in the line of thinking for the developed conceptual framework presented in Chapter 6.

Chapter 4 first reviews the different sustainability indices, which currently act as critical tools in the assessment of the progress of strategies adapted by nations and its industrial institutions to attain sustainability by enforcing cleaner production and consumption. Several sustainability measures reviewed in Chapter 4 were used in Chapter 5 to assess the progress toward sustainable development for the G-20 countries was assessed. The Chapter concludes with a discussion of the results in terms of the agreement of the countries progress with the recently proposed goals by UN.

Chapter 6 discusses in detail the proposed comprehensive sustainable prosperity index that assesses both the sustainable development and profitability of a "system".

Chapter 7 applies the developed model on the G-20 countries that are defined as the top 20 countries that are driving the global economy.

Chapter 8 details the numeric countries' case results with the necessary analyses and discussion of the findings obtained from the development and application of this index.

Chapter 9 concludes the dissertation by presenting the overall implications and contributions of this research and recommends some future possible extensions of this work.

CHAPTER 2: The Impact of Linear Industrial System on Culture of Disposability

2.1 Introduction

The industrial revolution was successful in establishing the standard industrial paradigm in the form of a linear design-manufacture-consume-dispose industrial system (Figure 2.1). This model is the first type of industrial eco-system. It is based on the sequence of raw material extraction then labor and technology are used to transform raw materials into final products that create profit (Graedel and Allenby 2010). In this system, the manufacturing industry is considered efficient since it is producing more products. Therefore, better economy results from higher amount of money spent in the country by producing and/or consuming more goods and services. This creates wealth in the country, which is usually associated with a better public welfare and standard of living. This model led societies to continue their unsustainable consumption in their everyday life. It assumes an infinite regenerative and assimilative capacity of natural resources and sinks, which our planet is not satisfying with the current rate of aggravated extraction, use, and disposal. The economic activity fundamentals of this system are based on production and consumption. In this linear paradigm, nation's economic progress is measured by making the manufacturing industry more efficient thus producing more products. This results in the growth of the Gross Domestic Product "GDP" that fundamentally measures the production

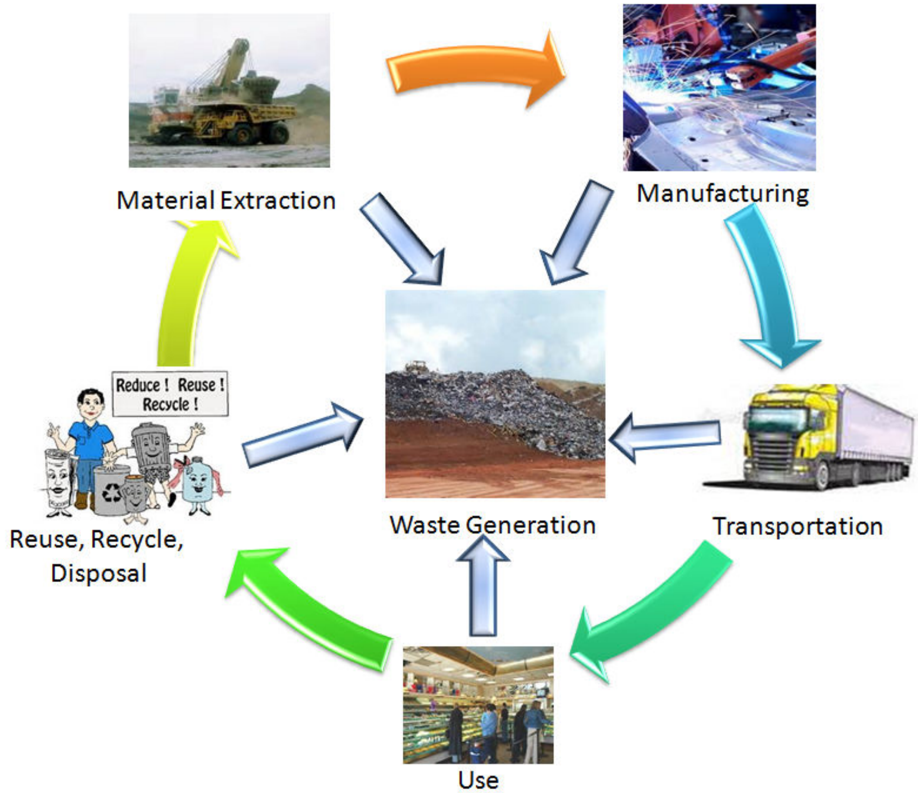

Figure 2.1: The linear manufacture-consume-dispose industrial system.

activity of a nation. Moreover, this mode of consumption has a deteriorating impact on the environment, which is a function of the way products are used, and disposed of. It also led to the creation of the throwaway society state of mind, which is also referred to as disposability (Lucas 2002). Indeed, this era has been associated with accelerated increase in the generation of waste, where from 1960 to 2010, the per capita waste generation increased from 2.68 to 4.43 lbs/person/day and the Municipal Solid Waste (MSW) in USA was increased from 88.1 to 249.9 million tons (EPA 2011).

The main objectives of this Chapter are four folds; First, to discuss the GDP as a main driver to the culture of disposability, second to summarize the negative impact of the current paradigm on the environment, third, to outline the waste generation throughout the product life cycle in the linear model, finally, to raise the question of how we can shrink waste generation and call for a shift in the paradigm.

2.2 GDP as a Main Driver for the Culture of Disposability

GDP[2] was used during World War II to evaluate the wartime production activity (Kuznets 1934; Kuznets 1941). Ever since, it has been considered the primary index of country's economic progress. This widely publicized traditional index measures the flow of money in the country and determines if the economy is growing within a time frame. There are three valuation methodologies for GDP: product, income, and expenditure approaches. The most widely used methodology is the expenditure approach, where its computation of GDP is based on the sum of its four main components: consumption, investment, government spending, and net exports. Consumption by private households, which is the result of the current industrial system and itemized by goods and services, is the largest GDP component and accounts on average of 68% of the total USA GDP for the years of 1988-2009 as illustrated in Figure 2.2 (BEA 2009). These goods are divided into durable and non-durable goods. Durable goods are defined as products that yield services and/or utilities of a lifetime of 3 years or longer such as cars, home appliances, furniture etc. Alternatively, non-durable goods are identified as products that are usable over a limited period of time i.e. less than three years or destroyed following single use such as syringes, disposable diapers, razors, hypodermic syringe, paper towels, plastic spoons, and disposable cigarette lighter. Over time, the contribution of durable and non-durable goods monetary values to the GDP net value increase, however, the

[2] GDP is discussed comprehensively in chapter 4.

increase in the non-durable goods value was higher than that shown with the durable goods (Figure 2.3) (BEA 2009). In 2009, non-durable goods had an average share percentage of 16 versus 9% for durable goods of the US GDP value (BEA 2009). Indeed, in the US, non-durable goods encompass 60% of municipal solid waste (MSW) while, durable goods contribution to MSW is only 16% (utoronto 2007).

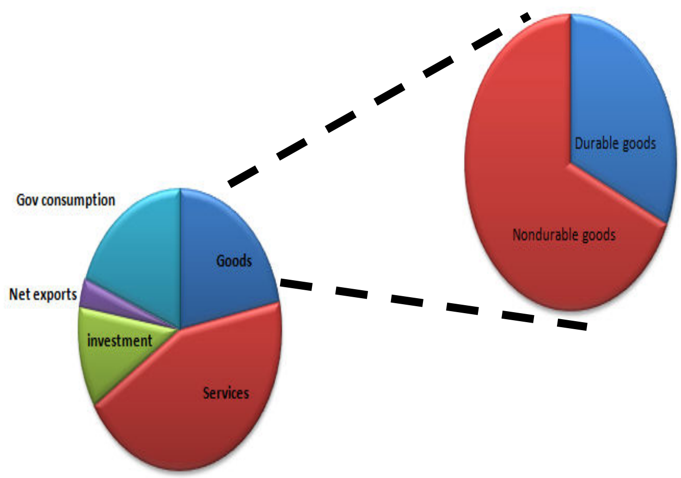

Figure 2.2: The components of GDP.

It should be emphasized that these points around the contribution of non-durable goods to GDP and solid waste generation is based on the GDP classification of the industry. For example, the goods of the electronics industry are considered durable goods although; there are many electronic products such as cell phones, tablets, and personal computers that would not last more than few months to couple of years. This is inconsistent with the general definition of durable goods as the products that have a lifespan of more than 3 years. Evidently, having these products classified as durable goods would underestimate the overall contribution of non-durable goods to both the GDP and MSW generation, which is still substantial even with current definitions.

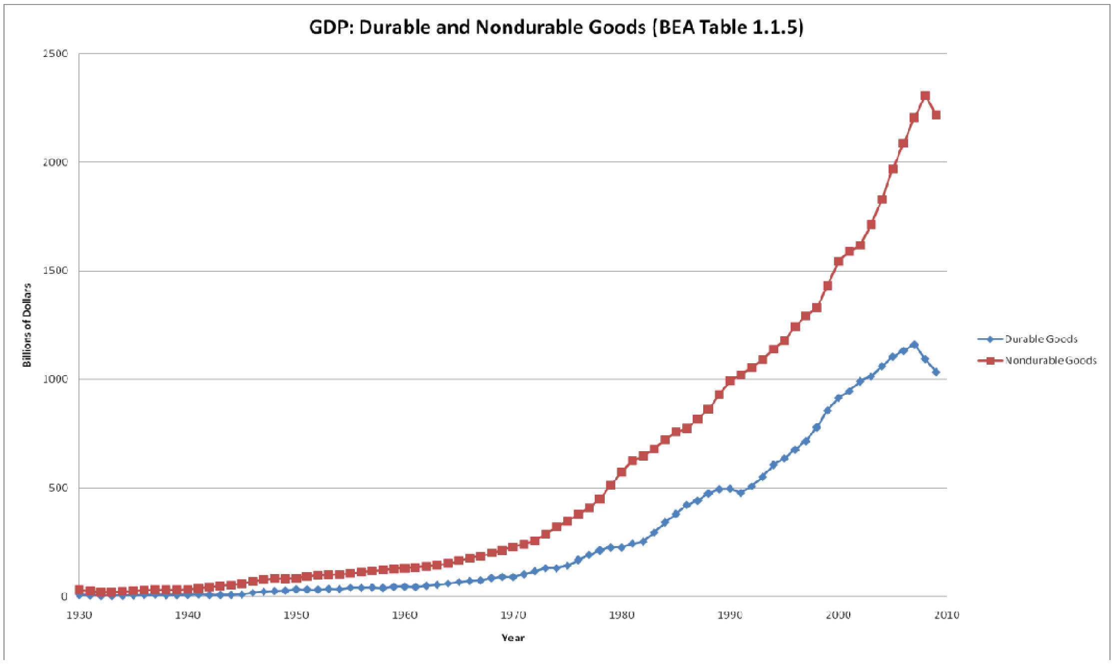

Figure 2.3: GDP: Durable and Nondurable Goods (BEA 2009).

The expanding contribution of consumption in the form of non-durable goods to the GDP is a key reflection of disposability. This is one of the pivotal outcomes of this economic index, which is based on this linear industrial system. The interest in disposability as a concept started as early as 1912 by Christine Fredrick, the American domestic reformer who was one of the early advocates of disposability in the name of both convenience and hygiene (Lucas 2002). The last decades were associated with a fast pace of life, where many consumers continued to suffer from time limitation and feel rushed. This led them to try to maximize their satisfaction by multitasking and the use of innovations i.e. disposable products that allow them to save time and feel happier. It is interesting to note that the culture of disposability is not only linked to the behavior of consumers i.e. use phase of the product life cycle, but also each stage of the product life cycle in this linear model has a major contribution to the spread of the culture of disposability (Figure 2.1). In the design stage, the first step in this industrial system that uses 5% of the time and resources of the overall manufacturing cost, the product is designed according to customer's needs and this determines the product efficiency throughout its life cycle (Ulrich and Eppinger 1995). It is generally believed that manufacturers and suppliers are purely "waste makers". For example, B Earl Puckett, former head of Allied Stores Corporation said "We must accelerate obsolescence ... It is our job to make women unhappy with what they have … We must make them so unhappy that their husbands can find no happiness or peace in their excessive savings" (Vance 1960). Hence, manufacturers design their products with planned or built-in obsolescence to push consumption by generating demands for new sales and stimulating replacement buying by consumers. This leads to premature disposal of products either through functional obsolescence where products break down and need repair or by fashion obsolescence where new products with aesthetic features can influence premature disposal (Cooper 2005). Furthermore, another approach that is implemented by manufacturers is the design for limited repair. The high cost of repair for appliances and electronic products makes it cheaper to dispose than to repair them (Adolphson 2004; McCollough 2007).

Another leading factor in the spread of the culture of disposability under this industrial system is the fact that at the manufacture stage of the product(s), companies adapt the techniques of mass production that were created by Henry Ford in 1920s (Liker 2003). This is based on economies of scale and extensive use of big equipments and assembly line techniques to produce very quickly many products at the lowest cost per unit. Evidently, the goal is to increase the efficiency of the individual processes by reducing machines down time and shutdown for repair. Technological advances also played a key role in improving productivity and product quality. Overall, this further accelerated economic growth and led to the realized advances in mass production and the spread of the culture of disposability (Schacht 2010). Indeed, a pivotal example on technological improvements that allowed high production rates by reducing production time, cost, weight and waste and provided the flexibility to use a wide range of materials with lower labor cost and minimal scrap losses is in the use of injection molding machines. Since its inception in 1940s, the industry expanded rapidly and evolved from producing simple products such as combs and buttons to a wide scale of products with different levels of complexity e.g. toys, packaging, automotive parts, medical and consumer products (Bryce 1996). In addition to injection molding, the expansion in the automation of manufacturing facilities through the use of robotics was critical in the wide adaptation of this linear system. This allowed the improvement in product quality and reduction in consumer goods prices (Stewart 2006). In addition to the above mentioned factors, technical improvements such as that observed in engineering, material science (i.e. using materials with better properties than the older ones), implementation of robotic production resulted in a substantial decrease in material intensity (the quantity of material used in the manufacturing of products). This, with mass production, further led to the culture of disposability spread (Cleveland 2008).

Many factors contributed to the increase in consumer spending and consumption, which is the third stage in stage in this linear model. As discussed earlier, planned obsolescence is a deliberate strategy by companies to make their products lose their value rapidly and induce replacement purchases by consumers. This improves a company's sales by reducing the amount of time between the repeat purchases consumers make of products. In addition, mass production combined with injection molding and other relevant technological improvements resulted in higher rate of production and decrease in overall products cost. For example, the following are seven categories of products that have become cheaper today than they were 10 years ago and include phones, electronics, footwear, new vehicles, toys, apparel and watches (MacDonald 2008). For example; the toys prices have declined 44.4 % over the past decade. This is mainly attributed to the outsourcing of toys manufacturing to other countries with lower labor costs combined with a decrease in the cost of electronics. Disposable products i.e. sterile syringes, disposable lighters, disposable pencils, razors...etc, also led to the culture of disposability spread . This is another strategy that companies implemented to increase consumption. These products are usually inexpensive and pose a low risk to the buyers if they make a mistake by purchasing them. In summary, the aforementioned factors drove higher consumer consumption and further contributed to the spread of culture of disposability.

The culture of disposability driven by the current linear system, that assumes infinite supply of both natural resources and sinks, which our planet cannot satisfy with our current rate of aggravated materials extraction, production, consumption, and disposal. It is associated with an accelerated increase in waste generation, which is the fourth stage of this linear system. In 2008, around 250 million tons of solid municipal waste disposed in landfill, with more than 70% of the overall waste divided into three main products categories including packaging and containers (30.8%), nondurable products (23.5%) and durable products (18.3%) (EPA 2009). Evidently, under this linear industrial system, governments, manufacturers, and consumers encourage the production and consumption of goods and services and no significant attention is dedicated to the negative consequences of products disposal at the end of their life cycle. This is a problem that continues to grow and negatively affect the well being of our planet and ecosystem, which is underscored by the growing amount of MSW.

2.3 The Negative Impact of the Current Paradigm on the Environment

The current paradigm based on the linear manufacturing model and culture of disposability leads to the unsustainable consumption patterns of non-renewable resources and hydrocarbon driven energy. This contributes to the negative consequences on the environment. These linear manufacture-consume-dispose industrial and economic systems continue to undermine the ecological limits of Mother Nature by erroneously assuming infinite supply of natural resources and sinks for the industrials wastes. It led to major environmental issues that include but not limited to climate change, pollution, resource depletion, and growing solid waste generation etc. Climate change is a significant disruption in the distribution of weather patterns over periods ranging from decades to millions of years. For example, CO_2 was balanced in nature where oceans and plants absorbed it and was usually emitted to the atmosphere by natural processes that were in equilibrium. However, current industrial system, which relied heavily on fossil fuels for its industrial activities that included energy burned for transportation, heating, and power plants. This led to the release of massive amounts of greenhouse gases (GHG) emissions and CO_2 disrupting this delicate balance. This resulted in an increase in the global temperature by 0.6 ± 0.2 ºC at a rate of 0.17 ºC per decade since 1950 (Lal 2004). In 2005, the atmospheric methane (CH_4) level, a key contributor GHG, surpassed the natural range evaluated over the last 650,000 years (Solomon 2007). Overall, this was associated with the accumulation of GHG in the atmosphere and amplification of GHG effects that were accompanied with significant alterations in the Earth's climate. China and USA, the largest two economies, GHG emissions counted for more than 37.42% of the total global GHG emissions. Interestingly, one of the main outcomes of the linear industrial ecosystem and culture of disposability is associated with an increase in the overall carbon footprint by more than ten folds between 1961 and 2005. This is also expected to increase by 25% to 95% by 2030 (Hails, Humphrey et al. 2008; Rose and McCarl 2008).

Another environmental issue associated with this paradigm is pollution, which is a result of the introduction of contaminants associated with the linear model into the surrounding environment leading to instability and the harming of the delicate balance of Mother Nature. Pollution encompasses many forms that include air pollution, littering, noise pollution, radioactive pollution, and water pollution. Combined with overpopulation, this linear industrial model is based on over-consumption and exhaustive use of renewable and non-renewable resources, at a rate that far exceeds their rate of replenishment. This led to natural resource depletion, which is considered one of the critical environmental issues. While major improvements have been realized in material intensity, there continues to be a proportional relationship between GDP and material extraction (Figure 2.4). This clearly underscores the negative impact of this system on the environment. Furthermore, over the past decades, the increase in GDP, associated with a higher increase in non-durable relative to durable products (Figure 2.4), was accompanied with an increase in the solid waste generation. For example, there were three folds increase in the MSW generation from 1960 to 2008. Indeed, nondurable and durable goods made up more than 40% of total MSW generated by weight, in 2008.

The aforementioned findings on the impact of this linear model on Mother Nature are outcomes of the GDP valuation methodology, which does not take into consideration neither natural resource depletion nor environmental damage. In fact, under this measure natural resource depletion and associated degradation of the ecosystem is considered a profit rather than a cost.

Another major consequence of current economic development that is driven by this model is that the global population is exceeding its ecological limits by 39% as reported by redefining progress latest footprint analysis. This indicates that we would need to have over one third more than the present biocapacity of Earth to maintain the same level of prosperity for future generations (Network 2008). Furthermore, World Wildlife Fund (WWF) published that on average the Ecological Footprint (EF) in developed countries is 6.4 ha/person which is 3.5 times higher than the availability of productive land of 1.8 ha/person. This reveals the unsustainable consumption behavior of our disposability culture.

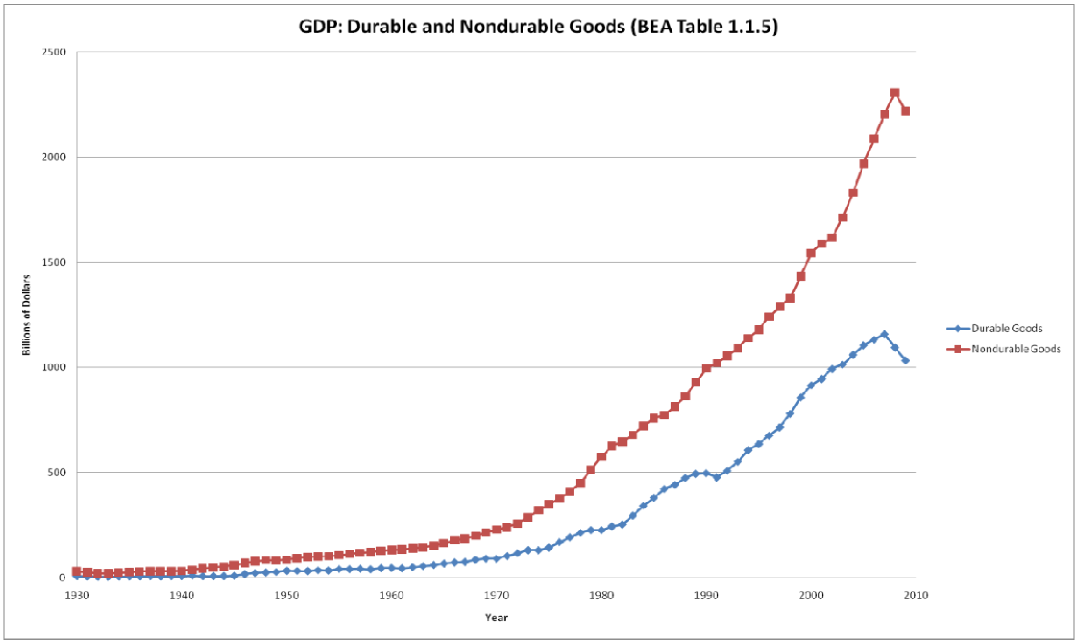

Figure 2.4: GDP: Durable and Nondurable Goods (BEA 2009).

If the human load continues to exceed the productive capacity of the biosphere then consumption patterns are clearly not sustainable given current trends.

In addition, non-durable goods are major contributing factor to the solid waste generation, where it encompasses 60% of the MSW vs. merely 16% for durable goods in the US (utoronto 2007).

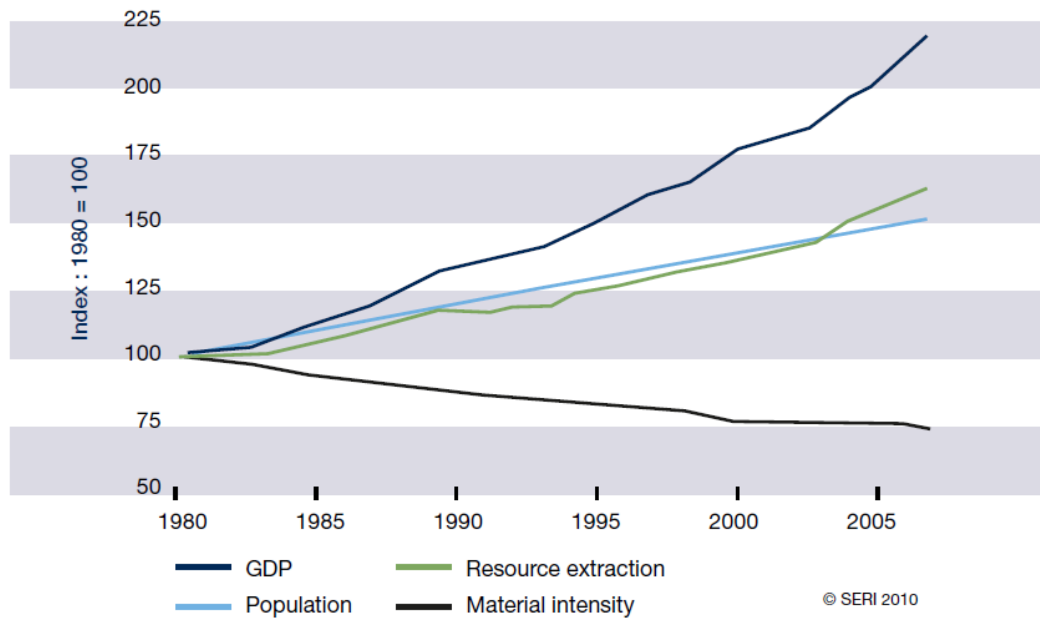

Figure 2.5: Trends in global resource extraction, population, GDP, and material intensity (Krantz, Shellaby et al. 2011).

2.4 Waste Generation throughout the Product Life Cycle in the Linear Model

The Organization for Economic Co-operation and Development (OECD) defines waste as "materials that are not prime products (that is, products produced for the market) for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose" (OECD 2001). This definition clearly demonstrates that each stage in the linear model contributes to waste generation. In fact, the design stage, which is based on planned obsolescence as discussed earlier, limits the lifecycle of the product and encourages consumer to dispose and replace it with new product(s). While major advancements have been realized in the fields of recycling and material intensity, raw materials extraction from primary material mining that are used in the production of finished goods continues to grow with GDP (Figure 2.5). It requires processing of large quantities of raw materials, which is believed to damage the environment without providing significant economic value. This critical step is composed of four phases: Mining, beneficiation, smelting, and refining where extraction waste materials are left behind and a purified product is sent along to the next phase. It is interesting to note that there are two types of waste in the mining and beneficiation stages: (a) Overburden, which is earth displaced in the process of searching for and removing ore. A point worth emphasizing here: is that this type of waste yielded a total of 1313.5 MMT for metal ores in 1993 where 1184.5 MMT contributed from non-ferrous metals and 129 MMT from iron ore (Ayres and Ayres 1998). While this overburden is not sent to the landfill and rather is returned to the original excavation site, it results in destruction of wild habitat and compromises the wellbeing of the surrounding environment. (b) Gangue is a commercially insignificant material that surrounds an ore or mineral body and may contribute to the contamination of ground water and other forms of pollution. The remaining material (concentrate) is then shipped to the next phase of processing into a downstream smelting or refining process, that generates further separation wastes such as, slags, air and water pollutants. Later, the processed raw materials are manufactured into intermediate and final products using the concept of mass production. It is associated with the creation of waste at every stage of the production. This system, as outlined earlier, is based on keeping machines and workers busy to reduce the cost per piece. This leads to over production where large amounts of products are stored in inventory with defects hidden in large patches. Usually, these are not spotted for weeks, which end up as scrap and waste (Liker 2003) . Mass production that is both capital and energy intensive, is also associated with disastrous impact on the environment represented in its critical roles in the depletion of natural resources, carbon emissions, pollution it expels into the ecosystem and arising human health problems. Furthermore, mass production allowed the evolution of the culture of disposability by lowering the unit cost of many goods and encouraging the rise of nondurable products in the name of convenience and hygiene. This resulted in over consumption where goods are used by customers and at the end of their life cycle, they reach the retirement phase and throw-away, which is the final stage of the linear life cycle. It is accompanied with increase in the rate of solid waste generation and the size of landfill areas used. In summary, under this linear system, every step is associated with waste generation, and further undermines Mother Nature by altering the environmental sustainability through the excessive use of nonrenewable resources on the source side and generation of pollution and waste on the sink side (Goodland 1995) .

2.5 The Call for a Shift in the Paradigm

As highlighted earlier, it is clear that this industrial paradigm compromises the right of future generations in equitable distribution of resources. Therefore, there should be a serious call for a new era of economic development that leads to a better life for inter and intra-generations. This new era focuses on living qualitatively rather than quantitatively (Goodland 2009). It is not founded on mass consumption, production and disposal of masses of waste. Rather it returns use of natural capital to sustainable limits, by consuming Mother Nature resources at a sustainable rate i.e. a rate at which they can be replaced. A key approach to move to this new era is to shift into an industrial paradigm that mimics the ecological system, where it operates in a cyclical manner. This system arrangement is termed type III industrial ecosystem where resources and waste are completely integrated. It follows the principle "waste from one component is the food for another" (Graedel and Allenby 2010). This approach promotes the reuse of the embedded value of the product rather than its disposal. Benefits of employing such system go beyond minimizing the environmental impact by saving natural resources, reducing energy consumption, and minimizing pollution (Giuntini and Gaudette 2003).

The next Chapter discusses the concept of sustainability, sustainable development, and the science of sustainability. These are considered evolving concepts that offer a unique approach to the design of systems and the implementation of viable sustainable strategies. Furthermore, it aims at incorporating cyclical patterns, which is a prudent attribute of ecosystems into our systems. This allows us to achieve a pattern of industrialization that is not only efficient, but also in compliance with the laws of Mother Nature. This designed industrial system intends to generate no adverse environmental effects, since it will eliminate potential causes in the design stage. The ultimate goal is to shift the economy from take-make-waste linear industrial system that assumes infinite sources of raw material and sinks for the industrial wastes into an industrial ecosystem, which operates successfully in a cyclical manner and address the major liabilities associated with the linear industrial system.

CHAPTER 3: Understanding "Sustainability"

3.1 The Antecedents of the Concept of Sustainability

The concept of sustainability is a convoluted and elusive term. Indeed, it is not a new concept and can be traced back to the 1713 publication by Von Carlowitz. He published a technical book titled "Sylvicultura Oeconomicathe". Von Carlowitz was responsible for the forest and mines of Erzgebirge of Saxony and realized the horrendous impact of forest destruction and overuse of wood for ore smelting during that era. He called for more responsible use of woods and forest to ensure long-term supply of wood. Von Carlowitz was a pioneer who was the first to use the term "nachhaltende Nutzung", which means "sustainable use" in English. In the 19^{th} century, the principles that were advocated for by Von Carlowitz on sustainability were followed and extrapolated to other economic sectors. It originated in Germany during the late 18^{th} and 19^{th} centuries. At that time, forests upon which Germany was dependent for wood to support its rapidly growing economy were declining while the population and economy continued to increase. Von Carlowitz et al. started to search for a solution for the national forest resource depletion and its harmful consequences. This resulted in a rise of the sustainability concept that was viewed as a mechanism to ensure prosperity through ongoing economic growth. This concept was defined as sustained yield. In the later part of the 19^{th} century, Gifford Pinchot, an American pioneer introduced the concept of sustained yield in the U.S. Pinchot thought that the U.S. should take an active role in managing the nation's natural resources in order to secure a sustainable future and make economic expansion indefinite [Zovanyi 1998].

Later on between the years of 1798-1830, Thomas Malthus wrote a series of publications in particular his leading book "An Essay on the Principle of Population" he raised his concern about the population growth, limited natural resources, and their overall negative impact on the socio-cultural system at large (Malthus 1798).

Several 19th-century economists such as Friedrich Engels and Karl Marx argued with Malthus's positions and warnings (Engels 1844; Marx 1867). They advocated that continuous advancements in areas notably finance, manufacturing and science would overcome Malthus's concerns and rendered them unlikely (Maddox 1972).

The 20th century observed the rise of a group of scholars who are Neo-Malthusians such as Paul R. Ehrlich. He authored in 1968, The Population Bomb and co-authored with Anne Ehrlich several books (e.g. Population, resources, environment: issues in human ecology in 1970); where they believed that over-population crisis will lead to devastating food deprivation and starvation. Another example of Neo-Malthusians is in the early 1970's where Meadows *et al.* declared their alarming book published by "The Club of Rome: The Limits to Growth", which raised the concerns of the destructive impact of exponential increase of human population that is estimated to reach 9 billion people by 2025 and consumption on the environment(Meadows and Meadows 1972). They predicted that this trend would undermine the ecological carrying capacity of Mother Nature. Similar to what Mathus's endured, this book was also criticized and the controversy is still alive. For example, the defenders of the merits of the economic growth that is measured by Gross Domestic Product (GDP) are against the report recommendations. GDP valuation methodology is based on the notion that higher GDP results from higher amount of money spent in the country by producing and/or consuming more goods and services. They believe that this creates wealth in the country, which assumes better welfare and standard of living. Otherwise, the book was a call for a new era of economic growth that leads to a better life for inter and intra-generations, and thought of as sustainable economic development that focuses on living qualitatively rather than quantitatively (Goodland 2009). It calls for an era that is not founded on mass consumption, production and disposal of masses of waste. Simultaneously, major developments that echoed the "Club of Rome" publication were occurring in particular in the first United Nations major conference on global environmental issues, held in Stockholm in 1972. This was a successful meeting that resulted in a declaration that contained 26 guiding principles and an action plan with 109 recommendations and a resolution concerning the environment and development. This conference was considered as an turning point in the development of world environmental issues and also led to the establishment of the United Nations Environment Programme (UNEP) (UNEP 2013).

The momentum was maintained and in 1983, the World Commission on Environment and Development (WCED) was established. The goal was to have an independent organization that focused on identifying environmental and developmental issues and proposing resolutions. One of the major deliverables of this establishment is the Brundtland Report, also known as Our Common Future that was published in 1987. It provided the most widely accepted definition of the concept of sustainable development "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987).

The rising interest in sustainable development resulted in the Earth Summit, held in Rio De Janeiro, Brazil, in 1992 by United Nations Conference on Environment and Development (UNCED). This historical event had major outcomes, particularly 'Agenda 21' also known as the 'Agenda for the Twenty-First Century'. This is an agreement where the attending 180 states declared their commitment to attain sustainability by adopting comprehensive global plan of action designed to achieve a sustainable pattern of development. Twenty years later, the United Nations Conference on Sustainable Development held in Rio de Janeiro in June 2012 (Rio+20), the member states agreed to develop a new set of Sustainable Development Goals that are based on the following pillars:

- Economic development inclusion that would end extreme poverty by 2030. This would be pivotal in improving happiness.
- Environmental sustainability, this will be the cornerstone for attaining sustainable use of available resources at both ends of Mother Nature.
- Social inclusion, this is the society commitment that the benefit of technology, good governance, and economic prosperity won't be limited only to certain class of people and available for every person regardless of age or gender; good governance, the ability of society to act collectively through true participation in political institutions to realize the happiness that is achieved with active political participation, human rights protection, woman's empowerment and freedom.

Overall, these are action oriented goals. Achieving them is a cornerstone in realizing sustainability for all people regardless of their age, gender ethnicity and background.

3.2 The Definitions and Understandings of Sustainability

As discussed in the previous section, the concept of sustainability was not introduced in the 1980's. Indeed, its meaning and necessity can be traced back to the German forestry 300 years ago. In the last three decades, many conferences were held to discuss sustainability definition and the challenges of the strategies adapted to achieve it. It is interesting to note that this major investment in time and effort, didn't conclude with a consensus on definition and meaning of this term among scientific and political parties (Weber-Blaschke, Mosandl et al. 2005). This also is echoed in the plethora of definitions of sustainability that were reported in the literature. In which, no clear progress was made and each group defined sustainability according to the framework to which it is applied. This resulted in a countless number of definitions of the word "sustainability (Bell and Morse 2008). This has the danger of rendering the concept meaningless and useless (Weber-Blaschke, Mosandl et al. 2005). A good example of this trend is well documented in Fowke and Prasad (Fowke and Prasad 1996). The authors allocated more than eighty definitions on sustainability. Interestingly, they reported that they tend to be both conflicting and controversial. This conclusion is consistent with other reports (Earll 2005). Table 3.1 provides a snapshot on sustainability definitions.

I believe Paul Hawken's definition of sustainability in his book "The Ecology of Commerce" neatly and rationally describes the term in simple words, yet successfully incorporated the concept's three interconnected bounds of sustainability i.e. ecological, human, and economical bounds (Hawken 1993).

"An economic state where the demands placed upon the environment by people and commerce can be met without reducing the capacity of the environment to provide for future generations. It can be also expressed in the simple terms of an economic golden rule for the restorative economy: Leave the world better than you found it, take no more than you need, try not to harm life or the environment, make amends if you do" Thus, sustainability encompasses the principle of taking from the earth only what it can provide indefinitely thus leaving future generations no less than we have access to ourselves.

Sustainability was also defined anthropocentrically as *meeting the needs of all humans, being able to do so on a finite planet for generations to come while ensuring some degree of openness and flexibility to adapt to changing circumstances.*

I believe that the goal of sustainability is to offset the adverse anthropogenic environmental impact that is the result of the human population, renewable and non-renewable resources consumption and depletion, and environmental degradation. Thus, the ultimate goal is to control each of these causes to attain sustainability. While, sustainability is an ethical and moral principle, it is also an ideal state that we strive to achieve, which is proven to be challenging (Weber-Blaschke, Mosandl et al. 2005). This is partly due to the lack of agreed on guidelines that would facilitate the assessment of the progress toward reaching the ideal state of sustainability. This research argues that to put sustainability in perspective we should approach it as agglomerate of systems, where each has its own indicators that describe the progress made in that particular system toward the ideal sustainability. Therefore, it comes as no surprise that we call for no one set of guidelines that describe all types systems rather assessing it according to its own criteria. Finally, we come to the conclusion that the concept is complex and as a result no one definition of sustainability that fits all type of systems. This calls for approaching sustainability as a concept rather than a definition where we attempt to understand key drivers that influence and underpin achieving sustainability.

Table 3.1 Definitions and Understandings of Sustainability.

Author (s)	Definition
WCED (1987, p. 43)	Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs
EPA	Sustainability is a new way of thinking about an age-old concern: ensuring that our children and grandchildren inherit a tomorrow that is at least as good as today, preferably better. We want to make sure that the way we live our lives is sustainable - that it can continue and keep improving for a long, long time (EPA 2014).
The Lowell Center for Sustainable Production	Sustainable Production is creating goods by using processes and systems that are non-polluting, that conserve energy and natural resources in economically viable, safe and healthy ways for employees, communities, and consumers and which are socially and creatively rewarding for all stakeholders for the short- and long-term future (LCSP 2014).
(IUCN/UNEP/WWF 1991)	Improvement in the quality of human life within the carrying capacity of supporting ecosystem.
Costanza and Patten (1995, p. 193)	A sustainable system is one which survives or persists.
Pronk and ul Haq 1992	Economic growth that provides fairness and opportunity for all the world's people, not just the privileged few, without further destroying the world's finite natural resources and carrying capacity.
(Sikdar 2003)	A wise balance among economic development, environmental stewardship, and social equity.
(Natl. Commission on the Environment, 1993, cited in (Beatley 1998)	A strategy for improving the quality of life while preserving the environmental potential for the future, of living off interest rather than consuming natural capital.
(1994)	Sustainable consumption "the use of services and related products which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of future generations.
Brugman (1997b, p.301	Sustainability is a condition in which the imposition of social values on complex, objective biophysical systems does not so destabilise these systems that we can no longer achieve our basic values.

3.3 Concept of Sustainable Development

The concept of “development” was originated post World War II, in the period of reconstruction initiated by the USA. The ultimate goal was to raise the standard of living throughout the world. This led to the creation of the World Bank, along with other global institutions such as the International Monetary Fund (IMF), United Nations (UN), and the General Agreement on Tariffs and Trade (GATT). UN defined development as “the promotion of “social progress and better standards of living in larger freedom” (UN 2014). This is believed to be the basis for improved quality of life, a key goal that UN strives to achieve. Interestingly, a paradigm shift in the development definition was realized during the 1970s, where national and international organizations are seeking instead sustainable development. This concept is short for “environmentally sustainable economic development” that was introduced in 1972 with the publication of Donella Meadows book and with the United Nations' Conference on Human Environment in Sweden, which coined the term sustainable development, as a growing concern to our continuous environmental degradation (Meadows 1972). In the Limit to Growth publication, they believed, “if present growth trends in world population, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached within the next one hundred years” (Meadows 1972). Therefore, this concept is intended to be launched as a viable alternative to economic growth by integrating current and future global environmental and social concerns to the economic dimension. Since then, it has received growing consensus among numerous groups, researchers and more importantly through deliberate discussion and support via ongoing global conferences.

The concept of sustainable development gained popular momentum when it was baptized in the Brundtland Report by the United Nation's World Commission on Environment and Development (WCED) known as *Our Common Future* in 1987. The concept was defined as "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Sustainable Development achieved more growing consensus and awareness at the Earth Summit, held in Rio De Janeiro, Brazil, in 1992 by United Nations Conference on Environment and Development (UNCED).

In 2012, at the 20th anniversary of the 1992 United Nations Conference on Environment and Development (UNCED), in Rio de Janeiro, the Rio+20 Conference was held, with the theme "The Future we want." It was attended by world leaders along with thousands of participants from governments, the private sector, Non-governmental organizations (NGOs), and other groups. They made an agreement that secured the commitment of governments, public and private parties to shape a more sustainable future for the benefit of the planet and its people. It spans a wide range of challenges and issues that continue to face human mankind, that include access to fresh water, food, renewable energy, gender equality and sustainable transportation. This agreement provides a solid basis for economic, social, and environmental well-being which is the triad of sustainable development (Charnes, Cooper et al. 1984).

Herman Daly [1996] defined sustainable development in his book *Beyond Growth* as "development without growth – without growth in throughput beyond environmental regenerative and an absorptive capacity. Throughput is the flow of materials and energy through the human economy. It includes everything we make and do. Throughput is calculated as the total number of people multiplied by their consumption. In other words, the regenerative and absorptive capacity of the environment is its ability to produce raw materials for our use and to provide us a sink for discarding our wastes. To be sustainable, our throughput should not exceed the capacity of the environment; otherwise, negative consequences will be produced.

This paradigm calls for a new era of economic growth that leads to a better life for inter and intra-generations. It should be thought of as sustainable economic development that focuses on living qualitatively not quantitatively, and not founded on mass consumption, production and dispose of masses of waste. It is basically about living quality of life for all Earth's citizens – current and future generations without increasing the carrying capacity of our planet at both ends i.e. use of natural resources and wastes. Furthermore, sustainable development is an attempt that presents a radical paradigm shift away from our current approach of thought, attitude, and behavior that is not based on quality of life but on materialistic attributes of life that can easily quantified.

Without the willingness of people for a change, the pursuit of economic sustainable development as an objective will remain impossible to achieve. Consequently, when we think about attaining sustainability community should change their behavior, consumption, and appreciate Mother Nature. Then, this should also be supported by policies and incentives that support such behavioral changes. Succinctly, sustainability and sustainable development is ultimately a change of paradigms from living a "quantitative life" into a more "qualitative life".

Accordingly, sustainable development can be symbolized as the search for an economy that can exist in equilibrium with the earth's limited resources and its natural ecosystems. Furthermore, sustainable development can bring the environmental quality together with economic growth into harmony rather than conflict. It is a concept that recognizes that both economic activities and environmental considerations should always be integrated for humanity's long-term well being [Richards, et. al. 1994].

As a summary, sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality, and social equity. It improves the economy without undermining the social and environmental forces upon which it depends. It focuses on improving our lives without continuously increasing the amount of energy or raw materials consumed in a manner that is faster than the natural systems can regenerate. Furthermore, it requires managing our lives in a way that ensures that both economy and society can continue to exist without destroying the natural environment upon which our lives depend. Companies aiming for sustainable development need to perform not just in accordance with the economic aspect, but in accordance with all three aspects [Vanegas 1997].

3.4 What is to be sustained?

As discussed earlier, development must be environmentally, economically, as well as socially sustainable. Thus sustainable development recognizes that both economic activities and environmental considerations should always be integrated for humanity's long-term well being. Below is a discussion of each of these aspects:

3.4.1 Social Sustainability

As discussed earlier, "Our Common Future" report defines sustainable development as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [WCED 1987]. In fact, this definition encompasses the basis of social sustainability that is founded on the ethical principles of equity between inter and intra generations. In principle, this is accomplished by meeting their basic needs for food, a healthy living, employment, and most of all a quality life.

This aspect is considered the weakest of the three dimensions of sustainability. It is understandable when one considers that it is a natural outcome of the adopted environmental politics (OECD, 2001), or based on political agendas rather than being originated from theoretical background (Littig and GrieBler 2005). In addition, it is influenced by the fact that various countries, cultures, religions and communities would have different approaches toward achieving social sustainability for their constituents(OECD 2001) .

Indeed, there is no clear consensus on the overall definition of social sustainability. For example, Shearman defined social sustainability as "the continued satisfaction of basic human needs food, water, shelter as well as higher-level social and cultural necessities such as security, freedom, education, employment, and recreation [Shearman 1990]. Also, Littig and Geibler defined social sustainability as

".. a social sustainability is given, if work within a society and the related institutional arrangements satisfy an extended set of human needs [and] are shaped in a watt hay

nature and its reproductive capabilities are preserved over a long period of time and the normative claims of social justice, human dignity and participation are fulfilled."(Littig and GrieBler 2005)

On the other hand, the report released in 2005 by Vancouver City Council provides a sensible definition of social sustainability. It defines social sustainability as "the ability to build and maintain its own resources, and have the resiliency to prevent and/or address problems in the future in order to meet basic needs" (Gates and Lee 2005).

Vancouver City Council clearly outlines that for a community to be sustainable, both individual as well as community resources need to be used and developed. The individual resources are that individuals "can contribute to their own well-being and to the well-being of the community as a whole" e.g. education, skills, health. As for the community resources, they define it as "the relationships, networks and norms that facilitate collective action taken to improve upon quality of life and to ensure that such improvements are sustainable". Moreover, they point that those resources need to be used within a framework that is based on four interrelated principles:

1. Equity – is a state where there is equitable distribution of resources for various constituents regardless of their gender or socio-economic status. This enables them to fully engage in their community and continue their personal development partially by having access to gain good education. Realizing equity is believed to play a central role in improving the quality of life of

constituents, increasing their life expectancies, reducing community violence e.g. lower crime rate, and demonstrating stronger forms of civic engagement.

2. Social inclusion and interaction: the community provides equal opportunity for its people to fully utilize/celebrate their diversity.
3. Security: individuals have full confidence in the ability of their communities to provide safe and healthy environment, which is a cornerstone for establishing their economic security.
4. Adaptability – agility and the ability of for both individuals and communities to respond to change.

In addition to the domains outlined above, department for Environment Food & Rural Affairs (DEFRA) in England also perceives that attaining social sustainability is accomplished by Promoting Good Governance (DEFRA 2011). It is pertinent to keep in mind that the last two decades have realized a shift in the social sustainability themes and new emerging concepts such as happiness, quality of life, and wellbeing are noted (Table 3.2) (Colantonio 2011).

Table 3.2: Traditional and Emerging Social Sustainability Key Themes (Colantonio 2011).

Traditional	Emerging
Basic needs, including housing and environmental health	Demographic change (aging, migration and mobility)
Education and skills	Social mixing and cohesion
Employment	Identity, sense of place and culture
Equity	Empowerment, participation and access
Human rights and gender	Health and Safety
Poverty	Social capital
Social justice	Well being, Happiness and Quality of Life

3.4.2 Environmental Sustainability

In the late 1972, the book “Limits to Growth” expressed popular restlessness with the current economic system that originated from adapting the linear manufacture-consume-dispose model. The authors were discontent with the combination of the uncontrollable massive population increase in the developing countries and unsustainable consumption in the developed countries. Overall, this resulted in a serious environmental stress. For example, our Ecological Footprint has increased from 63% to 151% of earth biocapacity between the years of 1961-2007, respectively (Wackernagel and Rees 1996). This is a serious outcome of our unsustainable consumption, vicious use of non-renewable resources, and excessive production of emissions. If we continue with this behavior, the earth’s assimilative and regenerative resources will run out. Recently in 2012, Barnosky and other 22 international researchers published a review in *Nature* echoing the concerns of our growth limit. They projected that within decades to centuries a major “global-scale state shift” in the Earth’s biosphere is highly likely. Furthermore, they expected that 10–48% of the planets climates will disappear in the coming century, this is accompanied with an average projected increase in the global temperature by 2070 (or possibly a few decades earlier) to a level that has not been experienced since the beginning of humankind. (Barnosky, Hadly et al. 2012).

Based on what was outlined earlier, we should strive to attain environmental sustainability since the earth has finite regenerative and assimilative capacities. We, as humans, need to interact with our planet without continuing to destroy or damage it. Our consumption and economic activities should be designed to provide for the basic needs of present generations and do not compromise the environmental resources for future generations.

In 1995, Goodland defined environmental sustainability as "a set of constraints on the four major activities regulating the scale of the human economic subsystem: the use of renewable and nonrenewable resources on the source side, and pollution and waste assimilation on the sink side. He believes that our environmental capacity has become limited because it is wrongly thought that the regenerative and assimilative capacity from source and sink sides are infinite (Goodland 1995).

Indeed, Herman Daly recommended three intertwined approaches that if adapted can have a major contribution toward achieving ecological sustainability. They are based on management of human consumption as follows (Daly 1996):

1. Waste generation cannot exceed assimilative capacity of our planet.
2. Renewable resources should be harvested at a pace that does not exceed its regenerative rate (provide a sustainable yield).
3. Non-renewable resources should be harvested at a rate below or equivalent to that at which renewable alternatives are developed.

In addition, to the recommendations outlined above, we need to shift the linear model, which is currently the basis of our current economic model toward a cyclic model that mimics Mother Nature. This is accomplished by relying on more significant contribution to the embodied resource use and changing our human consumption patterns. Finally, Barnosky and co-workers outlined an overall strategy that should be adapted to diminish or postpone the "rapid and unpredictable transformations" expected to occur within a few human generations to the biological resources. The ultimate goal is to maintain and protect our natural capital, which consists of water, land, air, minerals and ecosystem services, the sources of raw materials, and sinks for wastes assimilation. They emphasized the need to adapt policies that will lead to a reduction in global population growth rate and per capita resource consumption. This should be accompanied with shifting energy use toward renewable resources and increase in the efficiency of food production and distribution. This in part will be accomplished by adapting advances in technological know how's.

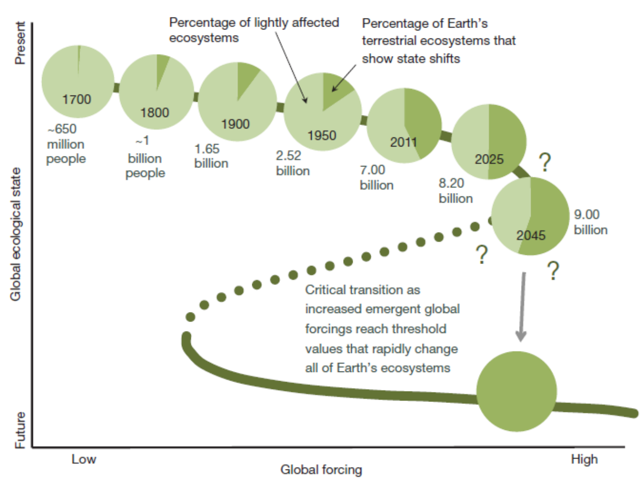

Figure 3.1: Quantifying land use as one method of anticipating a planetary state shift (Barnosky, Hadly et al. 2012).

3.4.3 Economic Sustainability

Economic development has typically required a continuous growth in the GDP. Leading economists argued that this is a natural outcome of both the global population growth and technological innovation. Indeed, this was accompanied with an accelerated decay in the environment, which threatens and compromises the ability of humankind to sustain this harmful economic growth. Economists like Thurow argued that "worries about natural resource exhaustion are hard to rationalize from the point of view of economics (Thurow 1980)". Moreover, he viewed that a Zero Economic Growth (ZEG) would result in inequality and higher unemployment rates, which usually compromises community well-being and security (Thurow 1980).

Conversely and in recognition of the alarming deterioration of the environment, Herman Daly, an American ecological economist, whose research focuses on understanding the interdependency of economy and the natural ecosystem, believes that global economy has grown so large relative to the earth ecosystem. He advocates for economic development without growth activity (Daly 1996). Where, the economic system does not grow beyond the carrying capacity of the Mother Nature. In this approach, economic sustainability is only achieved when it considers the finites limits of the earth's ability for providing materials to use and sinks for assimilating generated waste. Based on that, the economic theory of sustainable development has evolved in which the economy is viewed as a subsystem of the ecosystem as shown in Figure 3.2.

As a result, this theory considers economic activity as bound by the constraints of the ecosystem having the characteristics regenerative and absorptive capacity, i.e. its ability to provide us with high quality raw materials to make things, and to break down our wastes. Growth beyond these limits will result in negative rather than positive consequences [Motague 1998].

Nonetheless, the question that is raised by facing the limits of the planet is: For how long and for how many humans can the economy support, and how much good can we accomplish? That is, how large should the economy be before it harms the ecosystem? Daly thinks that "sufficient good for the greatest number", which means supporting the greatest number of people into the unlimited future. Hence, to achieve sustainable economic development, we have to offer the greatest number of humans enough resources for a sufficiently good quality of life [Motague 1998].

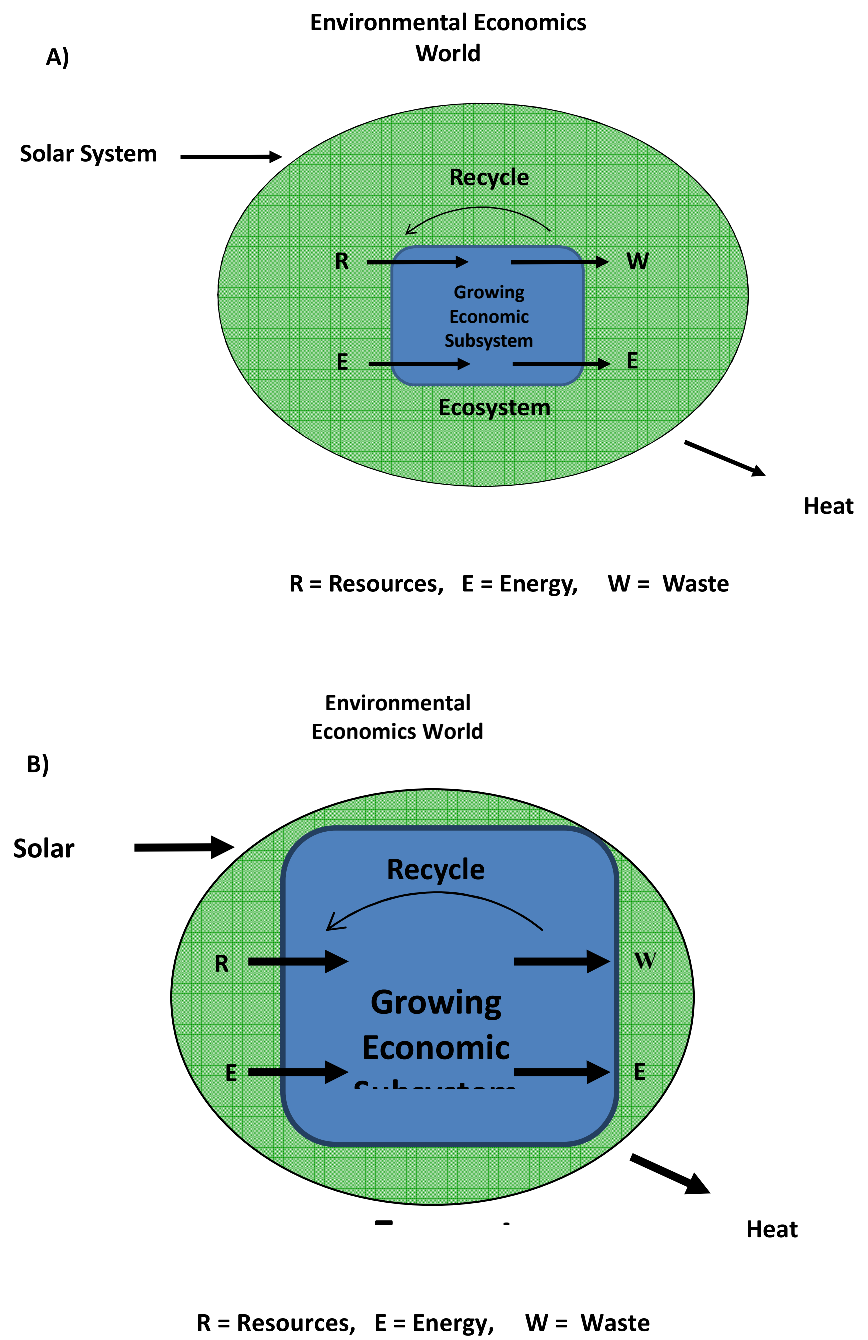

Figure 3.2: The Economy as a Subsystem of the Ecosystem (Daly 1996).

As a consequence, this eco-system actively supports the right of both the current and future generations in a sustainable economic development. Its success is based on continuous advancement in human capital and the utilization of more efficient green approaches in resource management and energy consumption (Daly 1996).

Thus, economic sustainability is therefore based on maintenance of capital, or keeping capital stock least unchanged. Actually, there are three main forms of capital: natural capital, Social capital, built capital, and financial capital.

Natural capital is all renewable and non-renewable resources that Mother Nature provides. Social capital incorporates resources such as system's infrastructure, its governing body, knowledge and skills embodied in its constituents and their health. Built capital is investing royalties from depleting natural resources in built structures such as information technologies, roads, factories, buildings in the country and manufactured goods. Finally, financial capital is money.

The success of any community is based on appropriate management of all types of capital discussed earlier. Failure to carefully manage may ultimately lead to community deterioration.

It should be stressed that theoretical differences in the approach toward attaining economic sustainability lead to the birth of two schools of thoughts that are based on different notions of capital theory. They are driven by their set of priorities that are either based on environmental or economic drivers. For example, the school that is driven by the pure economic objective is the weak sustainability. This approach allows the nation to overcome the depletion of natural resources by the innovation of new technologies and/or discovery of new raw materials. Here, what matters is the total capital stock, without consideration to the portioning of that among the previously discussed four forms of capital stock. Eventually, this is accomplished by increasing the social, built and financial capital (Hartwick 1977; Solow 1986).

Alternatively, the school that is driven by the environmental objective is the strong sustainability. Under this approach, natural and human-made capital is complimentary, it entails keeping all kinds of capital in separate accounts which assumes that they are not exchangeable.

Advocates for strong sustainability emphasize that there are certain services offered by Mother Nature that cannot be replicated by humans. For example, the ozone layer function of protecting our planet from harmful rays is difficult for humans to substitute. Other examples are losses of species and habitats, air and water pollution, ambiguity of natural capital substitutions to name a few (Hediger 2006). Overall, this approach calls for the right of Mother Nature to exist and human-mankind should use its functions in a way that will ensure our ability to pass it for future generations intact.

In summary, to attain sustainable development, humankind should strive to balance economic and social needs within the carrying capacity of our Planet. This can be realized only if we have a major shift in the social values, lifestyle and behaviors, that will ensure our consumption practices, industrial system, products, and materials use are environmentally friendly and sustainable. It should be emphasized, these measures can be realized by political and institutional policies and directives committed for such transformation.

3.4.4 Industrial Ecology

Major deterioration in the environment as shown by the increase in the global ecological footprint that reached 1.5 fold the carrying capacity of our planet led to the development of the industrial ecology concept. It seeks an essential paradigm shift in the approach toward industry-ecology relations. This is a multidisciplinary approach that promotes a holistic approach toward addressing environmental issues by incorporating inputs from relevant disciplines and variety of fields represented by law, economics, engineering and business to name a few. Moreover, industrial ecology is based on the incorporation of natural systems into our global industrial civilization and learning from the efficiency of natural systems. It takes the model of the natural environment as a way for solving environmental problems, creating a new paradigm for the industrial system in the process.

Graedel and Allenby defined industrial ecology as "the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a system's view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and finally to ultimate disposal" [Graedel and Allenby 1995].

One of the fundamental drivers is the call to change our industrial linear model toward the third industrial ecosystem that mimics Mother Nature. In nature, all materials are reused and nothing is endlessly discarded. Nature has acquired this approach because extracting these materials from reserves is costly in terms of resources and energy, and this is always avoided whenever possible. On the other hand, our current industrial system primarily discards materials to the ecosystem at unnecessary high cost. As a result, products should be thought of as residues rather than wastes, and it should be considered that wastes are basically residues that our economy has yet to use efficiently.

Characteristic features of Mother Nature that could be emulated by industry includes [Tibbs 1991]:

1. In natural ecosystems there is no such thing as "waste"; considering something that cannot be absorbed in the system.
2. Waste from one species is the food for another.
3. Concentrated toxins are not stored or transported in bulk at the system level, but are synthesized and used as needed only by the individuals of a species. (Snake venom is produced in glands immediately behind the snake's teeth.)
4. Materials and energy are constantly circulating and transforming within Mother Nature.
5. Mother Nature runs entirely on solar energy.
6. Mother Nature is dynamic and information-driven, and the identity of each of its species is defined in process terms.
7. Mother Nature allows independent activity of species individuals. However, cooperation and competition interlink them and hold them in balance.

In conclusion, the aim of industrial ecology is to incorporate the cyclical patterns of ecosystems into designs for industrial production processes, in order to achieve a pattern of industrialization that is not only more efficient, but adjusted to the characteristic features of Mother Nature. An industrial system of this type will have no adverse environmental effects, because it will have eliminated potential causes in the design stage.

3.4.5 Industrial Metabolism

It should be emphasized that the basis to industrial ecology is to follow materials and energy flows, transformations, and dissipation through various systems as well as into natural systems. This is a concept that was developed in 1989, by Robert Ayres and commonly referred to as industrial metabolism. Moreover, mass balancing concept of these flows is used to account their negative impacts on Mother Nature.

Metabolism, as used in its original biological definition, can be described as the process in which the organism ingests energy rich materials (food) to support its maintenance and functions, as well as a surplus to permit its own growth and reproduction. It also involves excretion of the generated waste consisting of degraded materials.

With this information in mind, industrial metabolism can be defined as a complete integrated collection of physical processes that convert raw materials, energy, and labor into finished products as well as wastes in a steady state condition. The stabilizing controls of the system are provided by its human component.

It is worth noting that this concept can also be applied to other self-organizing entities, such as manufacturing firms. A manufacturing firm is the economic synonym of a living organism. However, some differences prevail between a living organism and a firm. For example, biological organisms reproduce themselves. On the contrary, firms produce products or services. Furthermore, the firms are not specialized and can easily change from one product or business to another depending on the market demands. By contrast, organisms are highly specialized and cannot change their behavior except over a long period of time. The life cycle of individual materials in the living organism are closed, whereas, most industrial cycles are open. In other words, the industrial system doesn't generally recycle its wastes. However, it starts with high quality materials extracted from the earth, and returns them to the nature in degraded forms(Ayres and Ayres 1998).

The ultimate goal in industrial metabolism is to achieve advances across the horizon of industrial processes, bringing them more into line with the metabolic patterns used in the natural ecosystem. As a result of this, management of the interface between industry and the Mother Nature would become easier and the in-process energy demands would be reduced, process would be safer, and the industrial metabolites would be more compatible with natural ecosystems. This is the absolute longer-term objective, however, at this point and in the form of modest rationale process improvement, industrial metabolism has much to offer, as a result it is always considered as an important component of industrial ecology (Tibbs 1992). Frosch and Gallopoulos have discussed the relationship between biological ecology and that of industrial activities. They acknowledged that the symmetry between the industrial and biological ecosystems is not perfect, yet industrial system approaches can be significantly improved by adapting the best features of the biological analogue (Frosch and Gallopoulos 1989).

The approaches that can be used to achieve these goals are:

1. Optimizing the use of materials and embedded energy, waste reduction, re-evaluation of wastes as raw material for other processes, and consideration of wastes as products so as to close the manufacturing loop.
2. Understanding the ecosystem assimilative capacity and development of indicators to quantify the environmental impact of industrial processes so as to balance the industrial input and output in relation to natural ecosystem capacity.
3. Creating metabolic pathways in industrial processes.
4. Introducing systemic schemes of energy use.
5. Opening of long-term viewpoints in analysis of industrial system development.

It can be speculated that new processes (organisms) were created by the biological evolution to stabilize the inherently unstable situations and close the open cycles. This degree of stability that the biosphere reached took several billion years. However, in the case of industrial system, the time scales have been significantly shortened. Furthermore the rate of resources mobilization by human industrial activity is in most cases comparable to that of the natural rate. This is reason for concern about long term stability [Ayres and Ayres 1998].

The aim of the industrial metabolism is to understand the circulation of materials and energy in industrial systems from their initial extraction to their inevitable reintegration into the overall biogeochemical cycles. In addition, to develop an ecosystem in which the consumption of energy and materials is optimized, waste generation is minimized, and the effluents of one process serve as raw materials for another process. Ultimately, the industrial ecosystem should end up working as a biological system [Hileman 1998]. Table 3.3 sets a comparison among various political, social, industrial systems hierarchies relative to that of ecological systems.

Political Entities	Social Organizations	Industrial Organizations	Industrial Systems	Ecological Systems
UNEP	World population	ISO	Global human material and energy flows	Ecosphere
U.S. (EPA, DOE)	Cultures	Trade associations	Sectors (e.g., transportation or health care)	Biosphere
State of Michigan (Michigan DEQ)	Communities	Corporations	Corporations/institutions	Biogeographical region
Washtenaw County	Product systems	Divisions	Product systems	Biome landscape
City of Ann Arbor	Households	Product development teams	Life cycle stages/unit steps	Ecosystem
Individual Voter	Individuals/ Consumers	Individuals		Organism

Table 3.3: A comparison among various systems hierarchies relative to that of ecological systems (Garner and Keoleian 1995).

From the above discussion, it can be seen that industrial ecology is an expansion of industrial metabolism. The industrial metabolism aims to look at the total pattern of energy/material flows from initial extraction of resources to final disposal of wastes. However, industrial ecology looks for determining how the industrial system can be restructured to make it compatible with the way Mother Nature functions.

3.4.6 Types of Industrial Ecosystems

The evolution of industrial ecosystem is recognized in three possible stages:

Type I: In this stage, the potentially visible resources were so large, and the life is so small the industrial ecosystem might be described as linear, one-way flows of products where the life cycle of the product occurs with no regard for reuse or recovery of materials or components, and independent of all other flows. Schematically, it takes the form of Figure 3.3.

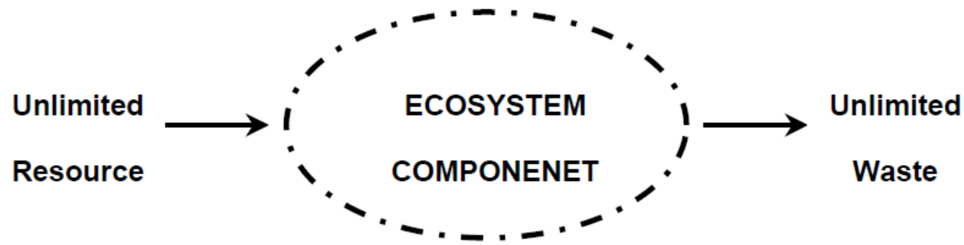

Figure 3.3: A Linear Material Flows in Type I Industrial Ecosystem (Graedel and Allenby 1995).

Type II: In this stage, the industrial ecosystem led to some resource cycling as an alternative to its opponent's linear system. Although there is still an input of virgin materials and a disposal of wastes outside the system, the flows of material within the system are larger, but the flows into and out of it are smaller. Schematically, it takes the form of Figure 3.4.

The Type II industrial ecosystem is more efficient than Type I, but still it is not sustainable because it continues to have an input (virgin materials) and an output (wastes); moving linearly in one direction.

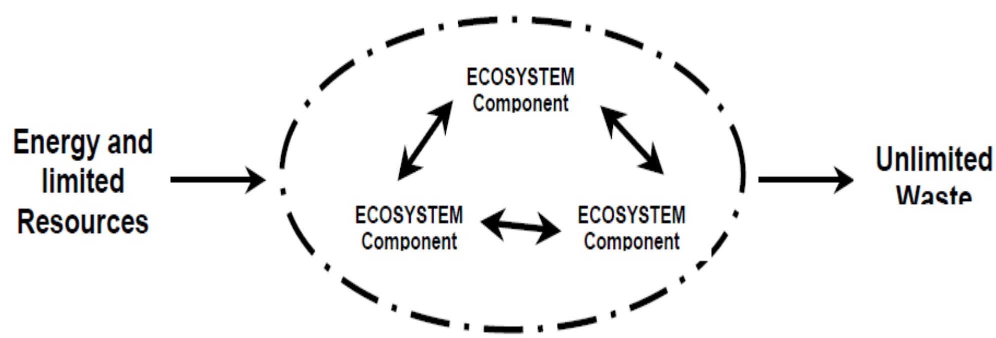

Figure 3.4: A Quasi-Cyclic Materials Flows in Type II Industrial Ecosystem (Graedel and Allenby 1995).

Hypothetical Type III: *In this arrangement, the industrial ecosystem follows the principle* "waste from one component is the food for another". It mimics the biological ecosystem, "waste from one component is the food for another". It mimics the biological ecosystem, and is characterized by complete cycling of products and related materials. The energy is an exception to the cyclicity since it enters as an external resource in the form of solar radiation. Schematically, it takes the form of Figure 3.5(Graedel and Allenby 1995).

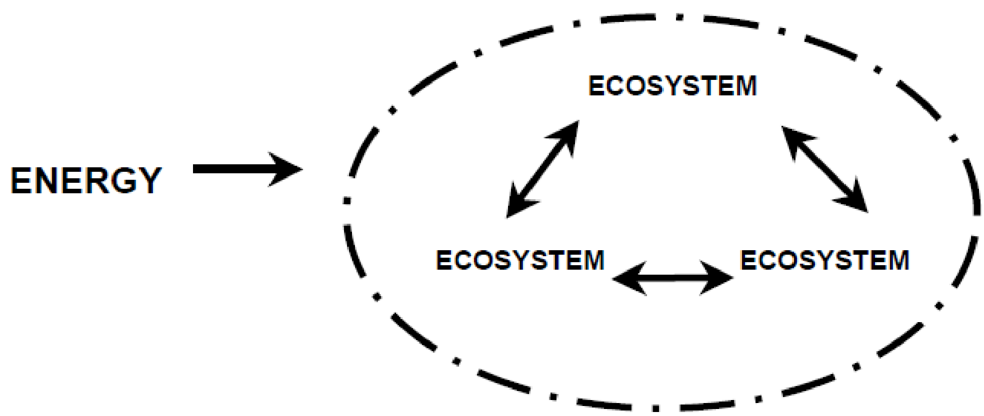

Figure 3.5: A Cyclic Materials Flows in Type III Industrial Ecosystem (Graedel and Allenby 1995).

Linking Industrial Ecology to the Issue of Sustainability

This novel framework serves as a key driver for achieving sustainable development by adapting strategies that will minimize the negative environmental impacts associated with current industrial systems. Industrial ecology advocates and promotes sustainable development at the industrial, community, national, and international levels.

It enables that by promoting the sustainable use of renewable resources, materials and energy and reducing the reliance on nonrenewable ones. Furthermore, this approach considers the wellbeing of surrounding ecosystem as an extension of the human health and wellbeing therefore; it ensures that adapted industrial practices will have minimal disruptions of Mother Nature. Implementing this framework would address the depressing imbalance of resource utilization between developing and developed countries and the ability of future generations to meet their own needs. In fact, this encompasses the basis of attaining sustainable development that is founded on the ethical principles of equity between inter and intra generations. This is the main theme of sustainable development that is defined by the United Nations World Commission on Environment and Development as "meeting the needs of the present generation without sacrificing the needs of future generations."

CHAPTER 4: How is Sustainability Measured?

4.1 Introduction

The industrial revolution was successful in establishing the standard industrial paradigm in the form of a linear manufacture-consume-dispose industrial system. This linear model is the first type of industrial eco-system[3] that is based on the sequence of raw material extraction, and then labor and technology are used to transform raw materials into final products that create profit (Graedel and Allenby 2010). After a relatively short lifetime, these products are disposed of and become waste at the end of their life cycle. In essence, this model assumes an infinite supply of natural resources, which our planet cannot satisfy with our current rate of aggravated extraction, use, and disposal. The economic activity fundamentals of this system are based on production and consumption. In this linear paradigm, the nation's economic progress is measured by making the manufacturing industry more efficient thus producing more products. This results in the growth of the Gross Domestic Product "GDP", which fundamentally measures the production activity of a nation.

GDP was presented during World War II to evaluate the wartime production activity. It is now generally considered as the primary indicator of the country's economic progress, health, and well-being. This well-publicized traditional indicator measures the flow of money in the country and determines if the economy is growing within a

[3] To attain industrial sustainability; the evolution of the industrial system is recognized in three possible stages that changes from type I a linear system to a more cyclic system Type III, like that of Mother Nature. This is a pivotal concept to industrial ecology. Graedel, T. E. and B. R. Allenby (1995). Industrial Ecology. Englewood Cliffs, New Jersey, Prentice Hall.

time frame. There are three valuation methods for GDP: product, income, and expenditure approaches.

The product approach calculates the value of every class of enterprise final goods and services produced to determine the total economic activity within the border of a nation irrespective of who produces them in a given time period. The income approach is based on the principle that the incomes of the productive factors must be equal to the value of their total expenditures on final goods and services. It is calculated by summing up wage, profit, rent, and interest income earned by households and firms in a given year (CliffsNotes 2011). This dissertation focuses on the expenditure approach. Where its computation of GDP is based on the sum of its four main components: consumption, investment, government spending, and net exports. Consumption by private households, which is the result of the current industrial system and itemized by goods and services, is the largest GDP component and accounts on average of 68 % of the total USA GDP for the years of 1988-2009 (BEA 2009). These goods are divided into durable goods and non-durable goods. Durable goods are defined as products that yield services and/or utilities of a lifetime of 3 years or longer such as cars, home appliances, furniture etc. Alternatively, nondurable goods are identified as products that are usable over a limited period of time less than three years or destroyed following single use such as syringes, disposable diapers, razors, hypodermic syringe, paper towels, plastic spoons, and disposable cigarette lighter.

According to this approach, higher GDP results from higher amount of money spent in the country by producing and/or consuming more goods and services. Consequently, this will create wealth in the country, which is usually associated with a better public welfare and standard of living. It should be emphasized that the economic value of natural resources as stated by this methodology lies not in its availability, rather in its market price. One of the main outcomes of this economic indicator; which is based on the manufacture-consume-dispose linear industrial system, is the creation of the throwaway society state of mind, which is also referred to as disposability. Here products are considered disposable if designed to be thrown away after short term use for cheapness and convenience. The interest in disposability as a concept started as early as 1912 by Christine Fredrick, the American domestic reformer who was one of the early advocates of disposability in the name of both convenience and hygiene. In addition, over-production, improvement in the manufacturing process, planned obsolescence*,* and *c*ost/price led to the spread of the culture of disposability (Lucas 2002).

This linear model has led societies to continue with their unsustainable consumption in their everyday life despite continuous losses of 'natural capital' that takes place around the planet. Such a linear industrial system does not take into account the limited resources of our planet at its interconnected ends i.e. material extraction and landfills. Moreover, this mode of consumption has a huge impact on the environment, which is a function of the way products are produced, used, and disposed of.

In the early 1970's Meadows et al. declared their alarming "The Club of Rome's" report: "The Limits to Growth", which raised the concerns of the devastating impact of exponential increase of human population that is estimated to reach 9 billion people by 2025 and consumption on the environment (Meadows 1972). They predicted that this trend would undermine the ecological carrying capacity of Mother Nature. This report was criticized and the controversy is still alive. For example, the defenders of the merits of the economic growth that is measured by Gross Domestic Product (GDP) are against the report recommendations. GDP valuation methodology is based on the notion that higher GDP results from higher amount of money spent in the country by producing and/or consuming more goods and services. They believe that this creates wealth in the country, which assumes better welfare and standard of living. The report suggests otherwise, it was a call for a new era of economic growth that leads to a better life for inter and intra-generations, and thought of as sustainable economic development that focuses on living qualitatively rather than quantitatively (Goodland 2009). It calls for an era that is not founded on mass consumption, production and disposal of masses of waste. The interest in sustainable development resulted in the Earth Summit, held in Rio De Janeiro, Brazil, in 1992 by United Nations Conference on Environment and Development (UNCED). This historical event had major outcomes where many countries declared their commitment to adopt new patterns of development that would attain sustainability. They also showed their dissatisfaction and concerns about GDP as an effective tool to assess progress, since economic growth does not usually translate into both human and ecological wellbeing (SNA 1993). This led policy makers to urge researchers to develop sustainable progress indicators that would monitor progress and assess their actions toward achieving their goals on sustainable development. At the 20^{th} anniversary of the 1992 United Nations Conference on Environment and Development (UNCED), in Rio de Janeiro, the Rio+20 Conference was held, with the theme “The Future we want”. It was attended by world leaders along with thousands of participants from governments, the private sector, NGOs and other groups. They reinvigorated the interest in developing broader measures of sustainability that would complement GDP, and better assess progress toward sustainable development (Charnes, Cooper et al. 1984) . As discussed in the previous Chapter, the most widely accepted definition of the concept of sustainable development was introduced in the Brundtland Report by the United Nation's World Commission on Environment and Development (WCED) known as "Our Common Future" in 1987. This concept was defined as "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs"(WCED 1987). Thus to measure sustainable development, a successful sustainability index should integrate time and/or thresholds. Moreover, Meadows suggested that "development indicators should be more than growth indicators; they should be about efficiency, sufficiency, equity, and quality of life" (Meadows 1998). However, this well publicized definition of sustainable development is still considered as a vague one by many researchers where it neither considers time frame nor specifies human needs categories and the roles of environment/ social concerns in long-term development (Bartelmus 2008).

Over the last two decades, researchers have developed numerous sustainability indices that aim at measuring sustainable development in quantifiable terms and guide policy makers on the progress and effectiveness of adapted strategies to improve country's overall sustainable development. It should be emphasized that an "indicator" is a qualitative or quantitative measure that evaluates progress with respect to one of the three main domains of sustainable development i.e. environmental, social, economic. Examples of such indicators are: concentrations of SO_x, ratio of crime/population, how does the city manage recyclables? How does the city manage hazardous wastes from hospitals and industries? Percentage of time lost because of traffic jams.

However, the weakness of measuring sustainable development using indicators is the inconvenience of assessing progress towards sustainable development and comparability since each is expressed differently. Therefore, what is more convenient is developing indices that are aggregated and compounded to facilitate measurement and reliability in assessing sustainable development. Researchers have developed indices that combine different indicators to provide a simplified, logical, multidimensional decision making tool that would provide policy makers with information to formulate strategies that would address areas of concern that need attention and predict the overall condition or direction of nation's progress.

Additionally, the success of sustainability is determined by the commitment of every part of the community that is not only limited to public programs, or the growing integration of scientific theories and disciplines (Bettencourt and Kaur 2011), but also spans industries and businesses. Consequently, many leading companies have started to implement a number of disclosure programs that ensure the implementation environmentally conscious manufacturing to maintain a progressive economy without damaging our environment. It also helps them continually assess and improve their impact environmentally, socially, and economically. This Chapter has two objectives. The first is to review the major sustainability indices, which currently act as critical tools in the assessment of the progress of strategies adapted by nations and its industrial institutions to attain sustainability by enforcing cleaner production and consumption. The selection criteria of the reviewed indices were primarily based on their consistency, importance, popularity and literature availability. The indices chosen were reviewed by definition, application, valuation methodology and foundations, in addition to identifying the strengths and limitations of each of them. The second goal is to highlight the efforts, indices, and measures adapted by leading industrial institutions with the goal of encouraging sustainable development. The chosen indices are discussed in the following subsections starting with GDP, the traditional progress measure.

4.2 Gross Domestic Product (GDP)

Gross domestic product (GDP) was formulated during World War II. It enabled policy and decision makers to monitor the wartime production activity and ensure enough supplies are provided to support fighting troops (Marcuss and Kane 2007). Ever since, the GDP has become the primary and most influential measure that is employed by the System of National Accounts (SNA) to determine countries' economic progress, health, and well-being. This well-publicized traditional index measures the flow of money in the country and determines if the economy is growing over a certain period of time (Lawn 2003).

According to this concept, higher GDP results from greater amounts of money spent in the country by producing and/or consuming more goods and services, which creates wealth in the country, assumes better welfare, standard of living and well-being. In this concept, the economic value of our natural resources lies not in its availability, rather in its market price.

It is worth noting that there is a major difference between GDP and Gross *National* Product (GNP). GNP is also an index of economic activity and measures the value of the goods and services over a certain period of time that are produced by domestic companies abroad. However, GDP only measures the value of goods and services located within the country's boundaries and produced by either domestic or foreign companies (Lawn 2003).

4.2.1GDP valuation Methodology

There are three interchangeable valuation methodologies for the calculation of GDP: product, income, and expenditure approaches. Based on this the country's total production (output) equals income, which also equals overall country's expenditure. Overall, the three valuation methodology should add up to the same GDP sum (Stanford 2008; BEA 2009).

The least widely used approach is the product or output methodology that assumes the sums of the production of every class of enterprise to ultimately contribute to the value of GDP. Countries' GDPs are estimated by income or expenditure. The income approach is based on that the incomes that the productive firms pay for production must be equal to the value of their output. Under this approach, GDP is assessed by the sum of all producers' incomes.

The most widely used methodology for the calculation of GDP is the expenditure approach (Figure 4.1). This is based on the principle that all of the outputs are "bought" by somebody. As a result, the value of the total goods and services must equal to country's total expenditures in buying things (Stanford 2008). Accordingly, GDP is calculated using the following equation.

$$GDP = C + I + G + (X - M) \qquad \text{Equation 4.1}$$

Where
C is Consumption
I is Investment
G is Government Spending
(X - M) is Net Exports

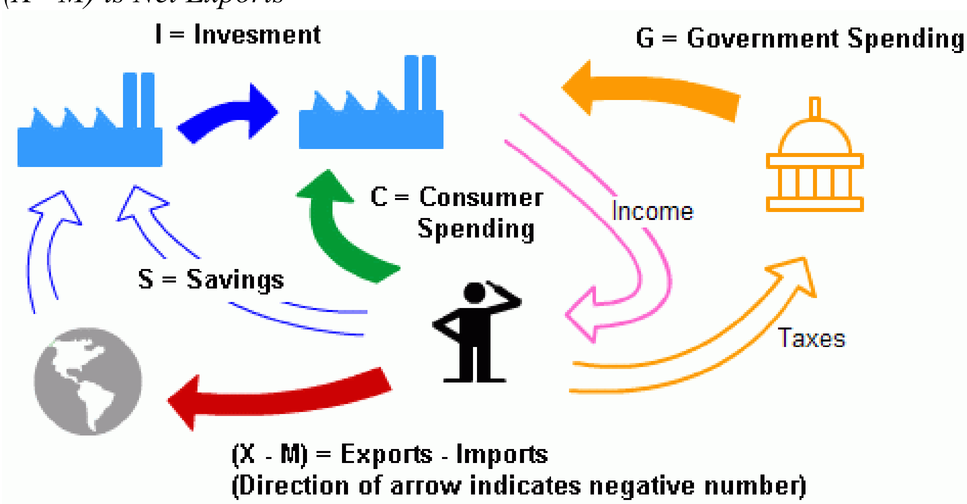

Figure 4.1: Money Flow in the GDP components. Source: http://www.mindtools.net/

Due to its relevance to this research I focused on the expenditure methodology and the following is a description of each GDP component using this approach:

Consumption is usually the largest component of the economy using this approach. It consists of private household expenditure, which is broken into: durable goods, non-durable goods, and services. Where: durable goods are defined as products that yield services and/or utilities of a lifetime of 3 years or longer such as cars, home appliances, furniture etc. Alternatively, nondurable goods are identified as products that are usable over a limited period of time less than three years or destroyed following single use such as syringes, disposable diapers, razors, hypodermic syringe, paper towels, *plastic spoons, and disposable cigarette lighter.*

Investment is a smaller yet a critical component of GDP. It is the driving force for production and employment which are the cornerstones of today's economy. Examples include business investment in equipment, software, accumulation of inventories, and construction of new homes to name a few.

Government spending is the government expenditures on the provision of goods and services. It includes salaries, purchase of weapons for the military, and infrastructure. It does not include social security, or unemployment benefits.

Net Exports represents the difference between gross exports, which contribute to an increment to domestic output, and gross imports which is subtracted because it is an expenditure on foreign produced output (Stanford 2008; BEA 2009).

Therefore, the genesis of the "throwaway society" or disposability can be traced to the use of GDP as a metric of progress since GDP leads to equating growth with consumption. Products are considered disposable and designed to be thrown away after one use for cheapness and short term convenience with lifetimes ranging from days to several months instead of design alternatives that last indefinitely (Lucas 2002).

4.2.2 Advantages and Limitations of GDP

The primary building block of GDP is consumption that accounts for 65 % of its sum. Based on this premise, higher nation's GDP is associated with higher spending, consumption, and production, which leads to better economic progress. Therefore, GDP is an effective tool that provides an idea on the size of the economic activity of a country measured in monetarized units. It is interesting to note that the input data used in the valuation methodology of GDP is based on (System of National Accounts) SNA ,which is reliable data base, an advantage that is not found in most of the sustainability indices. As a result, this measure can provide meaningful data in comparison between nations and assess progress over time (Hoti, Pauwels et al. 2004).

Even though GDP is regarded as a primary measure of economic activity, this index has been criticized for its failure to truly assess a nation's social and ecological well being since it does not delineate negative activities and considers them as a profit for a country (Kuznets 1934; Kuznets 1941; Lawn 2003; Van den Bergh 2009). Furthermore, it does not consider activities that are beyond the boundary of monetarised exchange and contribute to the quality of life and well-being (Bleys 2005). The Economist Simon Kuznets (Kuznets 1934; Kuznets 1941), the founding father of the SNA for USA was aware of GDP flaws and cautioned the U.S. Congress that "*The welfare of a nation can scarcely be inferred from a measurement of national income as defined by the GDP".* So it was realized that GDP is an indicator of wealth, yet not welfare (Kuznets 1934).

GDP Methodology does not take into consideration neither natural resource depletion nor environmental damage. Its valuation methodology promotes consumption, which is the primary driver for natural resources depletion. Under this measure, Mother Nature is assumed to have an infinite supply of natural resources. In which, higher commodity producing countries rate of natural resource depletion is associated with higher GDP (Anielski 2001). There is a positive relationship between the GDP and solid waste generation of various countries over the past decades. For example, Sweden, which was the top ranked country in many of the sustainability indices; had an increase in the per capita municipal waste generation by 60% and associated 66% increase in solid waste from its manufacturing industries from 1993 to 2006 (Sjöström and Östblom 2010).

Overall, this clearly testifies that under this measure natural resource depletion and associated degradation of the ecosystem is considered a profit rather than a cost. Also, GDP focuses on activities that would ultimately add to the economic growth without differentiating between "goods" or benefits and "bads" or the societal cost of pollution to the personal development and well-being. For example, it lacks accounting for income distribution and mainly focus on average income. Also, it focuses on material consumption, which is not a reflection whether basic needs such as water, food, shelter, clean air, basic medical care are satisfied (Tan 1997).

Moreover, GDP disregards any non-economic activities that are outside the economy even if they would contribute to wellbeing; household production where GDP promotes working moms who send their kids to day care rather than stay at home moms who would care after their own; and unpaid household labor volunteer or unpaid services are some such examples Van den Bergh (Van den Bergh 2009).

Another concern under GDP is it has incorrect accountability for defensive expenditures such as crime, or commuting to work, and insurance since they only prevent or fix social costs and do not contribute to economic growth. An in depth discussion of GDP shortcomings is advised in Van den Bergh (Van den Bergh 2009).

In brief, unlike sustainability indices "as discussed below", GDP shows the social and environmental damage as economic gain when it goes up the communities' well-being goes down and vice versa. Despite the limitations and well-documented flaws of the measurement, GDP and the System of National Accounts (SNA) are seen as powerful with available reliable data on GDP for most nations and still widely used as a measure of progress. This measure continues to dominate economic decision making and public policy.

4.3 Ecological Footprint (EF)

As discussed earlier, the main drive toward attaining sustainable development are the limits of the ecological natural system and our commitment to reduce current human consumption of natural resources below these levels. This is paramount considering the damaging impact of the current linear manufacture-consume-dispose industrial and economical systems on the ecological limits of Mother Nature. Furthermore, this linear model assumes infinite supply of natural resources and sinks for the industrial wastes. It is also threatening the biosphere on which our life depends. As an outcome, there is an urgent call for indices that are needed to assess human's consumption, disposability and associated pollution patterns, and determine our impact on the global biocapacity to provoke and implement a reduction of human footprint (Lucas 2002).

In 1996, Wackernagel and his colleagues at the Universidad Anahuac de Xalapa introduced the concept of Ecological Footprint (EF). This is a complex sustainability index that measures the demands humans place on earth's ecosystem and natural resources and provides a single index measured in land terms (gha) In other words, *"Ecological Footprint analysis is an accounting tool that enables us to estimate the* *resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area"* (Wackernagel and Rees 1996). Binningsbo *et al.* claims EF has emerged the most widely accepted, tested and implemented measure of environmental sustainability (Binningsbo, de Soya et al. 2007). Furthermore, it provides a quantitative assessment of the bioproductive land and sea area (the amount of nature's carrying capacity[4]) required to continuously produce the consumed resources of food, energy, and materials and assimilate all the wastes by an individual, population or activity generated in a given year using prevailing technology. Dietz *et al.* claims that EF is *"translating economic activity into the area required to produce the resources consumed and to assimilate the wastes generated by a given region"* (Dietz and Neumayer 2007). Consequently, the land area calculation is accredited to consumer country rather than the resource producing country. Accordingly, non-renewable resources generated in a developing country but consumed in a developed country credited towards the developed country's EF calculation (Dietz and Neumayer 2007). People consume resources from all over the world, so their overall EF can be thought of as the sum of these areas, wherever on the planet they are located (Wackernagel and Rees 1996). The EF ultimately measures the sustainability of human consumption where changes in its values will be determined by changes in both per-capita consumption levels and the rate of population growth (Hanley, Moffatt et al. 1999).

[4] Dietz et al defines the carrying capacity as "the maximum population size that can be supported by a given set of resources."

4.3.1 EF Valuation Methodology

The EF is effectively used to assess nation's sustainability based on ecological resource accounting. It evaluates individual, population, country, etc. consumption and waste assimilation by integrating different resources categories: Natural resources used in food, goods, and wood products production (crop land, grazing land, fishing grounds, and forest land); built up land required to accommodate human infrastructure (housing, transportation, industrial production, and other built-up land); surface area of the earth (land and water) needed to assimilate carbon dioxide emissions from fossil fuels use and production as exemplified in Figure 4.2. The end product of EF is measured using the unit of global hectare (gha), which is one hectare of land or water with world-average productivity. The measurements in global hectares are adjusted according to the productivity of land or water in a given year. For example, a land type of high productivity (eg. cropland) will have more global hectares than less productive land (eg. pasture) of an equivalent size (Ewing, Reed et al. 2008).

The Ecological Footprint *EF* of any country can be calculated as follows:

$$EF = \frac{\mathrm{P}}{\mathrm{Y_N}} \cdot YF \cdot EQF \qquad \text{Equation 4.2}$$

Where P is the amount of a product harvested or waste emitted, Y_N is the national average yield for P, YF is the yield factor for the land use type and EQF is the equivalence factor for the land use type. EQF converts the actual areas in hectares of different land use types into their global hectare equivalents. It should be emphasized that YF accounts for countries' differing levels of productivity for particular land use types. The *YF* also provides comparability between various countries EF and biocapacity calculations.

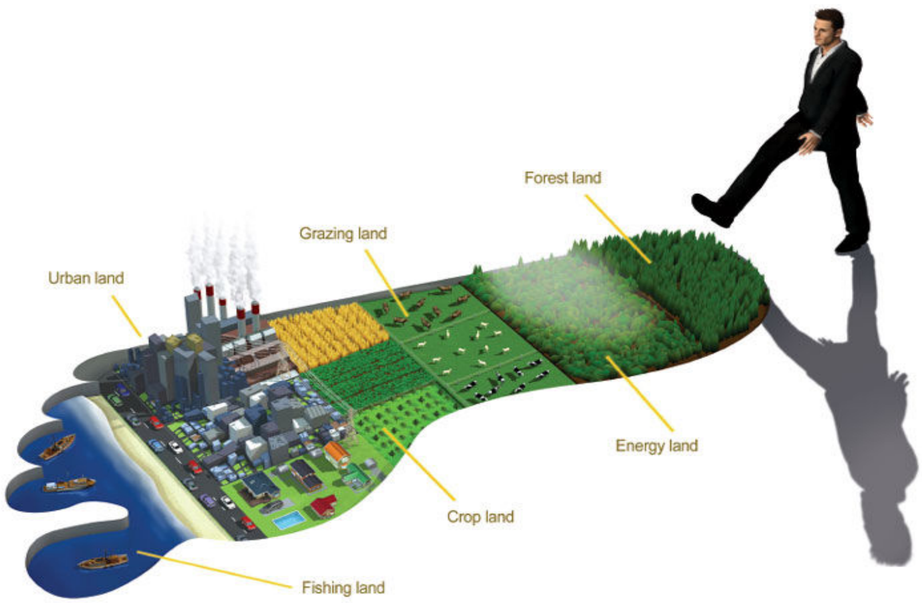

Figure 4.2: Resources' land categories employed in ecological footprint index calculation.
Source: Ministry for the Environment of New Zealand,2010

Alternatively, the country's biocapacity *BC* for any land use type is given by:

$$BC = A \cdot YF \cdot EQF \qquad \text{Equation 4.3}$$

Where *A* is the available area for a certain land use type discussed in advance.

Summing the Footprints of all primary harvests and waste absorptive capacity of ecosystem services yields the total Footprint of a country's domestic production.

A further comprehensive valuation methodology can be found in the publication of calculation methodology for the national Footprint accounts (Ewing, Reed et al. 2008).

It is interesting to note that in 2003, the share of the total footprint of energy, food, forest and built are 53.7%, 34.4%, 7.8%, and 4.1%, respectively as reported by White *et al.* (White 2007). In 2004, World Wildlife Fund (WWF) published that on average, EF in developed countries is 6.4 ha/person. This is 3.5 times higher than the availability of productive land of 1.8 ha/person. This reveals the unsustainable consumption behavior of our disposability culture. Furthermore, in 2006, (WWF) reported the EF values of 147 nations, which ranged from 0.52 gha/cap in Bangladash to 11.87 gha/cap in the United Arab Emirates (White 2007). For example, if the human load exceeds the productive capacity of the biosphere then consumption patterns are clearly not sustainable given current circumstances. According to Redefining Progress latest Footprint Analysis, the global population is exceeding its ecological limits by 39%. This indicates that we would need to have over one third more than the present biocapacity of Earth to maintain the same level of prosperity for future generations (Network 2008).

4.3.2 Advantages and Limitations of EF

The advantages and limitations of EF are well documented in the literature (Moffatt 2000) (Van den Bergh and Verbruggen 1999; Wackernagel, Onisto et al. 1999). EF provides a valuable insight of Mother Nature by combining complex resource use patterns into a single number that places all individuals within a universal scale that depicts a clear and unambiguous message that is usually easily understandable (Constanza 2000). *"Ecological footprints can become an easy-to-read measurement tool for ecological sustainability. By summarizing the diverse ecological impacts in an ecologically meaningful way, it helps to communicate the magnitude of the issues and* *provides a context for tangible action.”* (Wackernagel, Onisto et al. 1999). EF determines the stage where human practices invade ecological limits and compromise economic progress (Martinez-Alier 1995). It is interesting to note that the per capita EF index is significantly interrelated to critical environmental impacts such as ozone depleting emissions lending it to be considered as an effective tool to compare the ecological impacts of nations (Prescott-Allen 2001). Taken as a whole, EF is a tool that helps mankind reflects on their living practices and their direct and indirect impacts on surrounding environment in a given year (White 2007). One of the most important merits of EF is that it can be assessed on many levels and situations. For example, from a global level; the 2006 WWF report stated that in 2003, the global ecological footprint was estimated to be 14.1 billion gha. This footprint is 25% higher than our global available land. Nationally, WWF estimated the EF in 2006 for 147 nations, which would enable policy makers to take decisive measures towards a more responsible and efficient use of current available natural resources. It also promotes the implementation of preventive measures that would save the environment for current and future generations. Moreover, EF was used to assess the environmental impact from particular activities such as commuting, water use to name a few (Muñiz and Galindo 2005; Jenerette, Marussich et al. 2006).

While being considered as the best estimate to date in assessing the global ecological sustainability, EF is still not precise and is important to be cognizant of its constraints. For example, Hanley et al. pointed that EF fails to be used as a metric to predict its future values. Where, next year’s Ecological Footprint for a nation is not determined by current year value, it can be higher or lower than the value of the current year.

(Hanley, Moffatt et al. 1999). Furthermore, EF is based on determining the land used to manage different aspects of human consumption. There are many events that would limit our ability to predict the land use with confidence such as natural disasters, wars and economic down turn. In addition, it fails to consider the long term systematic degradation of ecological productivity associated with unsustainable practices such as overgrazing, soil erosion, and clear cutting of rainforest for agriculture. EF land calculation is imperfect; it does not take into consideration important environmental issues such as cumulative impacts of air and water pollution products (Wackernagel and Rees 1996; Wackernagel, Onisto et al. 1999). The only environmental issue that it considers is the CO_2 emissions. It should be stressed that the methodology used in converting CO2 emissions into forest land is not fully embraced by the scientific community (Van den Bergh and Verbruggen 1999). Therefore, the final outcome of EF evaluation is considered as an underestimate of its true value. Moreover, EF valuation methodology fails to assess the replacement of fossil fuel through renewable energy alternatives. If realized EF can be used as an effective decision making tool that encourages more sustainable energy supplies (ALLEN, ATHANASSOPOULOS et al. 1997).

One of the key limitations to this index is; it only considers environmental and economic aspects of sustainability dimensions and fails to incorporate the third pillar i.e. the social dimension. Wackernagel *et al.,* believe that social indicators should be combined with EF to comprehensively attain progress toward sustainability (Wackernagel, Onisto et al. 1999). Moreover, the valuation methodology of EF is based on land uses. As a result, this would only assess two types of environmental impacts, land occupation and global warming. This limits its use and application in some economic sectors such as agricultural products since it neglects some environmental impacts such as eutrophication and acidification (Fu and Ou). In addition one of the main factors that compromises the accuracy and consistency of the EF value is that the data that feeds into the calculation of EF comes from various sources and databases such as the Food and Agriculture Organization of the United Nations (FAO), the International Energy Agency (IEA), also some data are from studies in peer-reviewed science journals (Ewing, Reed et al. 2008). This would potentially compromise the quality of the evaluation due to discrepancy of the approach and render it more challenging to compare different studies outcomes.

4.4 Carbon Footprint

Carbon Dioxide (CO_2) and other greenhouse gases (GHG) are important to the earth. Indeed, GHG such as Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur Hexafluoride (SF_6) (Solomon 2007), allow sunlight to penetrate the atmosphere to warm the earth, by infrared radiation, to about 63 °F, otherwise, it would be 3 °F (Saleem 2001). CO_2 was balanced in nature where oceans and plants absorbed it[5] and it was usually emitted to the atmosphere by natural processes that were in equilibrium. However, the Industrial Revolution that played a pivotal role in advancing technology and creating the standard industrial paradigm in the form of a linear manufacture-consume-dispose industrial system relied heavily on fossil fuels. This provided the comfort and conveniences of our modern lifestyles and became an integral part of the global economy and facilitated

[5] Through a process called photosynthesis

mass production and consumption. In addition to fossil fuel combustion; other industrial activities that included and not limited to energy burned for transportation, heating, and power plants; resulted also in the release of massive amounts of GHG emissions and CO_2. This was accompanied by an increase in the global temperature by 0.6 ± 0.2 ºC at a rate of 0.17 ºC per decade since 1950 (Lal 2004; Solomon 2007). Furthermore, in 2005, the atmospheric CH_4 level surpassed the natural range evaluated over the last 650,000 years (Solomon 2007). Overall, this was associated with the accumulation of GHG in the atmosphere and amplification of greenhouse effects that were accompanied with significant alterations in the Earth's climate.

To lessen these long-term harmful effects on environment and communities; governments, businesses, and individuals realized their responsibility and became more concerned of the impact of their activities on the GHG harmful effects on climate and environment. Various parties called for an action to reduce GHG emissions and reverse their negative impact on Earth's climate. In the last few years, the debate on the negative consequences of CO_2 and GHG emissions on environment and the lack of public action against the threat of global climate change was conceptualized in the term "Carbon Footprint". Other various terms have been used too, such as climate footprint, CO_2 footprint, GHG footprint, methane footprint, and GWP footprint (Malik 2013). However, Carbon Footprint (CF) is a "buzzword" that has popularized and become a widely used term over the last few years and is now used worldwide at all levels with the purpose of measuring the amount of GHG emissions from their activities and identifying strategies to reduce their impacts on Mother Nature (NAS 2008).

Carbon Footprint as a sustainability indicator stems from the concept of EF developed by Wackernagel and Rees (Wackernagel and Rees 1996; Wackernagel, Onisto et al. 1999; Dasgupta 2010). There are various definitions for Carbon Footprint, for example, it is defined as the total set of GHG emissions caused by an organization, event, product or person (UKCT 2011). Where for simplicity these GHG emissions are converted into CO_2 equivalent and expressed in terms of the amount of CO_2 (Wiedmann and Minx 2008). Other definitions for Carbon Footprint are outlined below:

"A methodology to estimate the total emission of greenhouse gases (GHG) in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product (excluding in-use emissions)." (The Carbon Trust, 2007).

"A technique for identifying and measuring the individual greenhouse gas emissions from each activity within a supply chain process step and the framework for attributing, these to each output product (we [The Carbon Trust] will refer to this as the product's Carbon Footprint) (UKCT 2007).

" The carbon footprint is the amount of carbon dioxide emitted due to your daily activities – from washing a load of laundry to driving a carload of kids to school."(BP 2007) .

The carbon footprint was calculated by "measuring the CO_2 equivalent emissions from its premises, company-owned vehicles, business travel and waste to landfill." (Patel 2006)

"*The demand on biocapacity required to sequester (through photosynthesis) the carbon dioxide (CO_2) emissions from fossil fuel combustion. Although fossil fuels are extracted from the Earth's crust and are not regenerated in human time scales, their use demands ecological services if the resultant CO_2 is not to accumulate in the atmosphere. The Ecological Footprint therefore includes the biocapacity, typically that of unharvested forests, needed to absorb that fraction of fossil CO_2 that is not absorbed by the ocean*." (GFN 2011).

"A 'carbon footprint' is the total amount of CO_2 and other greenhouse gases, emitted over the full life cycle of a process or product. It is expressed as grams of CO_2 equivalent per kilowatt hour of generation (gCO_2eq/kWh), which accounts for the different global warming effects of other greenhouse gases." (POST 2006).

"The carbon footprint is a measure of the exclusive total amount of CO_2 emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product" (Wiedmann and Minx 2008).

"A measure of the amount of CO_2 emitted through the combustion of fossil fuels; in the case of an organisation or business, it is the CO_2 emissions due to their everyday operations; in the case of an individual or household, it is the CO_2 emissions due to their daily activities; for a product or service, it includes additional life-cycle CO_2 emissions along the supply chain; for materials, it is a measure of the embodied CO_2 emissions determined through life cycle assessment"(2011).

"The total amount of CO_2 and other greenhouse gases, emitted over the full life cycle of a product or service". (MCI 2010).

4.4.1 Carbon Footprint Valuation Methodology

In recent years, individuals, corporations, and countries are becoming more concerned about the issues of climate change and global warming (Pedraja-Chaparro, Salinas-Jimenez et al. 1997). As a result, individuals, corporations, and countries use "Carbon Footprint" index to estimate the impact of their activities on the environment as a way to control these issues and identify strategies to reduce their climate impacts. This is accomplished by assessing GHG emissions of how much CO_2 equivalent produced to directly and indirectly support the individuals' or companies' related activities in a given time frame usually the time period of a year.

Various sources such as the GHG Protocol (WBCSD and WRI 2007), ISO 14064 from the International Organization for Standardization (ISO 2007), PAS 2050 from the British Standards Institute (Sinden 2008), the General Reporting Protocol and sector-specific protocols from The Climate Registry (TCR 2009), and the International Local Government GHG Emissions Analysis Protocol from the International Council on Local Government for Sustainability (ICLEI 2008) that were developed, from collaborations between governments and business leaders, are used as references to assess GHG emissions associated with individuals, corporations, and countries related activities i.e. CF assessment for tourism accommodation facilities (Pedraja-Chaparro, Salinas-Jimenez et al. 1997; Policy 2013). The goal is to quantify their "CF" and develop strategies to manage and reduce it.

In this dissertation, the focus is on GHG Protocol, which is a product that is provided by the partnership between the World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD). GHG Protocol is considered the most widely implemented international accounting tool to assess GHG emissions and continues to develop reliable, comprehensive, and effective programs for managing climate change. These are consistent with the guidelines proposed by the Intergovernmental Panel on Climate Change (IPCC) [6] and enable companies and businesses to calculate their GHG emissions and develop sound climate change strategies.

The first step in quantifying the Carbon Footprint is to set emissions boundaries. According to GHG Protocol (WBCSD and WRI 2007) are divided into two types of boundaries:

1. Organizational boundaries that allow institutions to differentiate between GHG emissions that are directly controlled by their institution or not.
2. Operational boundaries that enable institutions to define the emissions resulted from either owned or controlled assets and categorized into three different scopes. This would help the company to identify the source of their emissions and strategies for their reduction to achieve the ultimate zero Carbon Footprint.

The second step in quantifying Carbon Footprint is to define emissions scopes to prevent double counting estimates of GHG emissions and trace emissions across the economy.

Scope one: Emissions resulted from direct GHG emissions occurring within the organizational boundary of a company from owned or controlled sources.

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[6] The Kyoto protocol is a legally binding international agreement between signatory nations to the United Nations Framework Convention on Climate Change (UNFCCC) to reduce greenhouse gases and of the stabilization of anthropogenic greenhouse gas emissions.

Scope two: Indirect GHG emissions resulted from the generation of purchased electricity consumed by the company in which GHG emissions physically occur at the facility where electricity is generated. Noteworthy, the GHG protocol recommends that companies account for and report scopes one and two categories.

Scope three: This is a voluntary reporting category, which includes other indirect GHG emissions resulted from the company's activities. However, the company does not own or have a direct control over the sources. Although these emissions do not occur within the company's boundary, it is considered indirectly responsible for the emissions attributed to these activities. Figure 4.3 depicts the interrelationships of the different scopes and activities that generate direct and indirect emissions.

The next step is calculating GHG emissions resulted from all sources, which can be done using a detailed analysis of the emissions accounted for all three scopes and known as Life Cycle Assessment (LCA). LCA is a method that attempts to assess environmental impacts at each stage of the life cycle of a product cradle-to-grave (from raw material extraction through ultimate disposal).

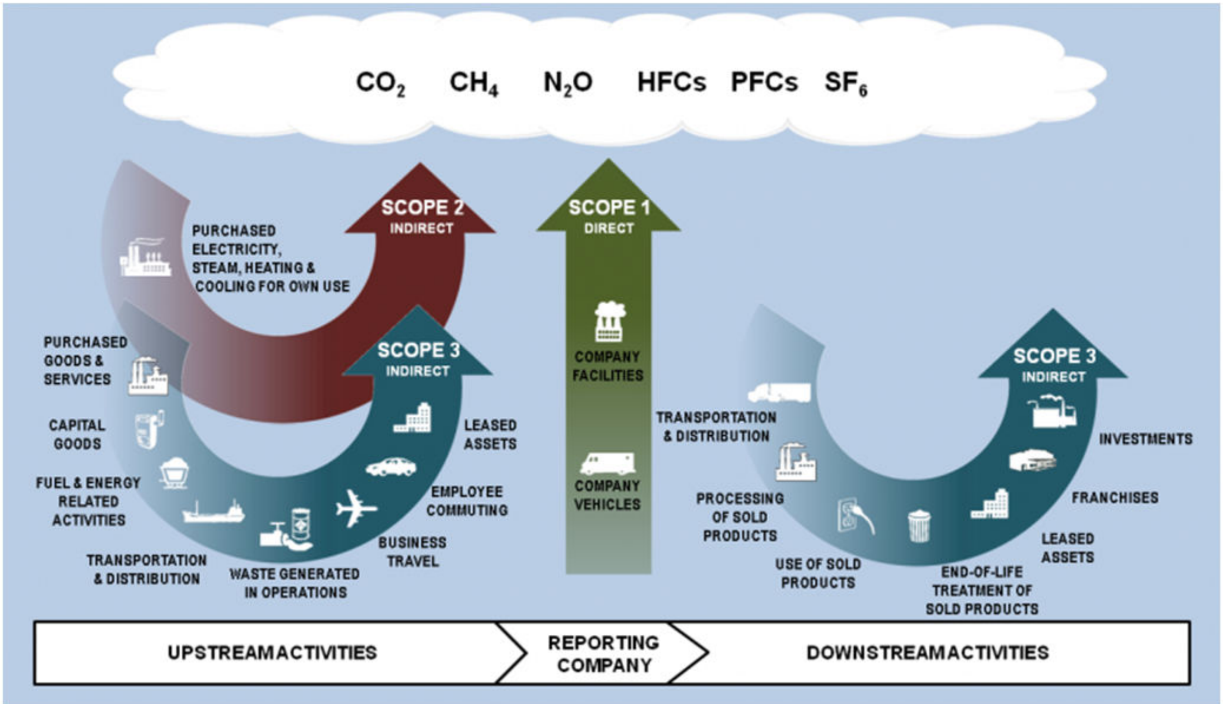

Figure 4.3: Overview of the interrelationships of the different scopes and activities that generate direct and indirect emissions (WRI and WBCSD 2011).

Using LCA, emissions are quantified from two different approaches; the first approach is Process Analysis (PA), which is a bottom-up methodology. It is a technique developed to assess the environmental impacts of individual products/processes from raw material extraction to ultimate disposal using detailed data based on involved processes. Furthermore, to minimize truncation error, identification of appropriate system boundaries plays a pivotal role in deriving Carbon Footprint estimates using PA (Lenzen 2001). It is interesting to note that that this approach is generally more precise yet time consuming that is mainly attributed to difficulty in obtaining comprehensive inventory data. (Arnold 1993; Portney 1994). Therefore, it is not suitable tool to assess Carbon Footprint for large entities (Wiedmann and Minx 2008).

The second approach is Environmental Input-Output (EIO) Analysis, which is a top-down methodology. This technique developed based on Leontief economic input/output model created in 1936 (Leontief 1986; Wiedmann 2009). Furthermore, EIO is calculated and developed as a software program by scientists at Carnegie Mellon University. The concept of EIO model enhances Leontief economic input-output tables obtained from the Bureau of Economic Analysis (BEA), at sector level with environmental account data[7] from both Environmental Protection Agency (EPA) and the Department of Energy (DOE) in a matrix form. EIO can capture emissions from the entire supply chain and is considered as a screening tool for estimating lifecycle emissions. In addition, the resulted data is used to assess the environmental impacts such as GHG emissions "Carbon Footprint" of production activities of any of the accessible industrial sectors in the US or other countries (Lave, Hendrickson et al. 1995; Hendrickson, Horvath et al. 1998; Hendrickson, Lave et al. 2005). Unlike PA, EIO utility in evaluating products or processes is limited and more convenient for large entities such as governments especially at the sector level (Wiedmann and Minx 2008).

In order to overcome the limitations of each of the discussed approaches, researchers started developing a hybrid approach in which the details of the process based calculations and EIO model are integrated to give a comprehensive and robust LCA analysis (Suh, Lenzen et al. 2004; Heijungs, de Koning et al. 2006). In essence, this is a new ecological modeling methodology that is still developing and its literature just emerging. Overall, both approached are needed if a comprehensive LCA is to be

[7] Multiplying it by its environmental impact per dollar (in emissions/$).

performed since they complement each other and each has its advantages and disadvantages (Wiedmann and Minx 2008).

GHG Protocol covers the accounting and reporting of the six main greenhouse gases covered by the Kyoto Protocol with the potential to cause climate change. Each of the main GHG has varying global warming impacts. Therefore, CO_2 has been assigned a warming potential of one and the other five gases are expressed in terms of a weighted CO_2 equivalents (CO_2-e) (Carbon N Zero, 2011). Table 4.1 illustrates the warming potential over 100 years of each of greenhouse gases covered by the Kyoto Protocol.

The Carbon Footprint is quantified by first identifying Carbon sources for the system. These sources and sinks are categorized according to the IPCC guidelines into six groups: Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, Land-Use and Forestry and Waste.

Finally, the CO_2 equivalence in tonnes or kg of all GHG emissions is summed up to find the overall Carbon Footprint and categorize major contributors attributed to the result and identify strategies to reduce their impacts. Based on what's outlined above, in 2005, WRI compiled a list of countries ranked by total greenhouse-gas. It is interesting to note that China and USA, the largest two economies, greenhouse emissions counted for more than 37.42% of the total global greenhouse emissions (WRI 2005). It should be stressed that the activities resulted from the linear industrial ecosystem was associated with an increase in the overall Carbon Footprint increased by more than ten folds between 1961 and 2005 and expected to increase by 25% to 95% by 2030 (Hails, Humphrey et al. 2008; Rose and McCarl 2008).

4.4.2 Advantages and Disadvantages of CF

Carbon Footprint has many advantages; it establishes a strong connection between the physical carbon-cycle with emission policy. This terminology continues to be appealing for the general public by providing consumers with easily comprehendible principle that encourages them to change habits toward more sustainable consumption. Furthermore, Carbon Footprint impact on companies, national and international policies has been realized. For example, Carbon Footprint started to impact companies' decision making by considering standardization at the product or

Table 4.1: Global warming potential of green house gases (Solomon 2007).

Greenhouse Gas	GWP time horizon		
	20 years	100 years	500 years
Carbon dioxide*	1	1	1
Methane	72	25	7.6
Nitrous oxide	289	298	153
Hydrofluorocarbons	437-12,000	124-14,800	38-12,200
Perfluorocarbon	5,210- 8,630	7,390-12,200	11,200-18,200
Sulfur Hexafluoride	16,300	22,800	32,600

*it is the baseline unit to which all other greenhouse gases are compared.

company level (ISO 2007; ICLEI 2008; Sinden 2008). Also, life-cycle thinking is included in the European Union policies. Internationally, issues such as the distribution of emissions between countries, carbon leakage, competitiveness concerns, border-tax adjustments, are being addressed by media and governments as a consequence of Carbon Footprint measurement (Weber and Peters 2009; Davis and Caldeira 2010).

As an index, Carbon Footprint came under criticisms that originated from its shortcomings as currently presented. So far, there is no agreement on a unified definition and methodology for Carbon Footprint and its assessment, which can lead to inconsistency in the interpretation (Wiedmann and Minx 2008). For example, in 2008, Johnson evaluated the Carbon Footprint for LPG and electric forklifts to decide if a fair and robust comparison could be made. He concluded that Carbon Footprint definitions continue to be misleading and complicate footprint comparisons. Furthermore, fuel Carbon Footprints of electric and (liquefied petroleum gas) LPG forklifts are, in principle, about equal, while in actual practice, LPG's footprint is smaller than that of electricity (Johnson 2008). Another example on the lack of consistency in methods and assumptions used to estimate the Carbon Footprint was reported by FPI when reviewed 13 LCA of wood and paper products. The group concluded that the differences and potentially contrary conclusions were attributed to differences in the assumptions and methods implemented (Sathre 2010).

Carbon Footprint is usually measured using the units of mass or weight i.e. tons or kilograms per person or activity. However, this is inconsistent with the term footprint that originated from the principles of EF index and should fundamentally be measured in spatial units' i.e. global hectares (gha) (Hammond 2007; Hails, Humphrey et al. 2008). In essence, the use of either units of measurement has its own advantages. For example, the use of spatial units has two benefits. First, it improves general public comprehension of the impact of their practices and consumption by comparing them with resources available by nature i.e. productive lands. Second, using spatial units allow better comparison of the impact of various demands on productive land (Kitzes and Wackernagel 2009). On the other hand, measuring CO_2 using the mass units (kg, t, etc) would not require the conversion into land area. This eliminates uncertainties and errors associated with assumptions needed to perform this conversion. Therefore, using the mass units is believed to be more accurate assessment of CO_2 production as related to the use of spatial units (Wiedmann and Minx 2008). Overall, the unit of measurement should always be consistent with the term used. For example, Ghazi and Lewis (Ghazi and Lewis 2007) implemented the use of "carbon weight" rather than "CF" in their program, where they used mass units to enable individuals/families to reduce their carbon emissions.

As outlined in the methodology section, to quantify the Carbon Footprint, three scopes are implemented. Scopes 1 and 2 are mandatory and should be reported and scope 3 is voluntary to report its related emissions. This is contradictory with the notion that only 26% of the total supply chain emissions are related to categories from Scopes 1 and 2 (Matthews, Hendrickson et al. 2008), while the remaining 74% of total emissions voluntarily disclosed from scope 3. Notwithstanding its major contribution to the total supply chain emissions, companies usually choose not to disclose emissions under scope 3 due to the lack of agreement on the framework and guidance for estimating emissions resulted from this scope (Huang, Weber et al. 2009). Consequently, this would underestimate the overall Carbon Footprint reported and compromise the strategies that should be developed to manage it.

Furthermore, the only environmental issue associated with CF is that it only considers the CO_2 and GHG emissions without any considerations of other environmental impacts such as ozone depletion, acid rain, resource depletion, toxins, volatile organic compound…etc. Furthermore, a key limitation to this index is; it only considers the environmental aspect of the three pillars of sustainable development i.e. the social and economical dimensions. Therefore, social and economic indicators should be combined with CF in addition to other environmental impacts consideration to comprehensively attain progress toward sustainability.

4.5 Environmental Sustainability Index "ESI"

The Environmental Sustainability Index (ESI) was developed by Yale University in conjunction with the Joint Research Centre of the EC and formally introduced in Davos, Switzerland, at the annual meeting of the World Economic Forum in 2005. ESI is a fundamentally multi-dimensional concept that assembles a broad array of data. It measures the performance of the nation's overall progress towards environmental sustainability and the capacity to protect and enhance their environment in the years ahead and avoid environmental deterioration. It provides an effective tool for tracking environmental performance, identifying leaders and laggards on an issue-by-issue basis, and designing policy responses (Esty, Levy et al. 2002; Esty, Levy et al. 2005). Therefore, this sustainability index is believed to provide for the first time a more analytically driven approach to environmental decision-making compared to other used composite indicators enabling meaningful cross-country comparisons (Morse and Fraser 2005).

This measure enjoys significant recognition among policy makers and considered as one of the mostly used indices alongside with EF in the assessment of the environmental sustainability of countries (Dietz and Neumayer 2007). However, ESI does not consider economic or social sustainability as part of its assessment.

4.5.1 ESI Valuation Methodology

The valuation methodology (Esty, Levy et al. 2005)for calculating the ESI is complex. In this section, I cover the critical steps in the ESI valuation methodology needed to calculate the index. While the approach used to calculate the index is consistent, details across the three published versions of ESI to date varied (2001; Esty, Levy et al. 2002; Esty, Levy et al. 2005).

The ESI score is a composite which is calculated through the combination of five broad categories:

(i) Environmental Systems, (ii) Reducing Environmental Stresses, (iii) Reducing Human Vulnerability to Environmental Stresses, (iv) Societal and Institutional Capacity to Respond to Environmental Challenges, and (v) Global Stewardship.

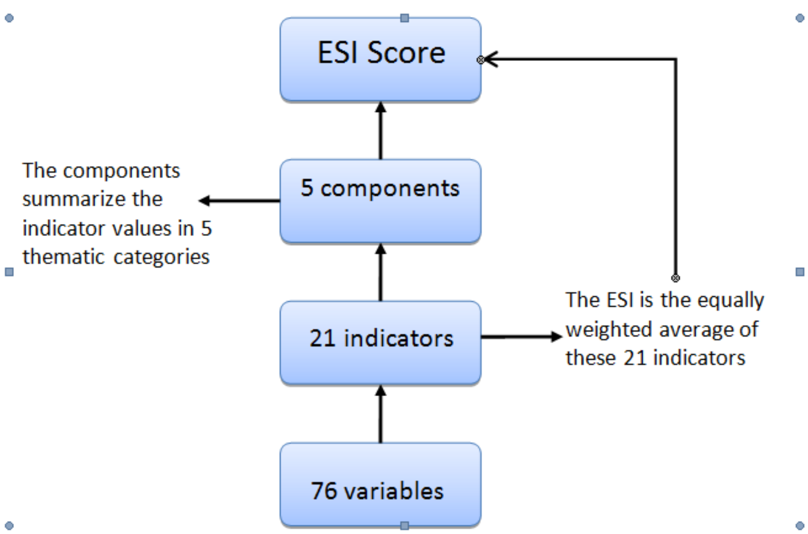

Figure 4.4: Constructing the ESI score.

These five categories are based upon a set of 21 building blocks "environmental factors" considered critical to sustainability (Figure 4.4). They are weighted equally and combined in a single number allowing it to be easily comprehendible as well as transparent. Each building block integrates two to twelve auxiliary variables for a total of 76 underlying variables (Table 4.2) (Esty, Levy et al. 2005). Table 4.3 outlines a summary of all 76 variables, their aggregation to 21 indicators, and their five components. These indicators and variables are chosen since they enable rational comparison across a wide range of issues. It should be stressed that EF (discussed in section 4.1.2) is a contributing variable to the calculation of this index.

Table 4.2: Components of the 2005 Version of the Environmental Sustainability Index (ESI). Regenerated From (Morse and Fraser 2005)

	Components of the ESI	Number of indicators	Number of variables
The Environmental Sustainability Index (ESI)	Environmental systems (SYSTEM)	5	17
	Reducing environmental stresses (STRESS)	6	21
	Reducing human vulnerability (VULNER)	3	7
	Social and institutional capacity (CAP)	4	24
	Global stewardship (GLOBAL)	3	7
	Total	21	76

In the ESI 2005 version, 146 countries were included, the country's selection criteria was based on (i) the size of the country where those with a population fewer than 100,000 or land area less than 5,000 square kilometers in the year of 2003 are excluded, (ii) variable coverage where each country with less than 45 reported variables out of the 76 underlying variables is excluded, (iii)

indicator coverage where country that pass the criteria outlined above and miss all the variables in any of the 21 indicators other than the air and water quality indicators is excluded.

To calculate the ESI scores of each selected country; first, the raw data are processed and each variable is standardized to comparable scales to enable their aggregation into indicators and facilitate cross-country comparisons. Second, the data within variables are tested for normality. If they are skewed; then they are transformed using the logarithmic function to move them closer to the mean. Finally, missing data or incomplete observations are treated using the Markov Chain Monte Carlo (MC) method for the 2005 ESI data.

Following missing data treatment, data are truncated, using the 2.5 and 97.5 percentile as limits. This avoids extreme values that would dominate the aggregation algorithm. The outcome of the previous step is standardized into z-scores to eliminate the scale effect of different measurements units while preserving the relative distances among observations. This can be calculated by the following equations depending on the rapport of the variable with respect to sustainability. i.e. if high values reflect that the Country's is more sustainable then:

$$Z\ Value = \frac{Observation\ x - mean}{Satndard\ Deviation}$$ Equation 4.4

Otherwise if high values correspond to "bad" sustainability the Z value can be calculated using the following equation (Bell et. al., 2008):

$$Z\ Value = \frac{Mean - Observation\ x}{Satndard\ Deviation}$$ Equation 4.5

The average z value for each indicator is calculated, and then it is changed into "standardized normal percentile". The resulted percentiles of all indicators are averaged (weighted equally) to calculate the ESI measure. The higher the country's score of ESI the more environmentally sustainable it is for that country (Morse and Fraser 2005; Bell and Morse 2008).

Table 4.3: 2005 Environmental Sustainability Index Building Blocks – Indicators and Variables (Esty, Levy et al. 2005).

Component	Indicator Number	Indicator	Variable Number	Variable Code	Variable
Environmental Systems	1	Air Quality	1	NO2	Urban population weighted NO2 concentration
			2	SO2	Urban population weighted SO2 concentration
			3	TSP	Urban population weighted TSP concentration
			4	INDOOR	Indoor air pollution from solid fuel use
	2	Biodiversity	5	ECORISK	Percentage of country's territory in threatened ecoregions
			6	PRTBRD	Threatened bird species as percentage of known breeding bird species in each country
			7	PRTMAM	Threatened mammal species as percentage of known mammal species in each country
			8	PRTAMPH	Threatened amphibian species as percentage of known amphibian species in each country
			9	NBI	National Biodiversity Index
	3	land	10	ANTH10	Percentage of total land area (including inland waters) having very
			11	ANTH40	Percentage of total land area (including inland waters) having very high anthropogenic impact
	4	Water Quality	12	WQ_DO	Dissolved oxygen concentration
			13	WQ_EC	Electrical conductivity
			14	WQ_PH	Phosphorus concentration
			15	WQ_SS	Suspended solids
	5	Water Quantity	16	WATAVL	Freshwater availability per capita Environmental Systems
			17	GRDAVL	Internal groundwater availability per capita
Reducing environmental stresses	6	Reducing Air Pollution	18	COALKM	Coal consumption per populated land area
			19	NOXKM	Anthropogenic NOx emissions per populated land area
			20	SO2KM	Anthropogenic SO2 emissions per populated land area
			21	VOCKM	Anthropogenic VOC emissions per populated land area
			22	CARSKM	Vehicles in use per populated land area
			23	FOREST	Annual average forest cover change rate from 1990 to 2000
	7	Reducing Ecosystem Stress	24	ACEXC	Acidification exceedance from anthropogenic sulfur deposition
			25	GR2050	Percentage change in projected population 2004-2050
	8	Reducing Population Pressure	26	TFR	Total Fertility Rate
			27	EFPC	Ecological Footprint per capita
	9	Reducing Waste & Consumption Pressures	28	RECYCLE	Waste recycling rates
			29	HAZWST	Generation of hazardous waste
			30	BODWAT	Industrial organic water pollutant (BOD) emissions per available freshwater
	10	Reducing Water Stress	31	FERTHA	Fertilizer consumption per hectare of arable land
			32	PESTHA	Pesticide consumption per hectare of arable

					land
			33	WATSTR	Percentage of country under severe water stress
			34	OVRFSH	Productivity overfishing
	11	Natural Resource Management	35	FORCERT	Percentage of total forest area that is certified for sustainable management
			36	WEFSUB	World Economic Forum Survey on subsidies
			37	IRRSAL	Salinized area due to irrigation as percentage of total arable land
			38	AGSUB	Agricultural subsidies
			39	DISINT	Death rate from intestinal infectious diseases
Reducing Human Vulnerability	12	Environmental Health	40	DISRES	Child death rate from respiratory diseases
			41	U5MORT	Children under five mortality rate per 1,000 live births
			42	UND_NO	Percentage of undernourished in total population
	13	Basic Human Sustenance	43	WATSUP	Percentage of population with access to improved drinking water source
			44	DISCAS	Average number of deaths per million inhabitants from floods, tropical cyclones, and droughts
	14	Reducing Environment-Related Natural Disaster Vulnerability	45	DISEXP	Environmental Hazard Exposure Index
			46	GASPR	Ratio of gasoline price to world average
Social and Institutional Capacity	15	Environmental Governance	47	GRAFT	Corruption measure
			48	GOVEFF	Government effectiveness
			49	PRAREA	Percentage of total land area under protected status
			50	WEFGOV	World Economic Forum Survey on environmental governance
			51	LAW	Rule of law
			52	AGENDA21	Local Agenda 21 initiatives per million people
			53	CIVLIB	Civil and Political Liberties
			54	CSDMIS	Percentage of variables missing from the CGSDI "Rio to Joburg Dashboard"
			55	IUCN	IUCN member organizations per million population
			56	KNWLDG	Knowledge creation in environmental science, technology, and policy
			57	POLITY	Democracy measure
			58	ENEFF	Energy efficiency
	16	Eco-Efficiency	59	RENPC	Hydropower and renewable energy production as a percentage of total energy consumption
			60	DJSGI	Dow Jones Sustainability Group Index (DJSGI)
	17	Private Sector Responsiveness	61	ECOVAL	Average Innovest EcoValue rating of firms headquartered in a country
			62	ISO14	Number of ISO 14001 certified companies per billion dollars GDP (PPP)
			63	WEFPRI	World Economic Forum Survey on private sector environmental innovation
			64	RESCARE	Participation in the Responsible Care Program of the Chemical Manufacturer's Association
			65	INNOV	Innovation Index

	18	Science and Technology	66	DAI	Digital Access Index
			67	PECR	Female primary education completion rate
			68	ENROL	Gross tertiary enrollment rate
			69	RESEARCH	Number of researchers per million inhabitants
			70	EIONUM	Number of memberships in environmental intergovernmental organizations
Global Stewardship	19	Participation in International Collaborative Efforts	71	FUNDING	Contribution to international and bilateral funding of environmental projects and development aid
			72	PARTICIP	Participation in international environmental agreements
			73	CO2GDP	Carbon emissions per million US dollars GDP
	20	Greenhouse Gas Emissions	74	CO2PC	Carbon emissions per capita
			75	SO2EXP	SO2 Exports
	21	Reducing Transboundary Environmental Pressures	76	POLEXP	Import of polluting goods and raw materials as percentage of total imports of goods and services

In 2005, the ESI scores of 146 countries were reported; where Finland was the top ranked country. It had high scores across all the five dimensions of ESI. This suggests that Finland is more likely to successfully provide its people with high levels of quality environmental services in the near future. On the other hand, North Korea, had the lowest ESI scores, and scored low in many of the five components of ESI. This suggests that North Korea's future environmental prospect is poor.

4.5.2 Advantages and Limitations of ESI

ESI is considered a good communication tool that simplified the assessment of the country progress toward environmental sustainability in a single number that varies between 0 (most unsustainable) and 100 (most sustainable). ESI provides countries and policy makers with a tool that can successfully measure the country's environmental performance and resource use. It also helps them in identifying the major environmental concerns to adapt the best national practices that would attain better sustainability. Therefore, ESI is considered an effective tool in identifying nations that are leading the way in addressing various related environmental issues integrated in ESI (Hak et. al., 2007).

ESI has successfully attracted media attention since it is backed by the powerful group “World Economic Forum” referring to themselves as the “Global Leaders of Tomorrow”. This raised awareness about the issue of sustainability and had an impact upon policy makers, where, its league table’s style presentation would instill the sense of urgency and encourage countries to maintain and/or improve their overall performance.

Similar to other sustainability indices, this measurement has shortcomings given the significant gaps in critical data sets, divergent opinions about what comprises sustainability and how best to address underlying uncertainties and challenges. Further, ESI has been mainly criticized for the complexity of its valuation methodology, its aggregation, and the subjectivity and arbitrary of the weighting of its indicators. This may compromise important aspects of environmental sustainability. Furthermore, other research groups may have a different perspective on environmental sustainability and changing the weighting and aggregation of the indicators and removing some other which would change the outcome of the countries’ ESI score and ranking (2001; Morse and Fraser 2005). The variables that are aggregated to attain ESI score have from different units. They are normalized and converted to a common unit, which affects the reliability and transparency of the outcome. The reliability of the ESI is further undermined especially for poor countries, which usually have poor records, in term of quality and availability, needed for the 76 underlying variables. Therefore, missing data is managed by the process of imputations. It is interesting to note that around 65% of the data is imputed - this is high, which makes it a concern and compromises the reliability of the ESI score.

Initially, the group that developed ESI reported that there is a significant positive correlation between ESI and GDP (wealth), suggesting that economic activity is not compromised by sustainability. However, this was challenged in the Ecologist (2001; Morse and Fraser 2005) who noted that rich nations score better because indicators that they excel in are duplicated in different categories than the indicators that poorer countries score well in (Morse and Fraser 2005). This led to more in depth analysis of the relationship between GDP and ESI which resulted that a complex and changing relationship exists, and drawing any general inferences is misleading.

Many critics believe that ESI is Western biased, which takes away from its credibility as a viable tool to assess national rankings. For example, its valuation methodology rewards the countries with the capacity to tackle environmental issues[8] and invest in environmental advanced technology, facilities, and research even though, such countries have unsustainable consumption levels of natural resources. This is also accompanied by the harmful consequence of their industrialization that is partially realized by exporting pollution and low-wage production to poorer countries.

It should be stressed that ESI only measures the environmental sustainability and does not address economic or social sustainability. Hence, it should be combined it with other indicators that cover these aspects, to successfully measure the overall sustainability.

[8] Having the capacity of solving the environmental problem is different than doing something about it.

4.6 Environmental Space (ES)

In 1690, John Locke, one of the prominent founders of Liberalism, introduced the premise of Environmental Space[9] (ES) where he realized this concept as a rationale genesis of the liberal principles he advocated for throughout his life[10]. These principles are based on the premise that every person should have the ultimate liberty to shape and control his/her life and destiny provided that this won't compromise other people in their liberty (Davidson 1995). Consistent with the principles of sustainability outlined earlier, the people have the right to claim part of Mother Nature provided that they won't compromise current and future generations' right.

In modern time, ES was re-introduced as a concept by Horst Siebert (Siebert 1982) and developed by Opschoor ((Opschoor and Reinders 1991; Hille 1997) who stated that "the 'Environmental Utilization Space' reflects that at any given point in time, there are limits to the amount of environmental pressure that the earth's ecosystems can handle without irreversible damage to these systems or to the life-support processes that they enable". Similar to the EF[11], this principle is based on the concept of planetary carrying capacity, where there is a limited availability of space on earth for both stocks (i.e. renewable and non-renewable resources) and sinks (i.e. ability of Earth's Ecosystem to assimilate generated waste) to sustain human needs. It emphasizes the limits of the ability of Earth's Ecosystem to cope with environmental pressure on available resources i.e. sink and stocks and the inter- and intra-generational right to an equitable share in these resources. Therefore, for a successful

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[9] *ES* was translated from Dutch "milieugebruiks-ruimte" (precise translation: "Environmental Utilization Space")

[10] It should be emphasized that the concept of environmental utilization space was unknown to Locke.

[11] See Section 4.1.2 for more information about Ecological Footprint.

plan to attain sustainability by adhering to the principles of ES, policy makers should ensure that they considered future generations share in any action plan they undertake (Hens and Quynh 2008). Figure 4.5 depicts the concept of ES by outlining the upper and lower limits of Earth's Ecosystem that are based on social and environmental measures. Where, the minimum amount of resources needed by people (the floor) is determined by what is enough to overcome poverty and needs. The maximum limit (the ceiling) is determined by the amount of resources that can be used without compromising and/or irreversibly damage the Earth's Ecosystem. Closely monitoring sustainable development by using ES as an index; would increase the likelihood that resource consumption rate is applied equally to all people living in present and future. This index enables policy makers to realize the impact of the current practices in their countries on Earth's Ecosystem and set an action plan that would achieve a sustainable development and ensure that the usage of the environment and amount of natural resources are evenly distributed per capita (Hens and Quynh 2008). As a matter of fact, following inception, this index was used in Netherlands (Opschoor's native country) by Friends of Earth Netherlands (Buitenkamp 1993), as an outcome of the UNCED conference in Rio de Janeiro in 1992, to promote sustainable development and quantify the ES for the average Dutch person for major resources that will be available in 2010 as a short term goal and 2050 as

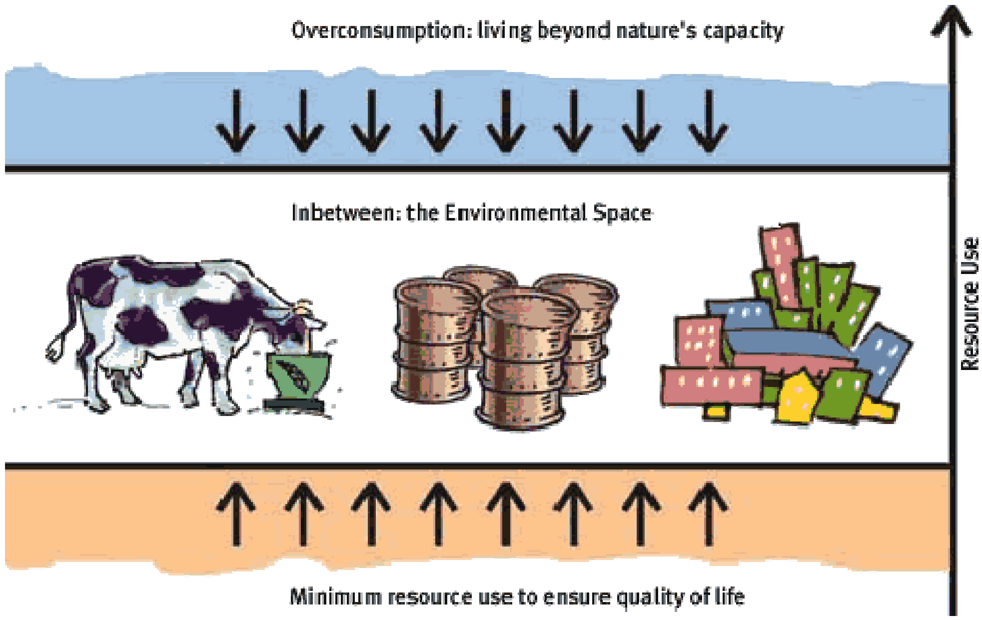

Figure 4.5: Floor and Ceiling of Environmental Space (FOE).

a long term goal (Hens and Quynh 2008). This was part of the Action Plan for a Sustainable Netherlands. Later on, this was followed in other European countries in Towards Sustainable Europe (TSE). ES is defined according to TSE as the quantity of energy, water, land, non-renewable raw materials and wood that we can use in a sustainable fashion (Hille 1997). Overall, a successful action plan should ensure that the following principles are strictly considered and they are as follow:

1. Respect for ecological limits.
2. Equal access to resources.
3. The proximity principle that states that environmental problems should be addressed near the resource as possible.
4. The emphasis on using renewable rather than non-renewable resources.

These principles are discussed in more details by different researchers (Buitenkamp, Venner et al. 1993; Hille 1997; Carley and Spapens 1998; Cohen 2007).

4.6.1 ES Valuation Methodology

The premise behind the valuation methodology of this index is to reflect the discrepancy in consumption patterns of non-renewable resources, energy, agricultural land, or any resource use that might contribute to a negative consequence on the environment among different nations. The calculation is based upon the comparison of a given resource consumption per capita in any one country to the world average use. Consequently, for a country, ES value for a resource is compared to the global resource use to determine the percentage change of resource in question. This is essential to reach the 'allowable' resource consumption per capita limit in a specific country with respect to the global average for the same resource. Subsequently, the result would be the basis for the action plan that will be provided to the policy makers in a form of recommendations to achieve the necessary percentage change in the country resource consumption for that particular resource (Bührs 2007). This action plan socially should ensure the social welfare of current and future generations. Environmentally, it should ensure that on-going consumption rate should not go beyond Nature's capacity. [12] (Moffatt 1996; Hanley, Moffatt et al. 1999).

The ES in a given time (*t*) is calculated as follow:

$$ES_t = \frac{GR_{xt}}{GP_t} \times P_{it} \qquad \text{Equation 4.6}$$

Where GR_{xt} is the global resource (x) (or assimilative capacity for pollutants i.e. CO_2).

[12] The same methodology can be applied to pollutants i.e. CO_2 by considering a maximum upper limit to the environment's absorption capacity to avoid further global warming (Hanley et al., 1999).

GP is the world population at time (*t*), P_i is the country (*i*) population at a time (t). Therefore, ES_t is an average number for resource *x* that should be consumed per capita in a given time (*t*) and it is used to compare the usage of resource *x* per capita consumed in country *i* to the average world usage per capita for that specific resource.

As a result, a percentage change is determined for that country to put action plan to ensure that consumptions are within limits (Moffatt 1996). In the case of over-consumption, this is identified as the 'sustainability gap', where a reduction in the resource use relative to what it presently consumes should be taken to ensure sustainability. Furthermore, for resources which are considered to be too environmentally debilitating, the ES is set to zero suggesting the urgent need to eliminate and find alternative options that are environmentally benign. Taken as a whole, industrialized countries such as Europe and USA have ES values that are significantly higher than the average global ES values implying that their current practices are not sustainable (Carley and Spapens 1998).

Part of "Towards Sustainable Europe", Spangenberg *et al.* published important results that outlined the needed change in Europe consumption per capita in key resources to achieve Europe sustainability by 2010 as a short term goal where TSE recommended that 25% of the needed reductions should attained. However, highly debilitating environmental impact such as nuclear energy and chlorine should be phased out by 2010 (Spangenberg 2002). In addition, 2050 date was put as a long term goal to attain the overall needed reduction (Table 4.4).

4.6.2 Advantages and Limitations of ES

ES has many well reported advantages. For example, ES provides a better basis for addressing, at the policy level, the challenges associated with environmental limits, than other measurements. It has been widely used by many countries in particular Europe to gauge their ES and accordingly develop national action plans that would ensure sustainable development and social welfare (Hens and Quynh 2008). Therefore, unlike EF, ES provides a futuristic vision and action plan that should be adapted to attain the sustainable development by a country.

ES has certain limitations that would challenge its utility. For example, ES only consider the environmental aspect of sustainability in its valuation method and fills shorts in addressing both economic and social dimensions. As a matter of fact, ES fails to derive applications that would consider the structure of the economic system i.e. macro and micro levels. Since it only assumes that including the environmental and social frameworks of the system is sufficient to appropriately assess sustainable development (Spangenberg 2002).[13] Therefore, to achieve sustainable development, this index should be used with social and economic indicators as complement (Hens and Quynh 2008).

Furthermore, ES won't accurately quantify person's share of overall resources since there is a lack of comprehensive information of earth's carrying capacity, resources availability, and the level of use (Hens and Quynh 2008). A further difficulty is that accurately identifying this data for regional/continental/global resources is

[13] It does not use monetary valuation of social achievements or environmental services, but emphasizes the importance of both independently. Instead it suggests the combination of system-specific measures (i.e. physical, social and economic ones) and offers a framework for their coherent presentation.

troublesome since the selection of these areas' boundaries is arbitrary (Hens and Quynh 2008). When considered, ES is calculated based on average per capita for various national studies. If standard deviation is not considered, this can be misleading and lead to results with large error limits (Moffatt 1996). Once considered, this would reduce the available space between the floor and ceiling and challenge the success of any proposed action plan. Another complicating factor is that a different ES exists for each resource with different units of measurement. Therefore, coming up with a comprehensive ES for all the resources used by a country at a definite time is unfeasible (Hille 1997). As a result, the scientific community agrees that ES is rather a crude estimate and the action plan that would be recommended to achieve sustainable development based on ES is therefore complex. Furthermore, considering the aforementioned limitations, researchers agree that EF is a better tool to replace ES (see section 4.1.2) since it provides one composite measure that is based on land area basis. This can be added up to determine the overall figure for a country and allow meaningful comparison.

Resource	Environmental space per capita (2050)	Reduction required from 1990	Suggested reduction goal for 2010
Total primary energy	60 GJ/a	50%	12.5%
-fossil energy	25 GJ/a	75%	19%
-nuclear energy	0	100%	100%
Timber*	0.56 m3/a	15%	4%
Cement	80 kg/a	85%	21%
Iron	36 kg/a	87%	22%
Aluminium	1.2 kg/a	90%	22.5%
Copper	0.75 kg/a	88%	22%
Lead	0.39 kg/a	83%	21%
Chlorine**	0	100%	
N, P, K fertilizer**	0	100%	
Built-up land	0.0513 ha	3.2%	3.2%
Agricultural land***	0.281 ha	30%	30%
"Imported" land (net)	0	100%	50%

* Based on self-sufficiency in Western and Central Europe. Environmental space increases to 1.0 m3/a if the resource base is extended to include the European part of the former Soviet Union.
** Based on the premise that the use of chlorine and chemical fertilizers is to be phased out. Sustainable Europe also gives other figures based on resource limitations only.
***Estimated amount required to cover nutritional requirements with organic agriculture. If agricultural area were limited only by the requirement that 10% should be set aside for conservation, availability would be 0.36 ha/capita.
Source: Spangenberg 1994.

Table 4.4: Per Capita Environmental Space For Major Resources in The EU and Required Reductions in Consumption from 1990s levels, According To "Towards Sustainable Europe".

4.7 Human Development Index "HDI"

Human Development is an economic approach that was launched primarily by Sen and Mahbub-ul-Haq (Amartya 2000). The main aim is to redirect the current focus of development economics from national income accounting to people centered policies. According to UNDP, this creates an environment where people strive to develop their full potential and lead a productive creative life that is in harmony with their needs and interests. People are the genuine wealth of the nations and therefore, the development is about expanding the choices people have to lead lives that they value rather than about economic growth. Indeed, it is about expanding people's choices, which basically accentuate the significance of human wellbeing as the centre of the country's economic development by recognizing their potential, choices, and freedom.

Mahbub ul Haq, the founder of the Human Development Report argues that the basic purpose of development is to enlarge people's choices. In principle, these choices can be infinite and can change over time. People often value achievements that do not show up at all, or not immediately, in income or growth figures i.e. greater access to knowledge, better nutrition and health services, more secure livelihoods, security against crime and physical violence, satisfying leisure hours, political and cultural freedoms, and sense of participation in community activities. The objective of development is to create an enabling environment for people to enjoy long, healthy, and creative lives (UNDP 1999; UNDP 2007).

Accordingly, UNDP introduced a new measure, which is the Human Development Index (HDI) in its 1990 Human Development Report. HDI was presented as a result of the need for an index that evaluates development not only by considering the economic growth, but equally important by integrating other social indicators into a one composite index. Therefore, HDI is a socio-economic index that reflects the progress of nations based on the three fundamental dimensions of human development which are (i) a long and healthy life, (ii) literacy and knowledge, and (iii) a decent standard of living (George and Alleyne 2002). It is used as a proxy of sustainability based on the rationale that human development facilitates sustainability.

4.7.1 HDI Valuation Methodology

HDI combines these three pillars of human development through different indicators: Life expectancy at birth, as an index of population health and longevity, knowledge and education, as measured by the adult literacy rate (with two-thirds weighting) and the combined primary, secondary, and tertiary gross enrollment ratio (with one-third weighting). Standard of living, as measured by the natural logarithm of gross domestic product per capita at purchasing power parity. The result is a simple composite comparative statistic with a value between (0-1), which is used as an index to rank countries relative performance by level of "human development" and separate developed (high development) (0.8-1), developing (middle development) if HDI is (0.500-.799), and underdeveloped (low development) countries if the result is (0-0.5) (UNDP 2007). Figure 4.6 depicts the approach used to create HDI using the indicators outlined above.

Prior to calculating the composite index (HDI), an index for each of the aforementioned dimensions is determined using a simple normalization method, which converts the data into (0-1) values, by using already chosen minimum and maximum values for each of the related indicators (Figure 4.7) according to the following equation:

$$\text{Dimension Index} = \frac{\text{actual value} - \text{min value}}{\text{max value} - \text{min value}} \qquad \text{Equation 4.7}$$

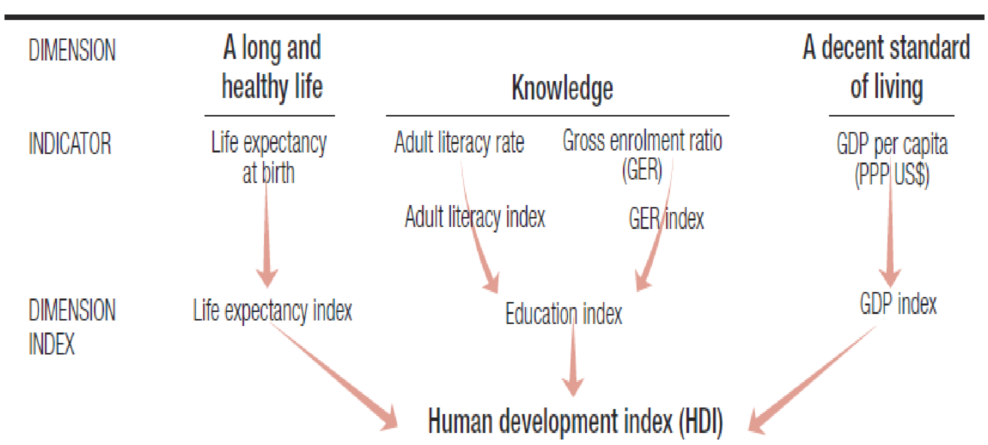

Figure 4.6: The Approach Used to Calculate the Human Development Index.
Source: (UNDP 2007)

It is interesting to note that the knowledge index is a combination of adult literacy index (with two-thirds weighting) and gross enrollment ratio (with one-third weighting). HDI is then calculated as an average of the three dimension indices as shown below.

$$\text{HDI} = \frac{\text{Life Expectancy Index} + \text{Education Index} + \text{GDP Index}}{3}$$

Goalposts for calculating the HDI

Indicator	Maximum value	Minimum value
Life expectancy at birth (years)	85	25
Adult literacy rate (%)*	100	0
Combined gross enrolment ratio (%)	100	0
GDP per capita (PPP US$)	40,000	100

* The goalpost for calculating adult literacy implies the maximum literacy rate is 100%. In practice, the HDI is calculated using an upper bound of 99%.

Figure 4.7: Goalposts Used in Calculating HDI the Three Dimension Indices.

4.7.2 Advantages and Limitations of HDI

One of the main advantages of HDI is the shift in the approach from economic growth based development measured by GDP to one that is multidimensional and rather focused on the quality of life and human centered development (Robeyns 2003; Robeyns 2005; Robeyns 2005). Therefore, HDI is thought to be more consistent and broader than just GDP (Lüchters and Menkhoff 1996). Furthermore, HDI is recognized for the simplicity of its valuation methods and theoretical basis, where it considers people developed if they live long healthy lives, educated, and have a sufficient amount of money to maintain individual's welfare. It is interesting to emphasize that the end product of HDI not only measures countries' achievements in terms of human development, but also clearly demonstrate how far is the country from the ideal situation, which equates to one (UNDP 1999). Furthermore, HDI provides intra and inter-countries comparisons of their people knowledge, health, and well being. It also assesses long term progress rather than short term changes and it is comparable over time provided that similar methodology was used in its calculation (UNDP 1999; UNDP 2007).

Instead of its reported merits, HDI has major disadvantages that limit its use and application. For example, various research groups reported a high positive correlation between HDI and GDP (Cahill 2005). This undermines the notation that HDI focuses on the non-monetary aspect of human development. Moreover, by considering indicators included in its valuation methodology and the three pillars of sustainability, HDI only considers the socio-economic aspects and fails to include both the political/civil dimensions of human development Dasgupta and Weale (Dasgupta and Weale 1992) as well as ecological considerations that may ultimately compromise human development. In a separate study, Hicks noted that HDI did not consider gender inequality in its valuation methodology[14]. Furthermore, he pointed out that there is an underestimation of distributional inequalities within and among countries considering the HDI framework calculation of its three indices, which indicates that this index conveys very crude information about its dimensions (Hicks 1997).

[14] As a recognition of the significance of this limitation, UNDP adjusted HDI for inequality between men and women and created a new indicator i.e. GDI. It follows the same methodology as HDI but adjusts for inequality between women and men. Also, UNDP constructed GEM - Gender Empowerment Measure (gender equality in economic and political participation and decision making) and HPI - Human Poverty Index (the level of human poverty) (UNDP website).

Another contributing factor to the poor methodology of HDI is that the theoretical framework of HDI is poor and its calculation requires data collected from developing countries that lack quality. Since it is: incomplete, biased, and some variables are estimated using mathematical simulation techniques such as life expectancy data and other inputs that are not based on standardized definition such as literacy.

4.8 Index of Sustainable Economic Welfare (ISEW) or Genuine Progress Indicator (GPI)

The Index of Sustainable Economic Welfare (ISEW) is a comprehensive monetary index of welfare and sustainability[15] and one of the earliest alternatives proposed to GDP. It considers the impacts of economic activity, social inequality, and environmental damage on human welfare. This measure is commonly credited to Herman Daly, Clifford Cobb, and John Cobb in 1989 (Daly 1996), who developed this measure to build on the Measure of Economic Welfare (MEW) and address MEW valuation methodology's shortcomings (Nordhaus and Tobin 1972). MEW main basis of calculation is personal consumption on both goods and services. It also considers government and household capital, non-market work and leisure. It then makes a series of additions, such as additions for services of consumer durables[16], goods and deductions. In this case, the deduction output is considered "regrettable necessities", which includes costs needed to produce welfare. Originally, Nordhaus and Tobin

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[15] Alternatively renamed as Genuine Progress Indicator (GPI) in 1995 by the organization Redefining Progress (Redefining Progress, 1995).

[16] *Durable goods* are defined as products that yield services and/or utilities of a lifetime of 3 years or longer such as cars, home appliances, furniture…etc. Alternatively, *nondurable goods* are identified as products that are usable over a limited period of time less than three years or destroyed following single use such as syringes, disposable diapers, razors, hypodermic syringe, paper towels, *plastic spoons, and disposable cigarette lighter*.

developed the MEW to determine if growth is obsolete as a direct assessment of welfare and basis for policy makers. This was accomplished by assessing the correlation between MEW and GDP over the period between 1929-1965. The group reported that there was a positive relationship between the two indicators where for every six units increase in GDP there was as associated four units increase in MEW. As a result, the resolution was MEW is a redundant measure of economic welfare and therefore, economists could focus on GDP moving forward (Eisner 1988; Daly 1996). Moreover, MEW was also criticized that it does not consider the depletion of renewable and non-renewable natural resources, and most importantly does not include education and health services in its valuation methodology (Eisner 1988; Daly 1996; Galbraith 1998).

Due to MEW limitations, Daly and Cobb developed ISEW to consider the main constituents that impact the progress of a nation toward its people welfare and effectively replace MEW. Later on, ISEW was revised by Cobb and Cobb (Cobb and Cobb 1994) with a goal of proposing *a Green National Product.* It should be emphasized that ISEW's basic methodology has not been changed but a minor change in the itemized deductions and additions. However, it was relabeled as Genuine Progress Indicator (GPI) since ISEW was not easily comprehendible as a term by the general public (Jackson 2005). The authors believed that rebranding the concept would enable more buy in from audience and general public. Moving forward, ISEW will be used in this dissertation to relate to both indices. In addition, according to

Lawn (Lawn 2005), ISEW is also referred to as a sustainable net benefit index (SNBI)[17].

ISEW was initially developed for the USA by Daly and Cobb based on the philosophy that better assessment of progress and welfare should be through an economic indicator that takes into consideration the social inequality and environmental pressure. ISEW's basic methodology has afterwards been modified, for data availability and researchers preference for precise valuation technique, and constructed to assess ISEW for several developed countries such as England, Sweden, Chile, the Netherlands, Italy, and few other less-developed countries (Lawn 2005).

ISEW is a comprehensive monetary index that integrates the economic, social, and environmental dimensions of sustainability into one framework. This is attained by taking into account non-monetarized costs and benefits that would determine welfare. Economically, it incorporates consumption of goods, services and capital growth, environmentally, it considers components associated with pollution and environmental degradation e.g. loss of natural resources, and socially, it accounts for social components such as commuting to work, expenditures on health and education and other related aspects. These components are converted into monetary term (unit cost) based on literature or studies from reliable government or research institutions (Jackson 2005).

[17] SNBI "differs is in the explanation of the rationale for an alternative index and the presentation of the items used in its calculation" (Lawn, 2003).

4.8.1 ISEW Valuation Methodology

The ISEW valuation method starting point is the private consumption expenditure, which is a sub-component of GDP[18]. This is basically the personal spending on consumer goods and services, through which it is assumed that welfare could be attained. This aggregate consumption figure is then weighted (typically with a modified Gini Coefficient[19], which was used by the original developers of the index) to account for the income distributional inequalities and widespread poverty; which neither the GDP nor GDP per capita may consider (Stockhammer, Hochreiter et al. 1997). This is then adjusted for some factors to measure the sustainability of consumption, extracted from the national accounts, which might be considered as benefits (contributions) or costs to the economic welfare. Additionally, social and environmental benefits are added to the figure such as public expenditures on health and education since it also contributes to the welfare. Conversely, social and environmental costs or losses to the welfare such as personal expenditures on pollution control and costs of car accidents will then be subtracted. The basic structure and a list of the main benefits/costs that are taken into account in the calculation of ISEW are illustrated in Table 4.5. For more in-depth analysis, assessment and calculation of the index and its items, the reader is referred to (Lawn 2005).

The presented categories in Table 4.5 are the actual contributions (benefits or costs) that were measured in the original ISEW. In summary,

[18] See Section 4.1.1 for further discussion on GDP.

[19] Gini Coefficient is a measure of inequality of income distribution where 0 is total equality and 1 is absolute inequality.

ISEW = Personal consumer expenditure - adjustment for income inequality+ public expenditures (non-defensive)+ value of domestic labor & volunteering+ economic adjustments - defensive private expenditures - costs of environmental degradation - depreciation of natural capital

Various countries, which implement this comprehensive index, share the same basic methodology. While countries' ultimate goal is attaining social welfare and sustainable development; there is no general consensus on the used items of deductions and benefits. This is mainly attributed to differences in relevant data availability, modifications of methodology and country's related political assumptions and issues (Jackson, Marks et al. 1997; Stockhammer, Hochreiter et al. 1997).

Table 4.5: Items Used to Calculate The GPI For USA From 1950 To 1995 (Lawn 2005).

Private consumption expenditure (+)
Index of distributional inequality (+/-)
Weighted personal consumption expenditure
Cost of consumer durables (-)
Services yielded by consumer durables (+)
Services yielded by roads and highways (+)
Services provided by volunteer work (+)
Services provided by non-paid household work (+)
Public expenditure on health and education counted as personal consumption (+)
Cost of noise pollution (-)
Cost of commuting (-)
Cost of crime (-)
Cost of underemployment (-)

Cost of lost leisure time (-)

The cost of household pollution abatement (-)

The cost of vehicle accidents (-)

The cost of family breakdown (-)

Net capital investment (+/-)

Net foreign lending/borrowing (+/-)

Loss of farmland (-)

Cost of resource depletion (-)

Cost of ozone depletion (-)

Cost of air pollution (-)

Cost of water pollution (-)

Cost of long-term environmental damage (-)

Loss of wetlands (-)

Loss of old-growth forests (-)

Total = sum of all positive and negative items = GPI (valued in dollars)

(+) = positive item

(-) = negative item

(+/-) = item that may be either positive or negative

Source: (Redefining Progress 1995).

ISEW challenges the myth that economic growth is the main driver of people's welfare and countries' sustainable development by integrating the three dimensions of sustainable development. For example, when studied, Daly and Cobb (Daly and Cobb 1994) reported that both ISEW and GDP showed growth over 1950s and 1960s, yet ISEW was at a slower pace. Later on, particularly in the end of the 1970s and beginning 1980s, the growth in the US economy as measured using GDP increased at a steady pace. In contrast, ISEW results showed that it was stagnant. Similar trends were observed in other countries such as Austria and Sweden. As illustrated in Figure

4.8, Netherlands ISEW was in a steady upward climb faster than their GDP till 1980s were it started to decline (Lawn 2005). Consequently, ISEW provides a different assessment of progress in comparison to GDP. It integrates non-market activity e.g. cost of commuting (Table 4.5) and deducts environmental degradation in its valuation. This questions the notion that GDP growth translates to social welfare (Stockhammer, Hochreiter et al. 1997).

4.8.2 Advantages and Limitations of ISEW

ISEW clearly demonstrates the environmental impact of economic activity and the unsustainable outcome of current economic systems (E., S. et al. 2004). It provides an alternative frame of reference for progress assessment and integrates a broad spectrum of social, environmental, and economic costs and benefits into one composite monetary index. Such composite index is considered easily comprehendible by the general public, and particularly valuable in assessing the overall direction of the

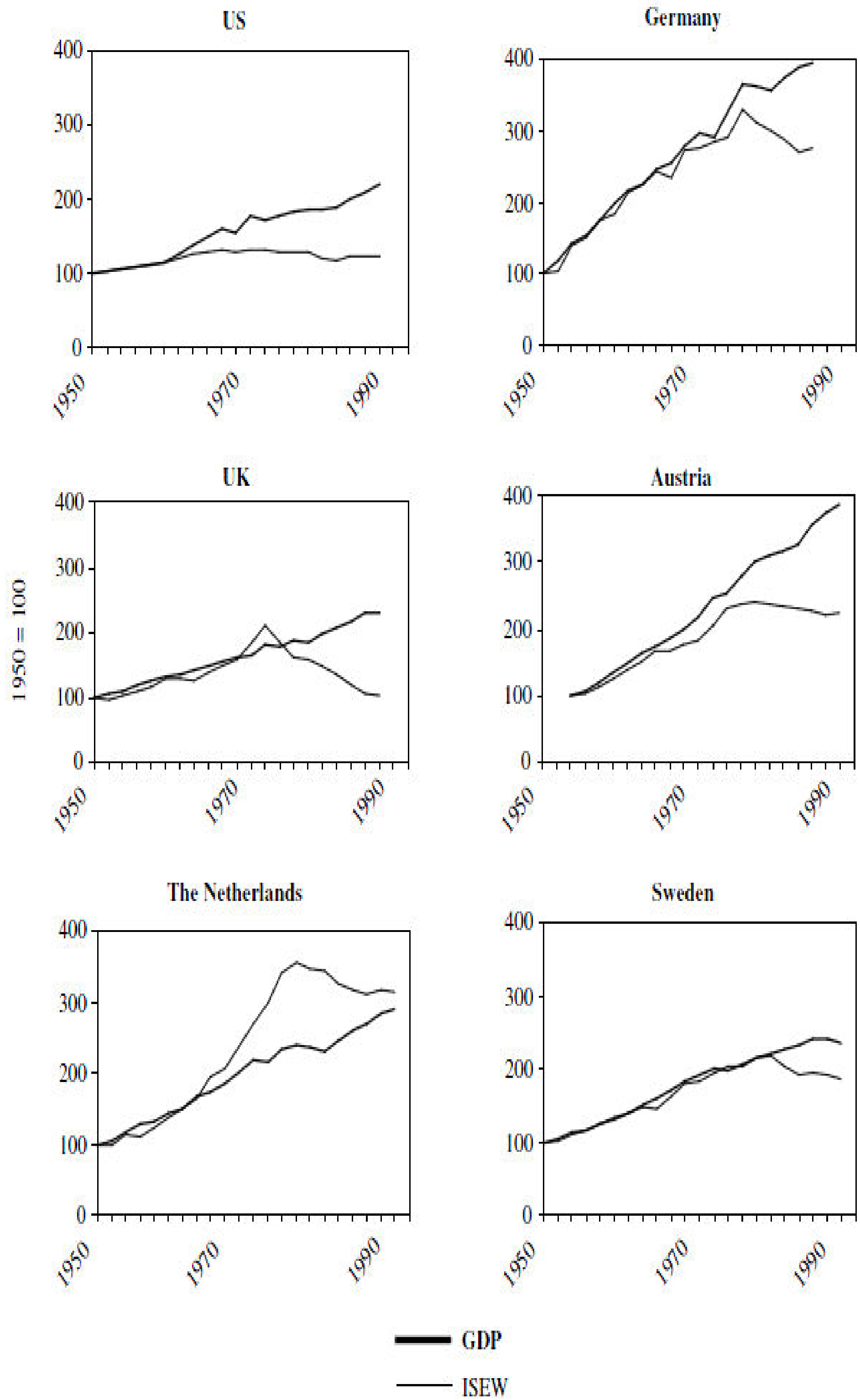

Figure 4.8: Comparison of GDP and ISEW for the US, Germany, UK, Austria, the Netherlands, and Sweden (Lawn 2005).

country's economy and future course of action. Therefore, ISEW is believed to be effective in assessing the direction of the country economy development and policy making process. Unlike GDP, ISEW equates consumption rather than production to progress. This challenges GDP perspective where country's growth is driven by production. In essence, ISEW is a concerted effort in expanding the assessment of nation's overall progress directly comparable to standard national accounts towards welfare beyond production.

One of the primary critiques that this measure receives is its valuation methodology, where it is empirical rather than being based on a solid theoretical foundation. For example, the corrections of the environmental costs terms adapted in this methodology are politically biased and arbitrary since it is not derived from a dynamic optimization model. Furthermore, the arbitrary assessed and accumulated costs of the long-term environmental damage, e.g. greenhouse gas emissions and ozone depletion have been criticized for the accuracy of their values they contend to measure. Whether deduction should be based on the accumulation of the costs approach or based on the costs of a given year approach would be more accurate for environmental valuation (Neumayer 1999; Neumayer 2000).

Various critiques mentioned that ISEW selection criteria for inclusion and exclusion of contributors (components) to welfare are rather arbitrary (e.g. (Atkinson 1995; Neumayer 1999; Neumayer 2000). Moreover, ISEW weighting of income distribution is considered empirical and neglects the technical progress. Overall, these different assumptions would compromise the right assessment of society's welfare and country's sustainable progress (Neumayer 1999).

Similar to the HDI, the costs and benefits (+,-) of these components calculated in such an aggregated index may cancel each other and compromise the assessment of the progress toward sustainability. In addition, many of the welfare-related factors are unaccounted for (Lawn 2003). For example, ISEW did not consider gender inequality in its valuation methodology. Personal consumption is adjusted for distributional inequality between, but not within households[20]. They exclude considerations of gender although women continue to be the lowest income earners in the society (Waring 1988)[21].

Notwithstanding its limitations, ISEW is believed to provide an overall better assessment of country's welfare and progress compared to GDP. Lawn (Lawn 2003) argues that *"Contrary to some opinions, the ISEW is soundly based on a concept of income and capital first advanced by Irving Fisher (1906) that is far superior to standard definitions of income."* However, he recommends that more robust valuation methodology and standardized set of items should be implemented to enable meaningful inter-countries comparisons.

4.9 Well-Being Index (WI)

In 1990s, Prescott-Allen in collaboration with the World Conservation Union (IUCN) and The International Development Research Centre (IDRC) developed the Well-being Index (WI) (Prescott-Allen 2001). This index views sustainable development as

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[20] The Austrian ISEW is an exception where their ISEW is adjusted for: the income inequality between workers and employees, between women and men, and between the employed and the unemployed (Stockhammer et al, 1997*)*.

[21] It should be again noted here that UNDP created an index the GDI which is a supplement for the HDI and measures life expectancy, education and income, but adjusts it for inequality between men and women.

a combination of human and ecosystem wellbeing. Human wellbeing is defined as "a condition in which all members of society are able to determine and meet their needs and enjoy a range of choices to meet their potential". The ecosystem wellbeing is defined as a "condition in which the ecosystem can maintain its diversity and quality, and thus its capacity to support people and the rest of life in addition to the potential to adapt to change and provide a wide range of choices and opportunities for the future" (Guijt and Moiseev 2001). Overall, this measure assesses the ecosystem, human and their interactions wellbeing conditions of a whole system. WI is based on the hypothesis that while a high level of human well-being is pivotal for a high quality of life, ecosystem well-being is as critical since it provides the needed life support system to maintain high standard of living. This is represented by the "egg of wellbeing" (Figure 4.9) where the egg yolk symbolizes people that are supported and surrounded by the ecosystem (egg white). In this analogy, the egg is well only if both the yolk and surrounded egg white are good. Thus ecosystem well-being and human well-being should both be considered and equally combined to attain sustainable development and fine life for people. This clearly re-enforces the symbiotic relationship between the socioeconomic system and the surrounding ecosystem (Hak, Moldan et al. 2007). The egg of well being is combined with another powerful visual and analytical tool known as the barometer of sustainability as depicted in Figure 4.10[22]. The combination of these tools is a systematic, clear, and transparent assessment that helps to visually put the results and articulate conclusions about overall performance toward attaining sustainable development and particular areas of concern.

[22] Refer to Section 4.1.8 for in depth discussion on the barometer of sustainability.

The ultimate goal of WI is to evaluate and compare the countries' human well-being with respect to the amount of pressure it places on the ecosystem on which their development is built on (Prescott-Allen 2001). The transparency of this communication tool makes it easy to use and comprehend by policy makers' in decision making and nations that are keen in evaluating their progress toward sustainable development over period of time (Prescott-Allen 2001).

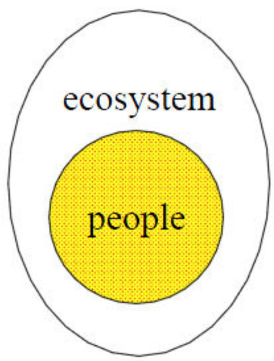

Figure 4.9: The Egg of Well-being.

4.9.1 WI Valuation Methodology

This measure combines a series of indicators that evaluate the performance of both aspects of Wellbeing separately; the Human Wellbeing Index (HWI) and Ecosystem Wellbeing Index (EWI). Each wellbeing index is a composite of five categories that are believed to be of equal importance as shown in Figures 4.11 and 4.12. The HWI categories integrate thirty-six indicators grouped into health and population, wealth, knowledge and culture, community, and equity. Conversely, EWI is composed from fifty-one indicators of land, water, air, species and populations, and resource use (Hak, Moldan et al. 2007). The indicators from both indices are considered comprehensive enough to encompass various areas of concerns for most nations to attain wellbeing and sustainable development. Furthermore, the measurements of each indicator are normalized to attain performance scores scaled between 0 –100 on the basis of the performance criteria for ease of aggregation. The scores can be combined into indices, or compound indicators throughout the hierarchy of elements. These are combined into a dimension index, which is further combined with the remaining four dimensions indices to formulate the subsystem index for people the HWI, and the EWI for the ecosystem. The two subsystems indices are equally weighted and combined to form the composite WI which is fundamentally the average of EWI and HWI.

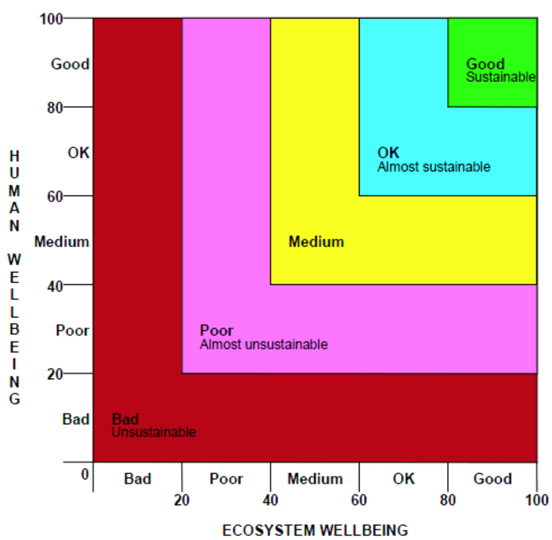

Figure 4.10: Graphical representation of the barometer of sustainability.

WI is fundamentally used to determine a country's wellbeing through a scoring system where a high WI index indicates a high overall well-being of the country. Or put into a ratio of human wellbeing to ecosystem stress) as Wellbeing/Stress Index (WSI[23]) that

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Ecosystem Stress Index can be calculated by subtracting EWI from 100. WSI can be found by dividing HWI by the Ecosystem Stress Index. . Where A WSI of 1.0 means that "ecosystem stress equals human wellbeing, and a WSI below 1.0 means the ecosystem stress exceeds human wellbeing. A higher score means more sustainability"Guijt, I. and A. Moiseev (2001). Resource Kit for Sustainability Assessment. Gland, Switzerland and Cambridge, UK. , IUCN. **Part B viii** 172.

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measures how much human well-being each country obtains for the amount of stress it places on the environment (Prescott-Allen 2001).

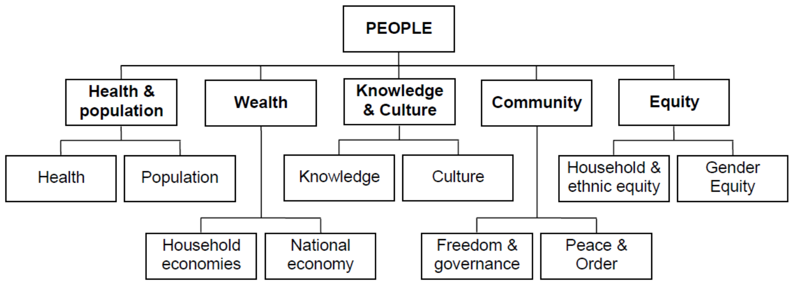


Figure 4.11: Suggested human dimensions and elements.

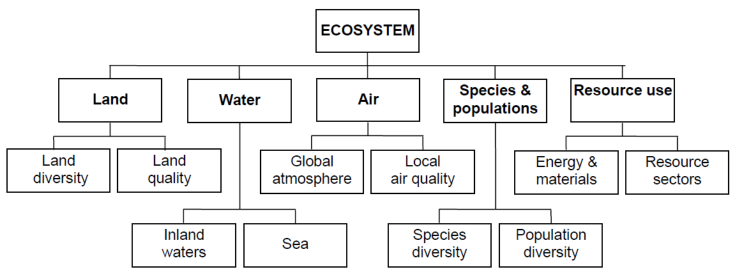


Figure 4.12: Suggested ecosystem dimensions and elements.

The HWI and EWI are then plotted in a two-dimensional graph, which visually represents the barometer of Sustainability (Figure 4.13). Each index is placed on one axis scaled from 0 to 100 indicating the human/ecosystem wellbeing of the country each axis is divided into five bands of 20 points each. They diverge from bad (red) to good (green). The intersection point of the two wellbeing indices is plotted in the graph, represented by the egg of wellbeing, to portray the overall sustainability of the city/country/nation in question. A nation would be considered sustainable if their HWI and EWI are both high. In 2001, IUCN released comprehensive results for the wellbeing indices for 180 countries. It ranked Sweden as the best performing since it had a very high HWI. However, its EWI is low and was considered as ecosystem-deficit country (Hak, Moldan et al. 2007). It is interesting to note that two-thirds of the world's populations reside in nations with poor or bad HWI; and only less than one-sixth reside in countries with fair or better HWI. As for the EWI there is no country that was scored with a good EWI. Furthermore, almost half of the countries were ranked with poor or bad EWI (Prescott-Allen 2001). Figure 4.13 depicts the barometer of sustainability of the countries of South East Asia. Each country's WI was represented on the barometer of sustainability by the egg of wellbeing. For example, the HWI for Sri Lanka was estimated as 46% and EWI was 53%. The egg was placed at the point on the barometer of sustainability where the HWI and EWI intersect. This suggests that Sri Lanka have a medium human and ecosystem wellbeing. In summary, this powerful visual tool enables interested parties to see a nation's performance and scores of human wellbeing relative to ecosystem wellbeing and also with respect to different dimensions i.e. land, resource use …etc.

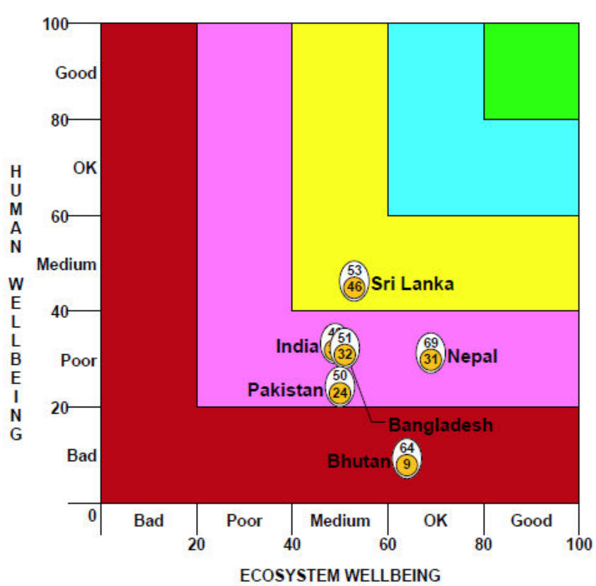


Figure 4.13: The human and ecosystem wellbeing: South Asia.

4.9.2 Advantages and Limitations of WI

The barometer of sustainability is a visualizing tool that can be used to compare countries in term of their sustainable development toward their people and environment wellbeing. Besides, it is an effective tool that ensures measurability without compromising effective communication of progress in a simple means to the public. This tool emphasizes that the wellbeing of any nation is based on its commitment toward its people, surrounding environment, and their interactions. This is clearly depicted in the egg of wellbeing Figure 4.9.

While, WI can be used as a composite indicator to measure the overall wellbeing of countries; it can be de-convoluted into HWI and EWI indices and used individually. This can provide policy makers with a better assessment of specific concerns.

The Barometer of Sustainability is used as an index to compare the progress towards sustainable development among countries. However, its usability among local communities is undermined since each has particular local concerns that will require specific indicators to be identified based on feedback from the public. This was shown to be challenging to accomplish in a timely manner. If implemented, this will lead to different barometers that would make comparison among various communities infeasible. A Similar conclusion was reported in assessing the barometer of sustainability in Venice (Sors 2001).

The WI is arbitrarily calculated using averaging of its two components (HWI and EWI), which may diminish the quality of the reported outcomes. For example, few countries with high HWI and yet poor EWI may still result in a biased high WI that may undermine the true challenges the countries face e.g. Sweden (Mayer 2008).

Similar to the ESI, this measure is based on a large set of indicators that relies on data availability. Any missing data especially for countries with poor records may compromise the range of the WI and look falsely sustainable. This is mainly attributed to that this index valuation methodology is based on averaging of its components (Mayer 2008).

4.10 Genuine Savings (GS)

Genuine Savings[24] (GS) or "Adjusted Net Saving" as identified by the World Bank (WB) is a comprehensive index of sustainable development. GS is credited to Pearce and Atkinson ((Pearce and Atkinson 1993)) who developed this measure based on the concept of weak sustainability that considers natural resources to be totally substitutable by manufactured assets as an input to production. This measure integrates the environmental damages and the depletion of natural resources with respect to reproducible capital depreciation to the nation's net saving. Hamilton (Hamilton 1994; Kunte, Hamilton et al. 1998; Hamilton and Clemens 1999), an economist in the WB, then further developed the 'genuine' savings index, which was estimated by the WB for various developing countries (WB 2006).

GS aims at measuring the net change in assets that are critical for a sustainable development of a nation. Such assets are: natural and man-made resources, foreign assets, environmental quality, and intangible capital human resources that include

[24] Alternatively referred to as "Genuine Investment" or "Inclusive Investment" (Arrow *et al*., 2003, Dasgupta, 2007).

knowledge, skills, and basic health services. This sustainability measure perceives the positive change in wealth as the source of wellbeing and welfare. It adjusts GDP to more accurately account for the depletion of natural resources with respect to reproducible capital depreciation and pollution damages in comparison with the nation's net savings (Sato and Samreth 2008). Consequently, when a nation is generating enough savings i.e. its saving rate is non-negative, this will render its economy and wellbeing to be sustainable and able to maintain adequate levels of environmental and man-made resources. Therefore, GS is an effective tool in differentiating among various countries their progress toward sustainable development.

4.10.1 GS Valuation Methodology

The detail on the economic background of the methodology of this index is outside the scope of this dissertation; interested readers are encouraged to refer to Hamilton and Clemens paper on this topic (Hamilton and Clemens 1999).

Genuine savings is calculated by subtracting depletion of natural capital and estimates of environmental damages for carbon dioxide emissions from net saving. This is fundamentally gross national saving minus depreciation of produced capital. The equation below outlines the valuation methodology of this index. The Genuine Savings is defined mathematically as:

$$GS = GNS - D_h + CSE — CD - \sum R_{n,i} \qquad \text{Equation 4.8}$$

$$GS\ rate = \frac{GS}{GNI} \qquad \text{Equation 4.9}$$

Where:

GS *is* Genuine Savings

GNS is Gross National Saving

D_h *is* Depreciation of produced capital

CSE is Current expenditure on education

$R_{n,i}$ *is* Rent from depletion of natural capital *i*

CD *is* Damages from carbon dioxide emissions

GNI is Gross National Income at market prices

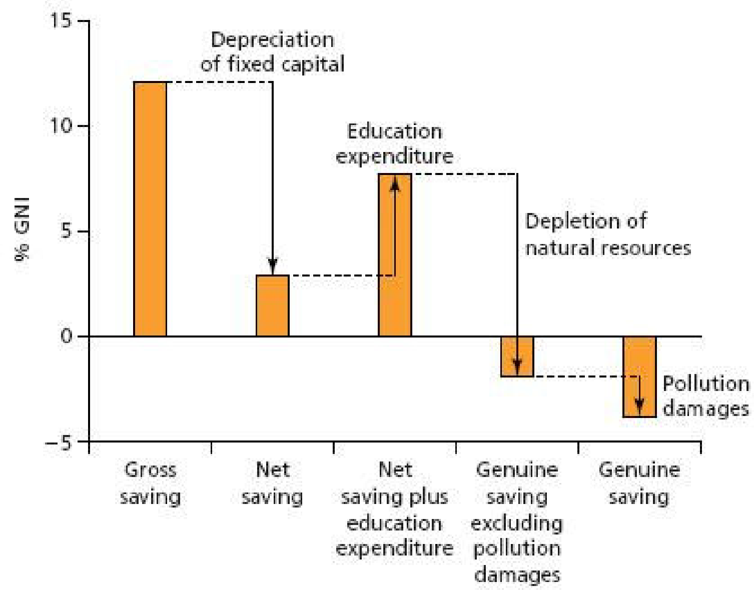


Figure 4.14: Calculation of Genuine Savings. Source: World Bank (WB 2006).

As depicted in Figure 4.14, the calculation of each component in the above equations is integrated as follow to reveal the overall change in wealth of a nation (Hamilton and Clemens 1999; WB 2006):

- The Gross National Saving (GNS) is the initial figure in this measure and obtained from SNA by deducting the public and private consumption plus net current transfers from GNI.
- Then, this figure is adjusted by deducting the D_h to obtain the net savings.

- Unlike in the SNA valuation methodology, the CSE is considered an asset since it is a key contributor to the human capital of a nation and is added to the net savings. CSE excludes capital investments in buildings and equipment and only includes wages and salaries.
- The next adjustment is the deduction of estimates of a variety of natural resources depletion ($R_{n,i}$), to denote the decline in asset values. This is measured by deducting the average extraction cost for the market value of material *I*, which is then multiplied by the quantity extracted (Sato and Samreth 2008).
- Now, the genuine saving is determined by deducting the overall value of pollution damages since it is a lost welfare that usually leads to chronic health damages (Hamilton and Clemens 1999). It should be noted that the latest version of GS calculation the pollutants emission are subtracted.
- Finally, the GS rate is determined by taking the ratio of GS to GNI.

It should be emphasized that the final value of this measure is obtained by monetizing the components listed above. This measure can be reported as a positive or negative rate, where negative rates reflect unsustainable income and country's wealth is being consumed. This is accompanied by a decline in the overall well-being. On the other hand, consistent positive GS rates for countries imply that their income is sustainable.

In 2005, WB released the GS rates for 118 countries. The top ten countries with the most positive GS rates were Solomon Islands, Bhutan, Botswana, China, Singapore, Nepal, Malawi, India, Bangladesh, and Philippines. This implies that the income of these countries is sustainable and associated with an improvement in the overall wellbeing. On the other hand, countries with the most negative GS rates are Sudan, Uzbekistan, Syrian Arab Republic, Trinidad and Tobago, Equatorial Guinea, Angola, Chad, and Congo. These countries tend to have high fixed capital depreciation accompanied with significant energy depletion (Butler 2005).

4.10.2 Advantages and Limitations of GS

Unlike standard measures, GS provides a better measurement of wealth accumulation by assessing the interplay between country's social and environmental aspects and their impact on its macroeconomic performance. Furthermore, GS is a successful tool in assessing the rate of change in the national wealth to determine if it is created or consumed. GS adopts the notion that human and natural capitals are pivotal for ensuring a sustainable nation's progress. Furthermore, investments in people's education and wellbeing add to the overall nation's genuine savings. However, air pollution and natural resources depletion would decrease its genuine savings (Everett and Wilks 1999). Overall, resource rich countries, which put forward policies that ensure that they maximize the value of the proceedings coming out of natural resources depletion to build educated workforce, diversify and industrialize their economy were successful in increasing their nations' wealth and having non-negative GS rate e.g. Botswana, Indonesia, Malaysia and Thailand. Therefore, only those nations with positive GS and able to maintain and/or grow their overall produced and natural assets are believed to be sustainable (Everett and Wilks 1999; Gylfason 2001).

As an index, GS came under a lot of criticisms that showed its shortcomings as it is currently presented. One of the main limitations is about the data used, where estimation of produced assets depreciation is compromised due to inaccurate value assumption since data is obtained from unreliable tax records and/or not referenced to real asset lifetimes. Also, there is a compromise in the method of estimation of the depletion of exhaustible resource deposits, net forest depletion, damage estimates for carbon dioxide emissions, human capital investment figures. This is based on the notion that the assessment of natural capital is limited to services that directly contribute to economic activity of a nation though inputs e.g. non-renewable and renewable natural resources that are directly used in the production of goods and services for consumption (Kunte, Hamilton et al. 1998). It should be emphasized that the concept of direct contribution to economic activity underestimates the natural resources contribution to the GS final score. Since, it limits it to monetary based value of related resources. In addition, many environmental impacts are not considered such as soil degradation; which further underestimates the GS. Overall, these factors would inflate the genuine savings figure and estimation of the resources available for future investments (Everett and Wilks 1999).

GS was also criticized since it is conceptually based upon the weak sustainability approach that assumes the substitutability of all different capital stocks it identifies (Everett and Wilks 1999; Pillarisetti 2005). Furthermore, this concept is valid provided that the earth ecological limits are not exceeded otherwise it is untenable (Arrow, Bolin et al. 1995). There is a general Conesus at the global level that our ecological footprint exceeded the Earth's carrying capacity (Section 4.1.2). Furthermore, under this approach the economy is viewed as a self-sufficient system instead of an integrated subsystem of a finite ecological system. It ignores the critical ecological limits of Mother Nature since the GS approach accelerates natural resources depletion.

This would threaten leaving an equitable share of resources for future generations, which would violate the inter-generational equity as one of the main aspects of ensuring sustainable development (Everett and Wilks 1999). In sum, this would compromise the utility of GS as a sustainability index since its driving concept is relies upon weak sustainability (Pillarisetti 2005).

Everett et. al. (Everett and Wilks 1999) noted that aggregated measures such as GS are over-simplistic and tend to offer misleading policy recommendations by diverting the attention from critical environmental and social issues that are necessary for country's progress and sustainable development. A successful sustainability measure would assess the costs and benefits of particular activities within a country.

Like earlier discussed indices, GS is GDP dependent. As noted in the valuation methodology, its calculation begins with the nation's GDP. This would justify economic growth (real GDP) as a main driver of nation's progress. High income OECD countries are more likely to be associated with positive GS while resource dependent Middle Eastern/North African countries are associated with negative GS (Everett and Wilks 1999). Despite these countries excessive consumption, that significantly exceeded their ecological footprint, and critical role in natural resources depletion and pollution damage, their GS rates are strongly positive, concluding that they are the most sustainable. This lends GS as a western biased index and compromises its credibility. Also, High income countries more likely to more invest in education which will further contribute to their overall strongly positive GS.

The valuation methodology the GS employs is based on converting the four types of capital stocks into monetary terms. This would devalue and hide information that would mislead policy recommendations (Guijt and Moiseev 2001).

In sum, GS defines wealth beyond standard national accounts and integrates the human and environmental capitals with the country's macroeconomic performance that are pivotal for sustainable development. However, the construction of its valuation methodology is flawed and ignores critical factors created by high income countries, and substantiates their unsustainable consumption. As a result, this would compromise its utility as a successful index of sustainability.

4.11 Gross National Happiness (GNH)

For generations, world cultures and leaders continued to call for their people‘s right to pursue happiness. For example, the US founding fathers recognized the immutable right of the US people to pursue happiness, which was the basis of the US constitution. Jeremy Bentham, a leading British philosopher, argued that the driver for politicians is to provide happiness for the greatest number of their constituents (White 2007). At the end of the last millennium, Bhutan famously adopted the goal of Gross National Happiness (GNH) as a measure of their country wellbeing. It replaced Gross National Product (Helliwell, Layard et al. 2012). This was in response to the criticism that Bhutan is considered economically poor relative to other countries based on their low GDP. The former King of Bhutan, Jigme Singye Wangchuck stated that *"Gross National Happiness is more important than Gross Domestic Product. Bhutan needs to ensure that prosperity is shared across society that is balanced against preserving cultural traditions, protecting the environment and maintaining a responsive* *government" (King Jigme Singye Wangchuck, 1974)".* In late 1980s, king Jigme Singye Wangchuck started to use GNH developed by the Center for Bhutan Studies as an alternative index to GDP to measure the overall well-being and happiness of Bhutanese people (Priesner 1996).

In 2004, the capital city of Bhutan, Thimphu hosted the first international conference on GNH that was organized by The Centre for Bhutan Studies. The theme was to agree on an accurate definition of the concept of GNH from operational and theoretical standpoint (Mancall 2004). While there was a lot of discussion and debate, no clear consensus on GNH as a definition was realized. Still, this was a major milestone that introduced the concept to the world and invigorated the interest in this important concept and index (Dorji 2003).

In the following year, Nova Scotia, Canada hosted the second conference on GNH. It focused on building on the progress made in the first conference and to seek to operationalize the concept by reflecting and discussing the experiences gathered from around the world (Mancall 2005). Later on, in 2008, the Center for Bhutan Studies, released an international mini version of the index to measure the well-being of many countries.

4.11.1 GNH Valuation Methodology

The methodology of this index originated from the principles of Buddhism. It is based on the premise that the success of human community is when both spiritual and material developments are concurrently considered and adapted. GNH encompasses four pillars on which happiness is measured:

1. The promotion of equitable and sustainable socio-economic development.
2. The preservation and promotion of cultural values.
3. The conservation of the natural environment.
4. The establishment of good governance.

Similar to other indices, this is a single number index originated from nine equally weighted domains (Figure 4.15), which are:

1. Psychological Well-being
2. Time Use
3. Community Vitality
4. Cultural Diversity and Resilience
5. Health
6. Education
7. Environmental Diversity and Resilience
8. Living Standard
9. Good Governance

These domains are evaluated using 33 sub-domains that are divided into objective, subjective or self reported sub-domains. Interestingly, higher weights are given to former, while smaller weights are given to the self reported sub-domains. Furthermore, the adapted approach is decomposable, which indicates that it can be classified by population, gender, district, or state.

Furthermore, they were chosen based on:

1. Normative values, official documents

2. Statistical properties
3. Accuracy across time
4. Policy relevance
5. Clarity of interpretation

These sub-domains are collated based on the outcome of a survey composed of more than 120 questions. This is based on a combination of the empirical research of happiness, positive psychology and well-being. The analysis tool used is the Alkire-Foster method which is a solid multidimensional approach.

Using this tool generates three different outcomes, which are:

1. Headcount defined as the percentage of Bhutanese people who are happy
2. Breadth defined as the percentage of domains in which not-yet-happy people enjoy sufficiency.
3. The overall GNH index

Figure 4.15: the nine domains of GNH (Ura, Alkire et al. 2012).

The overall GNH index is calculated using the equation below:

$$GNH = 1 - H_n \cdot A_n$$

Where:

H_n is the percentage of Bhutanese population who are classified as not-yet-happy since they have not achieved sufficiency in 6 domains.

A_n is the average percentage of dimensions where those not-yet-happy people lack sufficiency.

The final GHN index categorizes the Bhutanese people into four groups:

1. Unhappy: The group of people that achieved sufficiency in less than 50% of weighted indicators.
2. Narrowly Happy: The group of people that achieved sufficiency in 50-65% of domains.
3. Extensively Happy: The group of people that achieved sufficiency in 66-76% of weighted indicators i.e. in 6-7 domains.
4. Deeply Happy: The group of people that enjoy sufficiency in 77% or more of weighted indicators i.e. 7 or more of the nine domains.

Interestingly, in 2010, 10.4% of the Bhutanese population was categorized as "unhappy", and 48.7% were 'narrowly happy'. While, 40.9 % were identified as "happy" since they realized sufficient achievements in at least 66% of the weighted indicators, whichever domains they came from. This corresponds to 32.6% and 8.3%

of the Bhutanese population were identified as ‘extensively’ and ‘deeply’ happy, respectively (Ura, Alkire et al. 2012).

4.11.2 Advantages and Limitations of GNH

Similar to the Well-being Index, GNH is easily comprehendible by the general public. It used a sound statistical methodology that enabled a proper selection of its indicators classified under the 9 domains. Furthermore, leading economists concur that it is plausible to have a strong correlation between happiness assessment and other aspects relevant to people social and economic well-being. For example researchers found a higher tendency for unemployed people report lower happiness scores relative to employed individuals. This finding is not unexpected and consistent with other correlations established between divorce, addiction, depression and violence with unemployment. This further underscores the significance of happiness surveys in capturing the overall wellbeing of people, which clearly demonstrates its importance as a viable tool that should considered when assessing progress toward sustainable development (Di Tella and MacCulloch 2006).

GNH has certain disadvantages that would limit its utility. Owing to the fact that happiness cultivation is central in Bhuddism philosophy, Tashi argues that GNH principles can only be achieved if all the constituents strictly adhere to the Bhuddist philosophy and way of life (Tashi and Dorji 2002). This can be challenging to be practiced globally. Furthermore, one of the main limitations with GNH methodology is its reliance on subjective questions to assess the happiness status of an individual. For example, Norbert Schwartz and Fritz Strack contended that “what is being assessed, and how, seems too context dependent to provide reliable information about a population's well-being, let alone information that can guide public policy" (Schwartz and Strack 1999). Interestingly, policy makers can identify indicators for well-being assessment that meet their interests and cultural needs. Such assessment is typically subjective, which renders comparison of wellbeing among countries difficult and challenging (Diener, Diener et al. 1995). Other limitations that further exacerbate the international comparison of happiness ratings are: the possibility of inaccurate translation of surveys from English to other languages which creates a major difficulty, and diverse cultures have different norms in their willingness to express their happiness (Wierzbicka 2004).

It is interesting to note, that people change their definition of happiness overtime. As a result, this would undermine the ability to have comparison of happiness assessment with time (Ng 2008).

4.12 Overall Assessment of Sustainability Indices

The main attributes that a sustainability index should consider to successfully assess the progress of nations have been outlined and defined (Table 4.6). These 18 properties are divided as general, economic, social, and environmental or combinations. Table 4.7 illustrates a comparison and scores of the reviewed indices with respect to the outlined criteria. It is interesting to note that GDP score is 11. GDP attains this score mostly due to its data reliability since it depends on SNA. Also, its valuation is easily comprehensible, monetized, and comparable among countries. The main factors that contributed to the scores of some of the higher rated indices are primarily based on their successful integration of the sustainability dimensions into their valuation methodology. Also, many of these indices originated from well recognized institutions in the area of sustainable development, which made it helpful for policy makers.

The index that stands out in term of its score is the ISEW. It incorporates the three dimensions of sustainability in its valuation methodology, which most of the other indices reviewed lack. It provides an alternative frame of reference for progress assessment and integrates costs and benefits of the three aspects of sustainable development into one composite monetary index. Moreover, this composite index is considered easily comprehendible by the general public, and particularly valuable in assessing the overall direction of the country's economy and future course of action.

GNH is the second index following ISEW in term of its score. It is a comprehensive index that successfully measures happiness ratings for countries. GNH is also easily comprehendible by the general public and is a viable approach that effectively replaces GDP as a holistic measure for people happiness.

It is interesting to note that the index that stood out in the number of citations over the last two decades is HDI. However, in the last five years, significant increase in the number of citations was reported for CF in comparison to other indices. Many factors contributed to this observation. For example, CF is easily comprehendible by the general public and continues to be the buzz word that is used by different parties to assess their sustainable development practices and approaches that can be used to manage environmental liabilities. Nevertheless, CF has shortcomings that should be taken into consideration. For example, CF is not a comprehensive index since it does not consider the social and economic aspects of sustainable development.

Furthermore, CF emphasis is only limited to one environmental liability namely global warming driven by GHG.

The lack of the reliable data is considered one of the main issues that most of these indices continue to have. This is attributed to the fact that sustainable development is a multi-dimensional and complex system, and it is critical to incorporate its three dimensions, which requires complicated and interrelated elements (indicators) in its assessment that many countries don't have due to their poor records that would compromise the results of the indices. In addition, the high number of variables included in the calculation of some indictors obliges researchers to obtain their relevant data from various sources and databases and even from studies in peer-reviewed science journals which also compromise the quality and validity of these data. It is interesting to note that in the measures studied there is a trend to focus on assessing the economic and ecological aspects of sustainability and the social dimension is held in abeyance.

Category	Characteristic	Definition
General	Reliable Data	The data that feeds into the calculation comes from reliable sources and databases and not imputed.
General	Valuation Methodology	It does not require strong scientific background to be able to calculate the index
General	Easily Comprehendible	Single universal scale that depicts a clear and unambiguous message that is usually easily understandable
General	Complexity	The index that is calculated of complicated or interrelated elements (indicators)
General	Monetized	All indicators were transformed into the same unit before determining the final index to enable quantitative assessment (Land or $)
General	Over Time Calculation	It also assesses long term progress rather than short term changes and it is comparable over time
General	Helpful For Policy Makers	Enables policy makers to take decisive measures towards a more responsible and efficient use of available resources
General	Predict Future	Be used as a metric to predict future trends
General	Bury Information	conceal information due to its valuation methodology (averaging, addition)
General	Inter Countries Comparisons	Effectively used and calculated for various countries and allows meaningful comparison
General	Non Western Biased	Ensure final outcomes are not skewed due to the use of western advances.
Economic	Economic Activity	It integrates economic in its valuation methodology
Economic	Income Distribution	Consideration of income distribution not income averaging.
Environmental	Environmental Sustainability	It considers the major factors that would impact and deteriorate the environment e.g. CO_2, landfills (solid waste), impacts of air and water pollution
Environmental	Reuse & Recycle	it incorporates country's recycling and reuse ratio
Social	Waste of Time	Considers the time lost aspect
Social	Social Sustainability	It integrates social sustainability in its valuation methodology
Economic/Environmental	Natural Resource Depletion	Takes into consideration the economic and environmental impact of natural resources consumption

Table 4.6: Definition of the main attributes considered in the evaluated indices.

Dimension	Characteristic	EF	HDI	ES	ISEW	WI	ESI	GDP	GS	CF	GNH	Score
General	Reliable Data	0	0	0	0	0	0	1	0	0	1	2
General	Valuation Methodology	0	1	0	0	1	0	1	0	1	1	5
General	Easily Comprehendible	1	1	0	1	1	1	1	1	1	1	9
General	No-Complexity	0	1	1	0	0	0	1	0	1	1	5
General	Monetized	1	0	0	1	0	0	1	1	0	0	4
General	Over Time Calculation	1	1	1	1	1	0	1	1	1	0	8
General	Helpful For Policy Makers	1	1	1	1	1	1	1	1	1	1	10
General	Predict Future	0	0	1	1	0	0	0	0	0	0	2
General	No-Bury Information	1	0	1	0	0	0	1	0	1	0	4
General	Inter Countries Comparisons	1	1	0	1	1	1	1	1	1	0	8
General	Not Western Biased	1	1	1	1	1	0	1	1	0	1	8
Economic	Economic Activity	1	1	0	1	0	0	1	1	0	1	6
Economic	Income Distribution	0	1	0	1	0	0	0	0	0	1	3
Environmental	Environmental Sustainability	1	0	1	1	1	1	0	1	1	1	8
Environmental	Reuse & Recycle	0	0	0	0	0	1	0	0	1	0	2
Social	Loss of Time	0	0	0	1	0	0	0	0	0	1	2
Social	Social Sustainability	0	1	1	1	1	0	0	1	0	1	6
Economic/ Environmental	Natural Resource Depletion	1	0	1	1	0	1	0	1	0	1	6
Overall Score		10	10	9	13	8	6	11	10	9	12	

Table 4.7: Evaluated indices attribute comparison.

4.13 Sustainability Measurement: Industrial Perspective

The success of sustainability is determined by the commitment of every part of the community that is not only limited to public programs, but also spans industries and businesses. Leading industrial institutions realized the importance of the implementation of sustainability programs. These efforts will positively influence their bottom-line by reducing their overall costs, addressing the growing environmental concerns and higher expectations of environmental and public groups. Leading companies are setting ambitious goals to reduce their impact on the environment. For example, Dell the leading computer manufacturer committed in 2007 to reduce its carbon footprint by 15% in 2012 with an ultimate goal of achieving zero emission. Similarly, Timberland added a carbon label to some of its products to outline the amount of GHG emitted during their manufacturing. Environmental Defense Fund (EDF) designed a calculator that allowed industries to compare their packaging designs in term of weight, recycled content, and performance. In response to public criticism in 1990s, McDonald collaborated with EDF and used their calculator to determine the environmental impacts and assess the cost tradeoffs of different available packaging options for their sandwiches (DEUTSCH 2007; Mui 2007). This assessment was pivotal in replacing their polystyrene based foam clamshell packages with a more environmentally friendly packaging. Another company that implemented initiatives toward sustainability is Procter & Gamble Co (P&G). The company's sustainability program ensures attaining sustainability through their vision which includes: 100% renewable or recycled materials for all products and packaging, zero consumer and manufacturing waste to landfills, all plants powered with 100%

renewable energy, no fossil-based CO_2 or toxic emissions. In 2011, P&G released its report titled "Commitment to Everyday Life", highlighting their progress toward attaining sustainability. For example, it made significant strides in reducing their powder laundry detergents packaging for its entire portfolio of U.S. and Canadian by 33 percent, while consumers continue to have the same great performance with smaller doses. This results in less packaging, less waste and fewer delivery trucks on the road, which is environmentally rewarding (DEUTSCH 2007; P&G 2011).

A leading company that is committed to the principles of sustainable development while being economically profitable is Interface. This is a global carpet company that created what they refer to as the Evergreen Lease program - the leasing of carpet, rather than selling it. Where, the customer pays monthly fee for the service of using the carpet, not the carpet itself. Interface seeks to be the first sustainable corporation and restorative company. In 1994, they put into practice the Quality Utilizing Employee Suggestions and Teamwork (QUEST). Then, Interface Research managed a program called EcoSense, to measure their progress. They joined the two programs (QUEST and EcoSense) together to achieve their sustainability goals while maintaining profitability. Interface emulated Nature by redesigning its processes and products into cyclical material flow. They reduced the use of raw materials from earth and used natural organic materials where possible. Interface is already on the track to produce zero waste and scrap to the landfill (Interface 1997). The company now is 10 years from its goal of eliminating the negative environmental footprint by 2020. Through process improvements and energy efficiencies, of the over 400 million pounds of raw materials purchases in 2009, Interface has sent 3.4 million pounds of waste to landfills (less than 1%) this is a reduction of 77 percent compared to 1996. Furthermore, 6.9 million pounds of raw material were recycled to be reused, 9.6 million pounds of waste were reused for energy recovery, and through the QUEST program the company savings reached $433 million in cumulative, avoided costs since 1995. Additionally, the energy used to manufacture carpet reduced by 43% since 1996, greenhouse gas emissions are down 44% since 1996 and most importantly during the same time period, the company grew net sales by 27%. Overall, Interface has made significant strides to align itself with its sustainability goals. Such as, zero waste, benign emissions, Use renewable resources, Close the loop, by mimicking the Nature's biological ecosystem; operating in a cyclic - not a one-way system. Resource efficient transportation so that it will focus on service and value of the product instead of material (Anderson 1999; Interface 2011).

4.13.1 Wal-Mart Scorecard

Wal-Mart is a key company whose efforts in sustainability gained skepticism at the beginning and positive reactions later on by the public media and environmental groups. This is the leading retailer in the world and considered FORTUNE's most admired company (Useem 2003). Wal-Mart has more than 9,600 retail units under 69 different banners. It serves twenty eight countries with a total of more than 200 million customers per week. With fiscal year 2012 sales of $444 billion, Wal-Mart employs 2.2 million associates worldwide. In addition, it has 66,000 suppliers with more than 13,000 products (Wal-Mart 2012). Evidently, this lends Wal-Mart to be the biggest retailer in the world and the leading buyer with a substantial network of suppliers like Disney, Procter & Gamble, Kraft, Revlon, Gillette, Campbell Soup, and many other

America's famous branded manufacturers. It should be noted that Wal-Mart's scale resulted in a significant ecological impact and high carbon footprints. The media and environmental groups as shown by a 2005 documentary film by director Robert Greenwald "*Wal-Mart: The High Cost of Low Price*" scrutinized Wal-Mart by critiquing its unfavorable business practices (Nandagopal and Sankar 2009). As a consequence, in 2007, Wal-Mart announced a change in their mission from "Always Low Prices" that was associated with unsustainable consumption, massive solid waste, water and air pollution due to inefficient supply chain and excessive redundant products packaging to "Save Money, Live Better". The new mission of the organization 'is to help people save money so they can live better' (Nandagopal and Sankar 2009).

Wal-Mart outlined three platforms to accomplish this ambitious mission: first, to be supplied 100 percent by renewable energy; second, to create zero waste; and third, to sell products that sustain resources and environment by optimum utilization of preferred products and packaging (Figure 4.16). It should be stressed that suppliers such as Wal-Mart know that consumers judge a product by its package. As a result, they use this as an effective marketing strategy to increase the product appeal and attract the consumer's attention. Moreover, packaging has many benefits for example; it enhances product packaging, provides better product protection, and prevents spoilage. Indeed, sometimes product packaging costs more than the product itself. In their efforts to reduce their overall environmental footprint, and part of their sustainability initiative, Wal-Mart implemented the use of Wal-Mart Scorecard. This is a measurement tool that allows suppliers to evaluate themselves relative to others in their use of packaging and the assessment of their efforts to reduce it, based on specific metric (Zettlemoyer-Lazar 2007; Wal-Mart 2012). This is another example of how industry is approaching sustainability, with emphasis on the packaging component that accounts for $450 billion globally and has a visible role in grabbing customers attention.

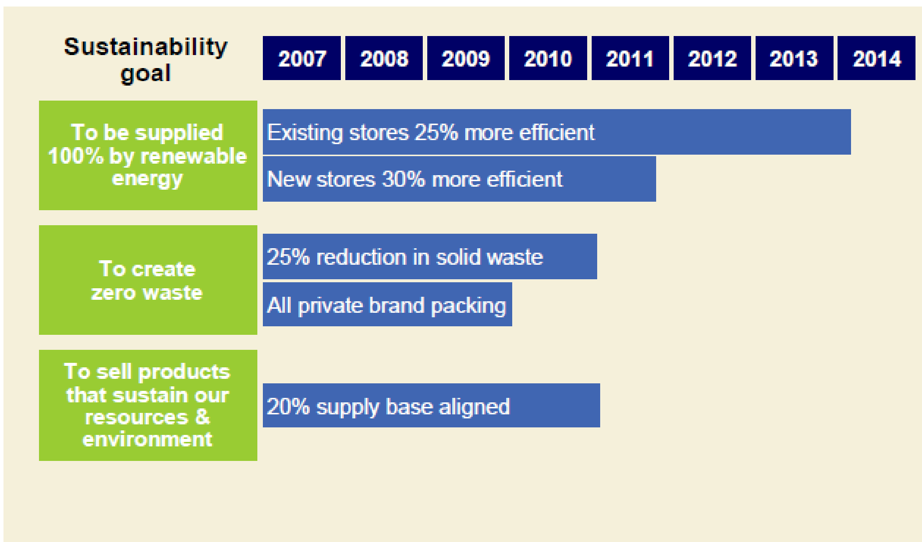


Figure 4.16: Wal-Mart sustainability goals (Wal-Mart 2012; Wal-Mart 2012)

A Wal-Mart scorecard is a system that their suppliers are expected to implement the "7 Rs' of Packaging" to attain their goals on sustainability and enable them to compare their progress to other competitors (Zettlemoyer-Lazar 2007). The "7 Rs'" of Wal-Mart scorecard are:

Remove packaging: It is accomplished by simplifying the current packaging design with a goal of eliminating unnecessary packaging and extra boxes/layers.

Reduce packaging: It involves activities that seek to use the right size packages and optimize material strength.

Reuse packaging: It is accomplished by choosing pallets and reusable plastic containers, which sustains the lowest impact on the environment.

Recycle packaging: It refers to choosing proper recycled materials without compromising the properties needed in the packaging design.

Renewable packaging: It is achieved by selecting materials made of renewable resources such as biodegradable bio-plastics.

Revenue: The above principles should be applied while maintaining currents costs or realizing savings.

Read: Continue to be educated on sustainability and approaches that can be adapted.

Indeed, Wal-Mart scorecard "7 Rs'" are constructed to enable the achievement and realization of Wal-Mart major three goals (Figure 4.15). Where the goal of achieving 100% renewable energy is realized through the implementation of the "3 Rs'" Remove, Reduce, Read. Also, Waste Reduction "R's" is achieved through Renew, Revenue, and Read. Finally, Sustainable Product "R's" are Renew, Revenue, Recycle, and Read.

It should be emphasized that Wal-Mart scorecard "7 Rs'" were originated from the 3Rs' (i.e. reduce, reuse, and recycle) of sustainable product life cycle principles (Jaafar, Venkatachalam et al. 2007) and substantiated with a more inclusive three other Rs' (i.e. recover, redesign, and remanufacture).

Furthermore, the Wal-Mart Scorecard combines a series of metrics that evaluate the performance of the supplier's packaging and is considered in its methodology. It includes: GHG emissions per ton of package production, raw material use/sustainable material, packaging size, recycled content, material recovery value, renewable energy use, transportation impacts, and innovation. The weighting factor for each component of Wal-Mart scorecard was based on experts' opinion methodology; where Wal-Mart had consultations with a group of 200 leaders in the global packaging industry. This group encompassed suppliers, experts, internal, and external stakeholders who outlined the metrics and weighing factors for each of them (Table 4.8). Furthermore, these metrics are constructed to achieve Wal-Mart three main platforms where the progress toward the utilization of renewable energy is evaluated through distance to transport, cube utilization, greenhouse gases (GHG), and renewable energy. On the other hand, progress toward waste reduction is assessed through the metrics of product to package ratio and package recovery. Finally, sustainable product is evaluated by the metrics: material type, recycled content and package innovation.

The discussion below outlines the valuation methodology with emphasis on the purpose of each metric key assumptions and implemented methodology. It should be emphasized that based on the system testing phase that ran from February 1, 2007 to February 1, 2008, Wal-Mart valuation methodology was updated to reflect the need to better evaluate metric performance by means other than the weighted average equation, where a better score is obtained if a material with a better performance that the industry average was added. This is inconsistent with the sustainability aspect of elimination of material use where a better score should be obtained from removing material not adding material even if it was with a better score. As a result, the scorecard evaluation was expanded to incorporate the CMUM variable, which stands for consumer meaningful units of measure. A combination of both equations (original and CMUM) are used in the scorecard depending on the product category as shown below (Richmond and McKiernan 2007).

Category	Weight Factor %
GHG / CO_2 per ton of package Production	15
Material Health & Safety	15
Product / Package Ratio	15
Cube Utilization	15
Transportation	10
Recycled Content	10
Recovery Value	10
Renewable Energy	5
Innovation	5

Table 4.8: The categories and weight factor % of Wal-Mart Scorecard.

4.13.1.1 Cube Utilization

This metric is assessed based on Selling Unit Cube Utilization (*pcu*) and Transport Cube Utilization (*tcu*). For the first, the purpose is to evaluate the efficiency of the material packaging volume relative to that consumed by the product with an assumption that the selling unit is rectangular or square. Below is the equation used to calculate the cube utilization for a selling product:

$$\text{Selling Unit Cube Utilization} = \frac{\text{Product Label Volume}}{\text{Total Selling Unit Volume}} \qquad \text{Eq 4.10}$$

Where the product Label volume is multiplied by a conversion factor to achieve $inches^3$ for liquid the conversion factor used is 1 U.S. fluid oz. = 1.805 $inches^3$. As for products sold in weight, it is multiplied by density conversion factor. In addition the results are stated as a percentage.

For the latter, Transport Unit Cube Utilization is assessed by determining the ratio of the number of all selling units multiplied by total selling unit volume and divided by the volume of transport unit as outlined in the equation below.

$$\text{Transport Unit Cube Utilization} = \frac{\text{\# Selling Units} \times \text{Total Selling Unit Volume}}{\text{Volume of Transport Unit}} \qquad \text{Eq 4.11}$$

The final score of this measure is a dimensionless measurement calculated using the average of the two ratios, i.e. Selling Unit Cube Utilization and Transport Cube Utilization. Furthermore, the updated final equation was proposed to determine the percentage of unutilized space the score is calculated as follows:

$$\text{Score} = 1 - (\text{pcu} \times \text{tcu}) \qquad \text{Equation 4.12}$$

This enables the calculation of the % of un-utilized space, which helps in understanding the efficiency of the packaging design.

4.13.1.2 Greenhouse Gas Emissions Per Ton of Package Production

This metric is an outcome of the growing pressure from national and international environmental groups, governmental influences, and legislative actions to measure and regulate GHG emissions. This is attributed to its devastating impact on the environment as shown with unpredictable weather patterns and polar ice cap warming to name a few.

The data source of GHG metric is mainly based on the life cycle of packaging materials inventory (LCI). The data is validated using quality assurance/quality control

(QA/QC) process and fulfillment of international organization for standardization "ISO" standards is ensured. Its main goal is to encourage suppliers to reduce GHG emitted.

GHG metric accounts for 15% of the final score. Similar to other metrics GHG is measured by one of the following two equations. The first measures the overall GHG emitted in ton CO_2/package as shown below:

$$\sum_{i=0}^{np-1} \frac{wt(i)}{2000} co(i) + \left(\sum_{i=o}^{nt-1} \frac{\left(\frac{twt(i)}{ns(i) \times pcu(i)}\right)}{2000} \cot(i) \right) \qquad \text{Equation 4.13}$$

Where

np is total number of selling unit materials

nt is total number of transport materials

wt(i) selling unit material (i) weight

twt(i) transport material (i) weight

ns(i) number of items shipped in each Transportation material i

pcu(i) number of uses before Transportation material i is discarded

cot(i) Transportation material i CO_2 emissions

co(i) selling unit material i CO_2 emissions

The latter determines, the overall GHG emitted normalized to number of uses in ton CO_2/use as shown:

$$\frac{\sum_{i=0}^{np-1} \frac{wt(i)}{2000} co(i) + \left(\sum_{i=o}^{nt-1} \frac{\left(\frac{twt(i)}{ns(i) \times pcu(i)}\right)}{2000} \cot(i) \right)}{\#CMUM} \qquad \text{Equation 4.14}$$

Where CMUM stands for Consumer Meaningful Units of Measure

It is interesting to note that the normalization by CMUM enables a better comparison among sizes and concentrations.

4.13.1.3 Material Health and Safety (MHS)

This metric aims at measuring the toxicological impact of the manufacture of packaging on communities and the environment. It accounts for 15% of the overall score and its main data source is LCI Data on Packaging Materials. The equations below are used to calculate this metric. The weighted average of metric calculation is:

$$\frac{\sum_{i=0}^{np-1}(wt(i))(s(i)) + \left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\text{st}\,(i)\right)}{\sum_{i=0}^{np-1}(wt(i)) + \left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\right)} \qquad \text{Equation 4.15}$$

Where

s(i) is Wal-Mart Selling Unit material (i) OSHA Score

st(i) Transportation material (i) OSHA Score

The packaging recovery scores that are used with the equation above are High = 3, Medium = 2, Compostable = 1, Low = 0.

Amount of MHS quality per CMUM is calculated below:

$$\frac{\sum_{i=0}^{np-1}(wt(i))(s(i)) + \left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times cu(i)}\right)\text{st}\,(i)\right)}{\#CMUM} \qquad \text{Equation 4.16}$$

It should be emphasized that the packaging recovery scores with the CMUM equation are re-characterized where MHS best material =”1” and worst = “5”. The use of CMUM allows for comparison of total impact towards MHS.

4.13.1.4 Product to Package Ratio

This metric makes 15% of the total score, and its data source is provided by user input. It assesses the ratio of package to product weight (customer relevant unit of measure), with a goal of encouraging the manufacturer to reduce the amount of packaging used. Two equations are used in the calculation of this score; depending on the type of the product. Package to product ratio calculation is determined using this equation:

$$\frac{\sum_{i=0}^{np-1}(wt(i)) + \left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\right)}{nw} \qquad \text{Equation 4.17}$$

Where

nw is net weight

Furthermore, the ratio of package weight to number of uses is calculated as the following

$$\frac{\sum_{i=0}^{np-1}(wt(i)) + \left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\right)}{\#CMUM} \qquad \text{Equation 4.18}$$

It is worth noting that the objective of this metric is to encourage the supplier is to reduce the amount of package weight per use.

4.3.1.5 Recycled Content

This metric makes 10% of the total score, and similar to others, its data source is based on LCI data on packaging materials. Indeed, Wal-Mart implemented industry average for post consumer recycled content to simplify the equations used. Recycled content formula is:

$$\frac{\sum_{i=0}^{np-1}(wt(i))(ppc(i)) + \left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\text{ptc }(i)\right)}{\sum_{i=0}^{np-1}(wt(i)) + \left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\right)} \qquad \text{Equation 4.19}$$

Where *ppc*(i) is selling unit percentage of post-consumer recovered content of material (i)

Where *ptc*(i) is Transportation percentage of post-consumer recovered content of material (i)

In addition, CMUM Recycled Content is measured using the following:

$$\frac{\sum_{i=0}^{np-1}(wt(i))(1-ppc(i)))+\left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)(1-\mathrm{ptc}(i))\right)}{\#CMUM} \qquad \text{Equation 4.20}$$

This metric aims at decreasing the use of virgin materials and replacing it with a higher recycled content.

4.13.1.5 Package Recovery Value

This measure accounts for 10% of the total score. Its data source is based on the municipal solid waste in the US, 2005 facts and figures, and predicted compostability[25]. It is determined by one of the following calculations:

Recovery Formula

$$\frac{\sum_{i=0}^{np-1}(wt(i))(crr(i))+\left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\mathrm{tcr}\ (i)\right)}{\sum_{i=0}^{np-1}(wt(i))+\left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\right)} \qquad \text{Equation 4.21}$$

Where

crr(i) is selling unit Wal-Mart recycle rate of material (i)

tcr(i) is Transportation Wal-Mart recycle rate of material (i)

CMUM Recovery Formula is determined as follow:

$$\frac{\sum_{i=0}^{np-1}(wt(i))(crr(i))+\left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\mathrm{tcr}\ (i)\right)}{\#CMUM} \qquad \text{Equation 4.22}$$

The main goal of this metric is to encourage the supplier to decrease the use of unrecovered material.

[25] http://www.epa.gov/garbage/msw99.htm

4.13.1.6 Renewable Energy Use

This metric purpose is to assess the percentage of the packaging manufacturing facility that runs on renewable energy and includes solar energy, wind power, water power, biofuel, liquid biofuel, solid biomass, biogas, geothermal energy. Furthermore, this metric doesn't incorporate any calculation, it depends solely on user input and verified by LCI.

4.13.1.7 Transportation Impacts

Similar to other Wal-Mart scorecard metrics; transportation is a direct user input metric. It aims at rewarding suppliers who minimize transportation distance from packaging supplier to Consumer Packaged Goods (CPG) converting facility.

Where the distance traveled from material supplier to the packaging manufacturing line is divided into four categories:

- Zero miles
- Under 500 miles
- Between 501 miles and 3000 miles
- More than 3000 miles

Where each category is assigned Wal-Mart Selling Unit Distance Score.

To determine the Average Distance to Transport Calculation the following equation is used:

$$\frac{\sum_{i=0}^{np-1}(wt(i))(di(i)) + \left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\text{dti }(i)\right)}{\sum_{i=0}^{np-1}(wt(i)) + \left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\right)}$$ Equation 4.23

Where

di(i) is Selling unit Wal-Mart distance score of material (i)

dti(i) is Transportation Wal-Mart distance score of material (i)

As for the CMUM Average Distance to Transport Calculation the following equation is used:

$$\frac{\sum_{i=0}^{np-1}(wt(i))(di(i)) + \left(\sum_{i=o}^{nt-1}\left(\frac{twt(i)}{ns(i)\times pcu(i)}\right)\text{dti }(i)\right)}{\#CMUM}$$ Equation 4.24

4.13.1.8 Package Innovation

The diminishing supplies of raw materials that are accompanied with increased universal demand are the main drivers for this metric. Similar to renewable energy metric, it is based on direct user input stated as a weighted average percentage and verified by LCI. Package innovation can be realized by achieving energy efficiency from unique manufacturing innovations to decrease overall energy use through the use of recycled content, sustainable sourcing, and bio-fuels that has having no net impact on climate change.

4.13.1.9 The Six Steps for Complete Scorecards

The process of determining Wal-Mart Scorecard to provide an overall evaluation of sustainability for an existing packaging is divided into six steps:

- Provide background and product information.
- Outline selling unit packaging materials.
- Supply information on transport packaging materials (packaging discarded at retail location after delivery).
- Provide additional information related to percentage of renewable energy use and manufacturing innovation.
- Review answers to verify inputs prior to submission.
- Calculate score for each sub-section (the nine metrics outlined above) where results are displayed as raw scores calculated for the previously discussed equations. Ranking is also provided, which is expressed as a percentage vs. competition in a product category. Finally, a total normalized score is provided where higher scores are better.
- The last step of this process includes modeling improvements if software has been purchased and submission to Wal-Mart.

In conclusion, the implementation of the scorecard system had many benefits: It enables Wal-Mart to track the progress toward their goals of reducing packaging used by their suppliers by 5% in 2013. Furthermore, this system allows Wal-Mart to estimate cost savings resulted from packaging changes (Zettlemoyer-Lazar 2007). For example, their recent efforts in reducing the packaging size of Wal-Mart toy brand, Kid Connection, the company not only realized monetary annual savings of US$ 2.4

million in transportation, but equally important was able to save 3,800 trees, which is good for the environment. Moreover, Wal-Mart had another goal of cutting their bag waste by one-third (9 billion plastic bags per year which is equivalent to more than 135 million pounds of solid waste) by 2013. Once realized, this would reduce CO_2 emissions by 290,000 metric tons per year and the energy consumption of 678,000 barrels of oil. It should be emphasized that this system ensures that customers are in a better position to make more sustainable purchasing decisions (Nandagopal and Sankar 2009).

This system allowed Wal-Mart to make decisions on suppliers' selection based on Quantifying packaging changes. Overall, this is a compelling case to oblige manufacturers to revisit their packaging practices and efforts to reduce them. Considering their mega scale, Wal-Mart's efforts are rerouting and expediting the process of transforming industries around the globe and enforcing manufacturers' commitment to embrace product innovation and adapt to more transparent supply chain to ensure sustainable development. Notwithstanding these advantages, Wal-Mart scorecard is rather a 'best practices' summary that is incapable of precisely determining the environmental impacts posed at all packaging life cycle stages; since it appears to be biased toward ensuring efficient use of available space of their stores and trailer fleets.

It should be emphasized that Wal-Mart is a member of the Sustainable Packaging Coalition (SPC), which was established in 2003 with an aim of transforming packaging system into a more sustainable and prosperous industry.

4.13.1.10 Global Reporting Initiative (GRI)

In 1997, Coalition for Environmentally Responsible Economics "CERES" a non-profit organization with membership of leading social investment professionals, environmental groups, religious organizations, pension trustees and public interest groups partnered with United Nations Environment Programme (UNEP) and launched GRI. This is a broad based framework that helps companies to integrate sustainable development in their business strategies and management processes. GRI is composed of guidelines that standardize environmental reporting with a set of generic indicators for industry. Subsequently, 20 organizations released sustainability reports based on these guidelines. In general, these standardized guidelines would make cross comparisons among companies more amenable. GRI utilizes a hierarchical framework based on the three dimensions of sustainability i.e. economic, environmental, and social (Figure 4.17). For the economic aspect; GRI covers organization's direct economic value such as employee wages, benefits, compensation, job creation, training, expenditures on activities due to climate change, expenditures on research and development, traditional financial information, other community investments and forms of human capital.

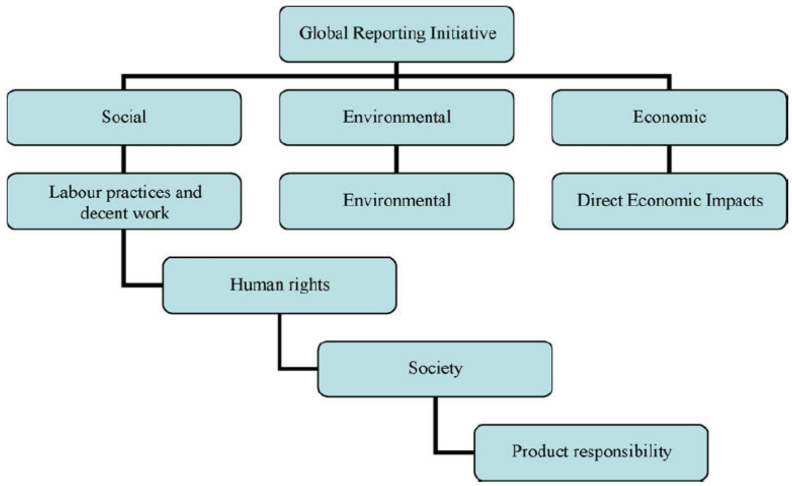


Figure 4.17: The Hierarchical structure of GRI framework.

For the environmental aspect, GRI covers companies' progress toward providing energy efficient products, the use of recycled input materials, energy/water conservation, efficiency improvement, habitat protection and restoration, and assessment of the organization's impact of its current practices on surrounding area biodiversity, air, water, land, and human health and welfare.

For the social aspect, GRI focuses on assessing the companies' progress toward the implementation of their practices toward anti-corruption policies and their contributions to public policy development and lobbying. It also measures the impacts of the companies' products and services in all life cycle stages on the health and safety of their customers. Furthermore, GRI considers other relevant indicators that focus on employee retention, human rights and diversity. Companies are not expected to cover all the elements and aspects of reporting listed above. However, they are expected to broaden their reporting elements and aspects over time to reflect their commitment to sustainability and its positive impact on their industries. Furthermore, the GRI recognizes that each sector will have to develop additional, sector-specific indicators that reflect individual characteristics of different types of industrial activities. For example, in 2004, Azapagic developed a framework that comprises economic, environmental, social and integrated indicators for metallic, construction, and industrial minerals. His proposed framework is consistent with the general guidelines of GRI and allow cross comparison among companies in the metallic, industrial minerals and construction industries.

GRI has many advantages, for example it provides an overall picture of the companies' sustainability practices by integrating the three aspects sustainability. This enables better decisions on investments, purchases and partnerships. It also evaluates and improves the companies' progress toward the implementation of sustainable development. Furthermore, Consistent and continuous application of GRI guidelines in reporting improvements toward sustainable development promotes transparency and credibility. In addition, it provides stakeholders with a format of information of their interests that is easy to comprehend yet reliable.

GRI has certain limitations that would challenge its utility. For example, its elements are both high level and general that lack details needed in measuring sustainability. This undermines its use in differentiating companies' progress toward sustainability. Due to the presence of regulatory requirements and mandates, companies tend to provide more detailed reporting on environmental rather than social and economic elements of sustainability. Unfortunately, participation in reporting companies' progress toward sustainable development using this initiative is voluntary.

In conclusion, the sustainability efforts by Wal-Mart, Interface, and other leading companies led to cost savings that increased the companies' profits, financed these initiatives, and equally important reduced the companies' potential negative impacts on the environment. In addition, sustainability reporting such as GRI plays a key role in promoting the concept of sustainable development and practices. Overall, these efforts provide motivation to establish rewarding relationship between business and environment. This clearly demonstrates that profit and sustainability can co-exist and be achieved.

4.13.2 Other Industrial Sustainability Measures

Various research groups continue to invest in developing sustainability measures that focuses on the diverse aspects of industry, such as production systems and production systems supply chain (Koopmans 1951; Jenkins and Anderson 2003; Nardo, Saisana et al. 2005; Adler and Yazhemsky 2010; Gower 2012). For example, Ragas *et al.* highlighted the need to develop sustainability measure for production systems, which would also consider all forms of environmental pressure into the assessment. They developed a tool that is comparable to the principles of LCA and determined the social and scientific barriers that should be overcome to better understand and evaluate the sustainability of production systems (Gower 2012). Furthermore, a research group at The Lowell Center for Sustainable Production at the University of Massachusetts Lowell developed a framework that is used to classify sustainability indicators. It consists of five levels which are: Facility Compliance/conformance, Facility Material Use and Performance, Facility Effects, Supply Chain and Product Life-Cycle, and Sustainable Systems. The group suggested twenty-two core indicators with detailed outline on their application, a guidance for selecting additional, production-specific indicators and an eight-step model for their implementation. Indeed, the purpose is to provide a method that determines a selected set of indicators ability to enable decision-making and assess progress to attain sustainable production. It is interesting to note that this framework was implemented in training workshops to increase awareness; and build skills of participants (Koopmans 1951; Nataraja and Johnson 2011).

Hutchins *et al.* noted the importance of developing frameworks to measure corporate social sustainability and incorporate this dimension in measuring overall sustainable development throughout the supply chain. The group presented new frameworks and tools that better define the social dimension of sustainability such as the use of category hierarchy for a social life cycle analysis and technique to integrate various measure of social performance into one single sustainability index to improve business decision-making (Nardo, Saisana et al. 2005).

4.13.3 Conclusions

The major sustainability measures adapted by countries and industrial institutions have been reviewed in this Chapter with respect to their definition, application, valuation methodology and their strengths and limitations. Despite, the scientific research that was conducted to establish these indices, there is no general consensus on a sustainability index that would replace or subsume GDP as an assessor of progress in economic and sustainability terms. This is partially attributed to the fact that sustainability is basically a complex system that incorporates many dimensions. This has led researchers to develop over-simplistic single value measures to evaluate and describe such complexity and allow for easy comparison among countries and institutions– however this leads to a de-valuation of sustainability impacts and buries hidden costs. Another contributing factor is there are also fewer consensuses on how to assess the ecological and human well being from a conceptual as well as a quantitative stand point.

Recent efforts to attain sustainability by Wal-Mart, Interface, and other leading companies led to cost savings that increased the companies' profits, financed these initiatives, and equally important reduced the companies' potential negative impacts on the environment. In addition, sustainability reporting such as GRI plays a key role in promoting the concept of sustainable development and practices.

Finally, the recent rise in acceptance of both Ecological Footprint and Carbon Footprint as widely used metrics for both countries and industrial institutions for measuring sustainability allows for a common currency, but with considerable limitations in particular from the economic and social aspects of sustainability. In spite of the diverse range of metrics implemented, the need for a multidimensional metric, which incorporates measurements that can be applied on the level of countries and industrial institution, made by GDP, CF and HDI is still unmet and the development of such a metric remains a challenge for the scientific community.

CHAPTER 5: G-20: An Assessment of its Progress toward Attaining Sustainability Using Major Indices

5.1 Introduction

As reviewed in Chapter 4, researchers have developed numerous sustainability indices e.g., Ecological Footprint (EF) (Wackernagel and Rees 1996), Human Development Index (HDI) (Amartya 2000), Index of Sustainable Economic Welfare (ISEW) (Daly 1996), Environmental Sustainability Index (ESI) (Esty, Levy et al. 2002; Esty, Levy et al. 2005), Genuine Savings (GS) (Pearce and Atkinson 1993), that aim at measuring sustainable development in quantifiable terms and guide policy makers on the progress and effectiveness of adopted strategies to improve a country's overall sustainable development. They act as pivotal tools in the assessment of the progress of strategies adapted to attain sustainability. While valid, each evaluated sustainability index has its own disadvantages that limited its use. Table 4.5 lists the attributes that should be considered to develop an index that successfully measures progress of nations toward environmental, social and economic sustainable development.

In this Chapter, the progress toward sustainable development for the G-20 countries (Table 5.1) was assessed. It should be emphasized that around 80% of international global-trade and 90% of the gross world product are generated by the G-20 countries. Moreover, these economies account for two thirds of the world's population (G20 2013) with 84% of the global fossil fuel emissions is produced by the G-20 countries. While, 66% of the planet's biocapacity lies within their territories, by 2007, they had used 95% of the planet's total biocapacity in order to generate their economic output and consumed nearly all the natural resources that the planet is capable of replenishing each year (Gower, Pearce et al. 2012; G20 2013).

In 2010 at the Seoul G-20 Summit, G-20 countries leaders declared their commitment to 'green growth,' where prosperity is achieved without compromising our planet's ecosystem. However, these countries vary in their ability to deliver on this obligation. For example, only four G-20 countries have reduced their carbon emissions since the Rio Summit in 1992: Russia, Germany, France, and the United Kingdom (Gower, Pearce et al. 2012; G20 2013).

As outlined earlier, the G-20 group is the major driving force for the world economy overall, human development and impact on the environment. Indeed, the interest in these countries is particularly relevant when we consider their projected fundamental role in the global economy growth over the next 40 years. Projections of growth for the foreseeable future don't suggest that the composition of the G-20 group will change substantially. However, the relative order of the countries may change yet they will as a group continue to cast an oversize shadow on the planet and its progress. Therefore, the policies of this group toward sustainable development will not only have a decisive influence on the global human development (Gower, Pearce et al. 2012), but this group will also serve as the models by which non G-20 countries seek progress.

This Chapter has two objectives. The first is to assess the impact of G-20 countries consumption and their progress toward sustainable development using a retrospective analysis from 1996-2008 of known sustainability indices. These measures are currently the only available tools in the assessment of the progress of strategies adapted by nations to attain sustainability by enforcing cleaner production and consumption. Secondly, this Chapter proposes a new approach that measures the progress and effectiveness of adopted strategies of countries toward sustainable development based on a set of minimum requirements needed to attain sustainable development and are consistent with the United Nation's new sustainability goals proposed in 2012. This is illustrated by investigating the interplay among major sustainability measures to assess the G-20 countries progress toward sustainability.

5.2 Methodology

Since the inception of GDP, there has been a continuous interest in developing sustainability measures that assess the progress made toward achieving sustainable development (Charnes, Cooper et al. 1984). For reason stated earlier, this is particularly important when the focus is on the leading G-20 countries. In this Chapter, the indices that were chosen are the GDP (year 2011), EF (year 2008), HDI (year 2011), and the Happiness Index (HPI) (that was calculated by Gallup based on data collected between 2005 and 2012).

In this research HDI, EF and HPI used as tools to measure the human well-being and the impact of adopted countries policies on the planet's ecosystem (Moran, Wackernagel et al. 2008). HPI is a new measure that is considered by researchers and policy makers as a pivotal tool in assessing the well-being of a country's constituents. It is generally believed that happiness and the well-being of people are critical drivers for economic prosperity. HPI is also favored by many policy makers. The indices considered (GDP, EF, HDI) were reviewed in Chapter 4, while, the Happiness Index (HPI) is discussed below.

5.2.1 Happiness Index (HPI)

There is a growing body of evidence in the literature that relates people's happiness to economic progress and prosperity. This has led to a growing interest by policy makers and media in measuring happiness. For example, Diener and Suh pointed out that "subjective well-being measures are necessary to evaluate a society, and add substantially to the economic indicators that are now favored by policy makers" (Diener and Suh 1997).

At the United Nations Conference on Sustainable Development held in Rio de Janeiro in June 2012 (Rio+20), the member states agreed to develop a new set of Sustainable Development Goals that would replace the Millennium Development Goals targeted to end in 2015. These goals are based on four tenets:

1. Economic development inclusion that would end extreme poverty by 2030: this would be pivotal in improving happiness.
2. Environmental sustainability: this will be the cornerstone for attaining sustainable use of available resources at both ends of our planet i.e. material extraction and landfills.
3. Social inclusion: this is the commitment of societies that the benefit of technology, good governance, and economic prosperity will not be limited only to certain people and will be available to every person regardless of age or gender.

4. Good governance: this is the ability of society to act collectively through true participation in political institutions to realize the happiness that is achieved with active political participation, human rights protection, women's empowerment and freedom.

Overall, these are specific, measurable and realistic goals, and achieving them is key in realizing happiness for all people regardless of their age, gender, ethnicity, and background. Therefore, it is paramount to have an index that measures progress made toward attaining happiness based on the four tenets discussed earlier.

It is intriguing to note that researchers have argued that while happiness is indeed a subjective experience, it can be objectively measured (Helliwell, Layard et al. 2012). In 2012, the World Happiness Report (Helliwell, Layard et al. 2012) discussed the state of world happiness, the causes of happiness and misery, as well as impact of implemented policies on happiness status. Moreover, it provided an assessment of the happiness state of countries around the world using four surveys: Gallup World Poll (GWP), World Values Survey (WVS), European Values Survey (EVS), and European Social Survey (ESS); when GWP was compared with the other three surveys, strong correlations were noted. GWP has the largest coverage of world countries: it is based on evaluating the quality of 1000 respondents' life based on an 11-point scale running from 0-10 from years 2005-2011. The core questions asked include: business and economics, citizen engagement, education and family, food and shelter, environment and energy, government and politics, communications and technology, law and order, religion and ethics, health, social issues, work, well being. These questions provide a perspective on progress made by the country toward sustainable development goals based on the four pillars discussed earlier. A cutoff value of 7 was predetermined by Gallup for the country to be considered happy.

5.3 Results

5.3.1 Retrospective Analysis of Major indices for the G-20 Countries

Figures 5.1, 5.2, and 5.3 illustrate a retrospective analysis of the G-20 GDP/capita, EF/capita, and HDI, respectively. It is noteworthy to point that the data were presented for the average values of these indices for developed and developing countries separately. This is to ensure clarity of the illustration. In addition, we noticed that the trend over the time period investigated is consistent among the individuals of each group for the three indices (Table 5.1). Combined, the GDP/capita of those major economies grew by two folds from 1990 to 2012. China realized the highest increase in the GDP/capita (approximately 5 fold), while Japan had the lowest increase in GDP/capita, which mostly remained constant. Interestingly, the developed countries among the G-20 group realized only 1.75 fold increase on average, and developing countries had 2.6 fold increase on average.

The G-20 countries' EF/capita decreased by 25% between 1996 and 2008. However, developing countries had only 11% decline on average; the United States had the highest decline in EF/capita, accounting for 40% reduction. Mexico realized the largest increase in the EF/capita (25%).

China had the highest increase in the HDI (35%), while South Africa is the only country that realized rather a decrease in its HDI that accounted for -1.2% between years 1996 to 2008. It should be emphasized that developed countries yielded an HDI increase of 10.8 % on average; however, developing countries had 18.8 % increase on average.

Table 5.1: GDP, Ecological Footprint, HDI, and HPI data used in this research.

Country	Class	HPI 2010-2012	HPI 2005-2007	GDP per Capita 2012 ($)	Total EF 2008	EF/W.Biocapacity 2008	HDI 2012
World	□	5.33	5.30	10291	2.70	1.52	0.69
Australia	Developed	7.35	7.31	67442	6.68	3.75	0.94
Canada	Developed	7.48	7.45	51206	6.43	3.61	0.91
European Union	Developed	6.36	6.48	32969	4.72	2.65	0.88
France	Developed	6.76	6.81	39772	4.91	2.76	0.89
Germany	Developed	6.67	6.51	42625	4.57	2.57	0.92
Italy	Developed	6.02	6.71	33837	4.52	2.54	0.88
Japan	Developed	6.06	6.37	46731	4.17	2.34	0.91
South Korea	Developed	6.27	5.54	22590	4.62	2.60	0.91
United Kingdom	Developed	6.88	6.89	38920	4.71	2.65	0.88
United States	Developed	7.08	7.36	51749	7.19	4.04	0.94
Argentina	Developing	6.56	6.19	11573	2.71	1.52	0.81
Brazil	Developing	6.85	6.48	11340	2.93	1.65	0.73
China	Developing	4.98	4.72	6091	2.13	1.20	0.70
India	Developing	4.77	5.15	1503	0.87	0.49	0.55
Indonesia	Developing	5.35	5.02	3557	1.13	0.64	0.63
Mexico	Developing	7.09	6.55	9749	3.30	1.85	0.78
Russia	Developing	5.46	5.12	14037	4.40	2.47	0.79
Saudi Arabia	Developing	6.48	7.17	25136	3.99	2.24	0.78
South Africa	Developing	4.96	5.14	7352	2.59	1.46	0.63
Turkey	Developing	5.35	5.17	10666	2.55	1.43	0.72

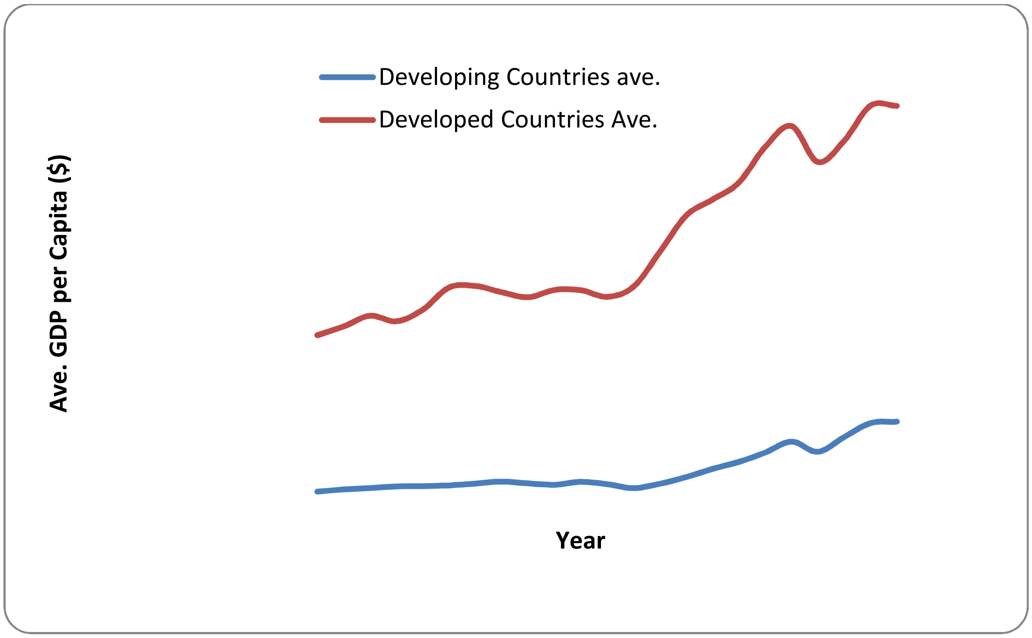


Figure 5.1: Comparison of GDP/capita among G-20 countries illustrated as the average values for developed and developing countries over a time period of 1990-2012**.**

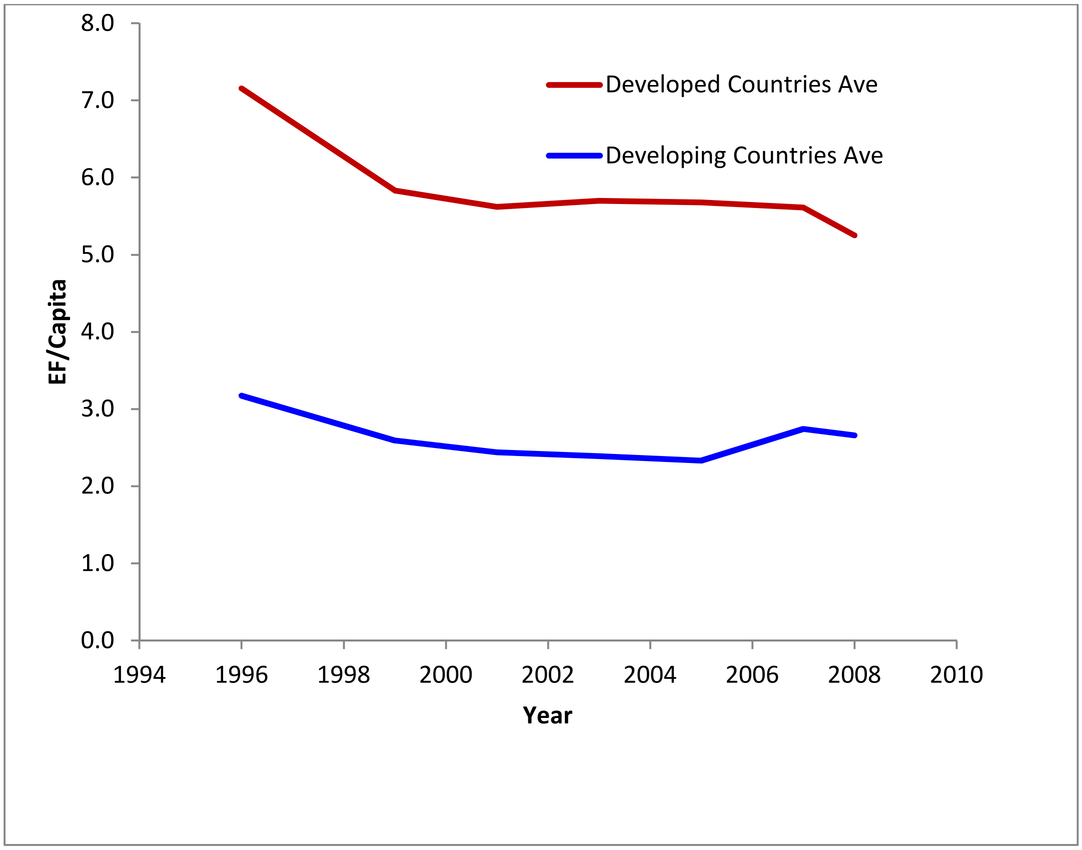


Figure 5.2: Comparison of EF/Capita among G-20 Countries illustrated as the average values for developed and developing countries over a time period of 1996-2008.

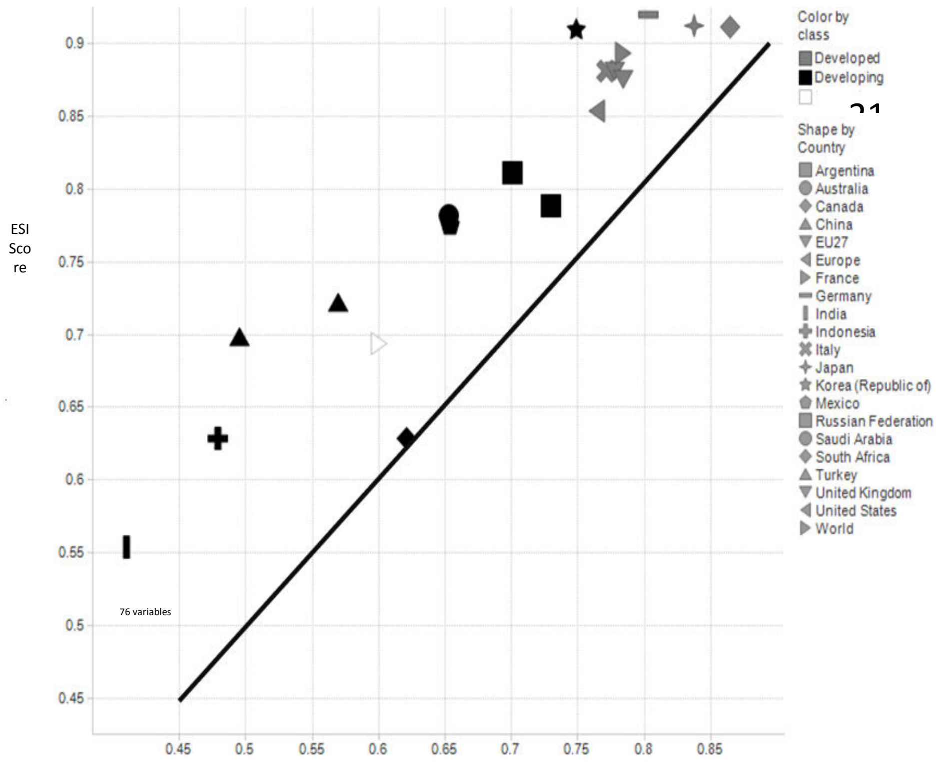


Figure 5.3: The relationship between G-20 Countries HDI 1990 and 2012 values. The line of unity assuming HDI 1990 equals HDI 2012.

5.3.2 Interplay among Major Sustainability Measures and Assessment of G-20 Countries Progress toward Sustainability

Figures 5.4 to 5.9 illustrate the relationship among the four measures considered in this research. Figure 5.4 depicts the relationship between GDP/capita and EF/capita normalized to globally available biocapacity/capita (EF/W.Biocapacity) for the year 2008. This is the latest available data for the ecological footprint for the G-20 countries. The vertical line represents the cutoff value for the EF/W.Biocapacity ratio. It provides a useful indicator of the country ecological sustainability; it measures the minimum number of Earth-equivalent planets that would be required to support the current human population if the given country's level of consumption were universal. Overall, increasing countries' GDP/capita is associated with an increase in EF/W.Biocapacity ratio. However, countries' GDP/capita varies even if the countries have similar ecological footprints. It is worth noting that India and Indonesia are the only G-20 countries that have EF/W.Biocapacity ratio less than 1 rendering them ecologically sustainable. However, the rest had EF/W.Biocapacity ratios higher than 1 suggesting that their practices and policies are not ecologically sustainable.

Figure 5.5 demonstrates the relationship between GDP/capita and HDI for the year 2011 for the G-20 countries. The vertical line represents the cutoff value of 0.80; this is pre-determined by the UNDP for a country to be considered developed. This figure shows that increasing a country's GDP/capita is associated with an increase in HDI. G-20 countries with the highest GDP/capita (i.e. > $20K) tend to have highly developed economies with advanced technological infrastructure. In contrast, developing countries tend to have manufacturing-based economies (e.g. China and

India) or economies driven by natural resource extraction and depletion (e.g. Saudi Arabia and Russia) (Table 5.1).

Figure 5.6 illustrates the relationship between HPI and GDP/capita of the G-20 group. The vertical line represents the cutoff value of 7 that is suggested by the Gallup Organization for a country to be considered happy. It demonstrates that increasing HPI is not always associated with an increase in GDP /capita.

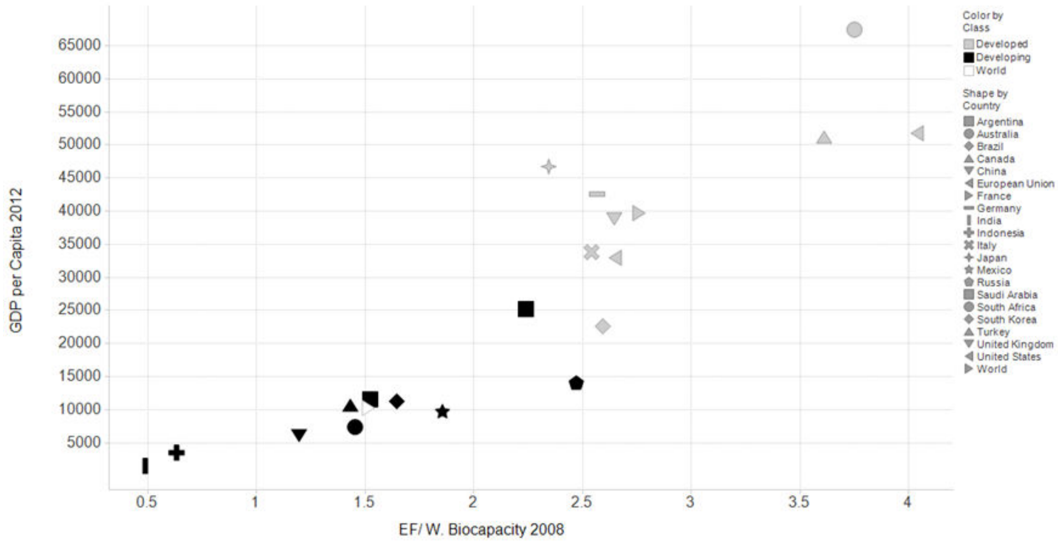


Figure 5.4: The relationship between GDP/capita 2012 and EF/W.Biocapacity 2008 of G-20 group.

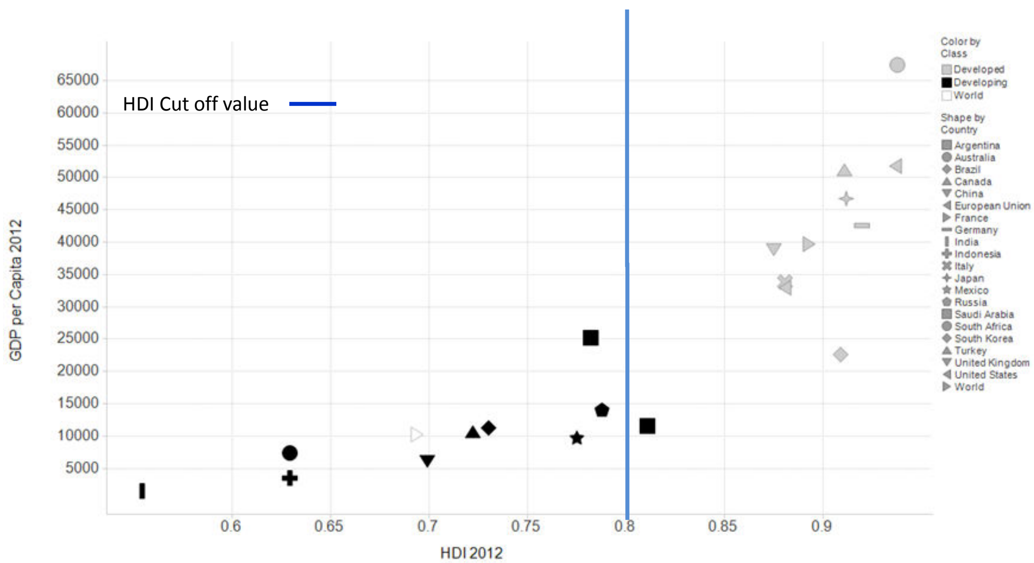
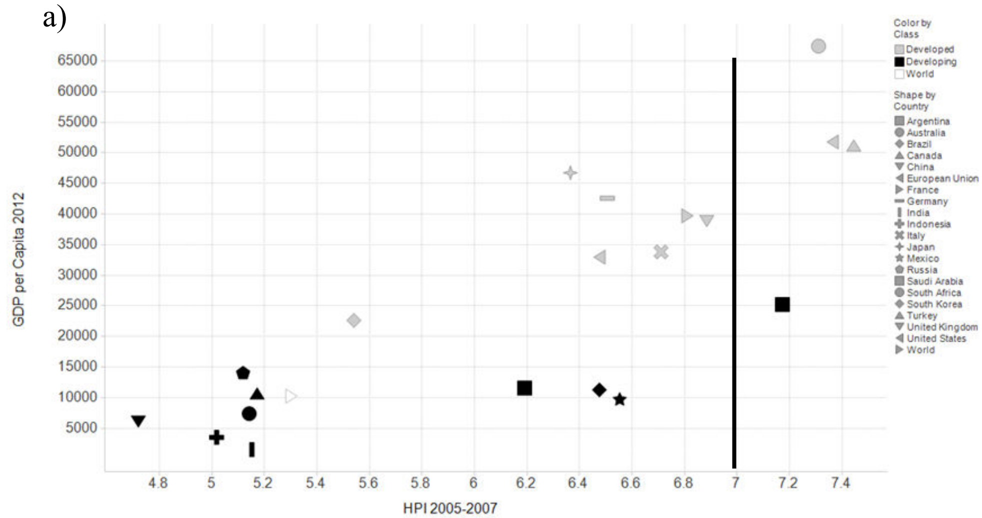


Figure 5.5: The relationship between GDP/capita 2012 and HDI 2012 of G-20 group.

a)



b)

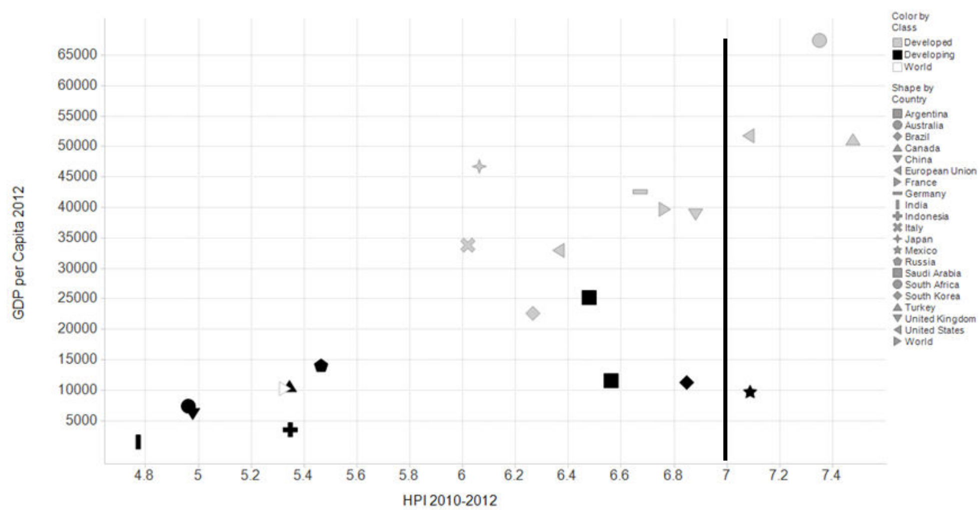


Figure 5.6: The relationship between GDP/capita 2012 and HPI of G-20 group.

Figure 5.7 shows the relationship between EF and HDI for the G-20 countries. The vertical lines represent the cutoff values of 0.80 and 1.00 for the HDI and EF indices, respectively. India and Indonesia were the only 2 countries that are considered ecologically sustainable (EF/W.Biocapacity ratio< 1). On the other hand, 11 countries of the G-20 group had a HDI value greater than 0.80 and were considered developed. Increasing EF is associated with an increase in HDI and this not unexpected since both indices have a positive relationship with the GDP.

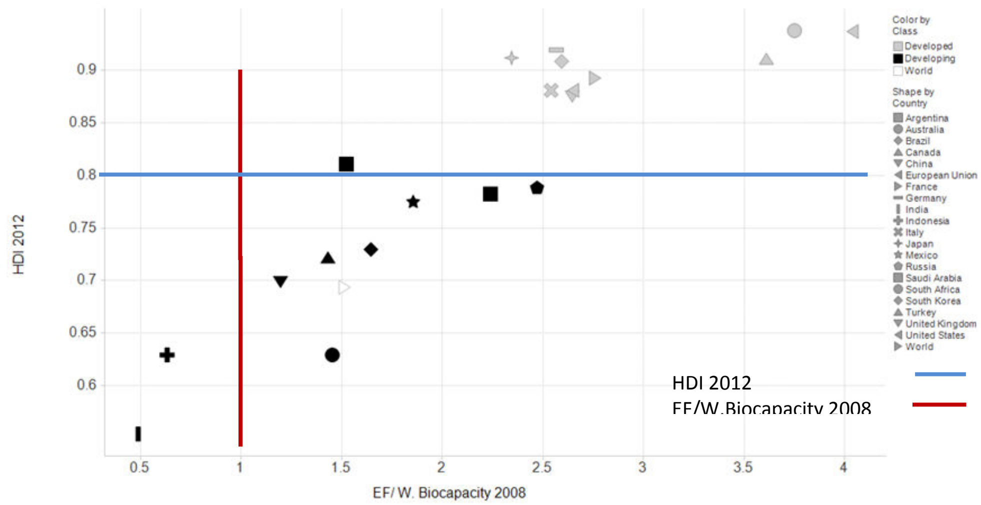


Figure 5.7: The relationship between HDI 2012 and EF/W.Biocapacity 2008 of G-20 group.

Figures 5.8 and 5.9 demonstrate the relationships among EF/W.Biocapacity vs. HPI and HDI vs. HPI for the G-20 group, respectively. Increasing EF/W.Biocapacity is not always associated with an increase in the HPI. There are only four countries that are considered happy (Australia, Canada, USA, and Mexico) and only two that are ecologically sustainable (India and Indonesia). Therefore, there is no G-20 country that is both happy and ecologically sustainable.

There are only 3 countries that can be considered both developed and happy (i.e. Australia, Canada, USA). Overall, the lack of strong correlation between HDI/EF/Bio and HPI is in concordance with the positive relationship of the two measures with the GDP but not the HPI.

Furthermore, the interplay among the three measures used in this work is proposed as the minimum requirements to attain sustainable development for the G-20 countries. These limits are based on the boundaries of the measures discussed earlier. This paradigm is consistent with the new goals called by United Nations. For the country to be considered sustainable under this definition, it should lie in the area that is bounded by the limits where HDI is higher than 0.80, EF/W.Biocapacity is less than 1, and HPI is greater than 7. Interestingly, there is no G-20 country that simultaneously achieved these goals.

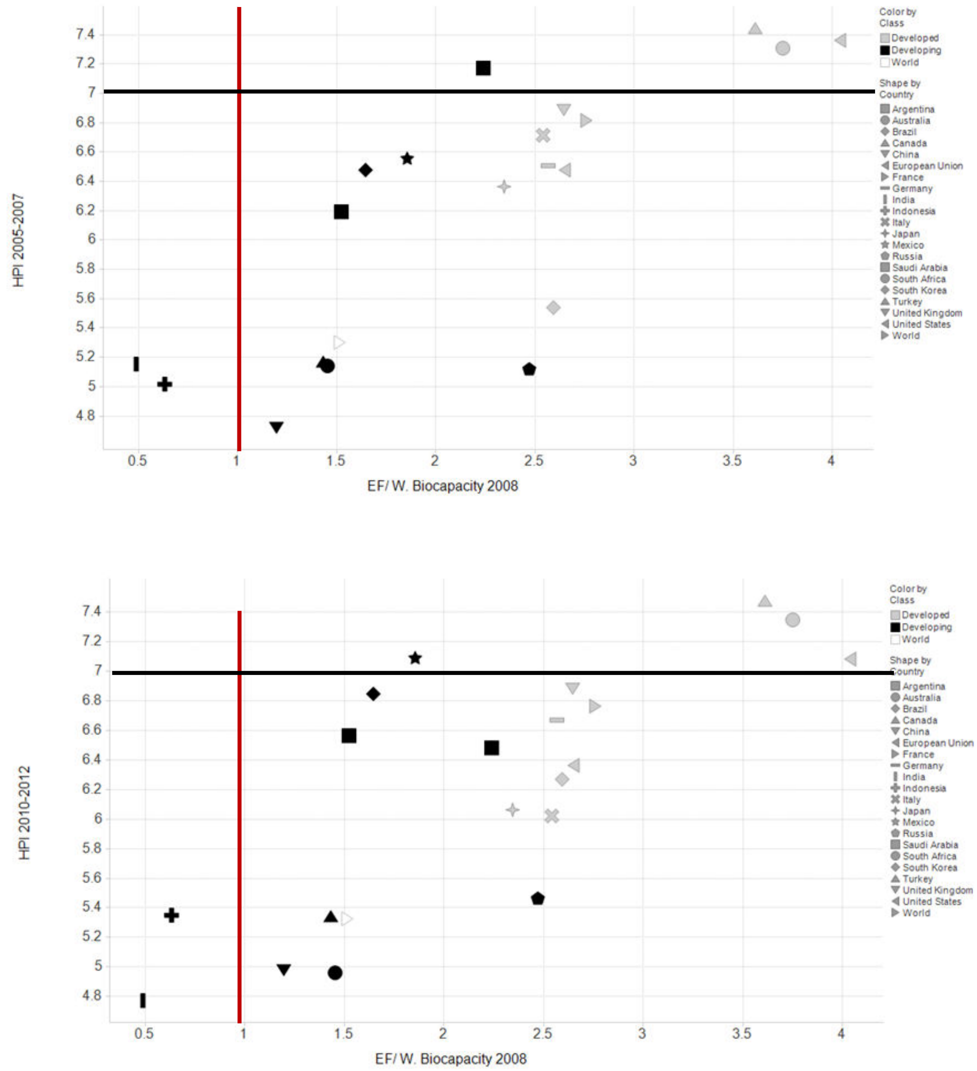
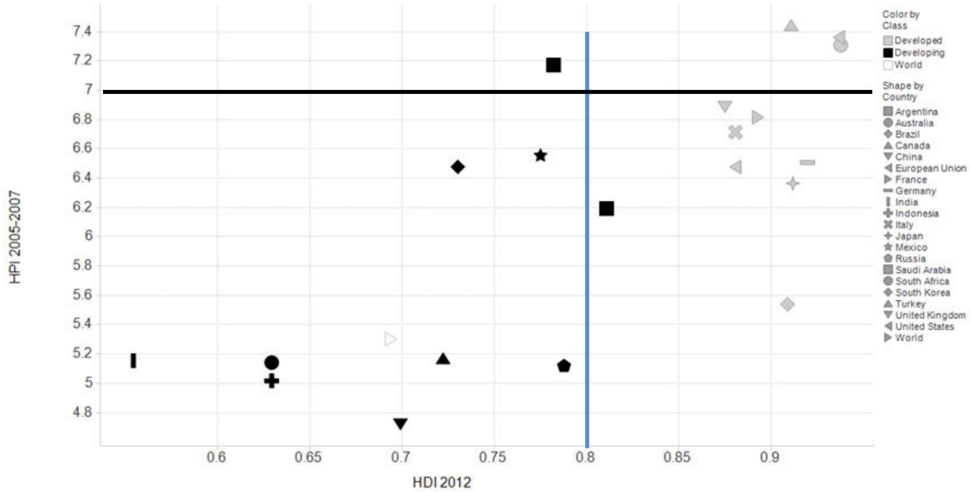


Figure 5.8: The Relationship between HPI and EF/W.Biocapacity of G-20 Group.

a)



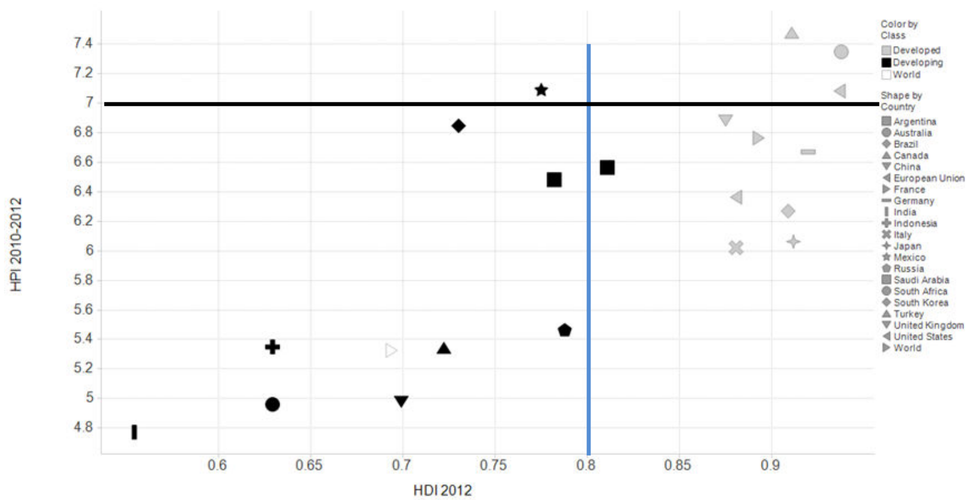


Figure 5.9: The relationship between HDI and HPI of G-20 group.

5.4 Discussion

GDP is the standard metric for assessing countries economic wellbeing and prosperity. In the last fifteen years, the GDP of the G-20 has increased with a significant difference in the rate of its increase between developing versus developed countries. It should be emphasized that the speed and scale of this growth rate in developing countries is unparalleled in history. For example, it took Great Britain over 150 years and USA 50 years to double their GDP per capita. On the contrary, it took key developing countries such as China and India less than 20 years to achieve that. This is intriguing when we realize that this economic force affected 2 billion people in China and India while fewer than 10 million people benefited from Great Britain and USA growth at the time of industrial revolution (Malik 2013).

Global practices and policies implemented between 1961 and 2011 to grow GDP resulted in a negative deteriorating impact on the planet's ecosystem. This is illustrated by the increase in the global EF from 63 to 151% of total earth's biocapacity (Network 2008). It is well documented in the literature that EF is based on three interrelated factors that are: population size, goods consumption and resource intensity in the production of goods and services (Moran, Wackernagel et al. 2008). For example, China realized a 5-fold increase in its GDP/capita between 1996-2008; this was associated with only a 1.2-fold increase in its EF /capita between 1996-2008 (2.1 gha in 2008). While this is only 80% of the world's average EF/capita (2.7 gha), taking into consideration China's population, China's total EF was 2.9 billion gha. Collectively, this renders it to be the largest EF value in the world. Interestingly, USA's EF/capita was 7.2 gha in 2008, which is significantly larger than that of China.

However, due to USA's smaller population relative to China, USA's total EF is 2.2 billion gha, ranking it 6^{th} in the world. Furthermore, China's population remained relatively constant over the period studied. This was accompanied with a major shift in China's population consumption pattern, which was reflected by the average rate of increase in its EF/capita. Before 2000, the annual rate of increase was 0.02 gha, while after 2000, China had an increase of 0.07 gha (Gaodi, Shuyan et al. 2012). Similar trends are observed in other developing countries where the main driver for their GDP growth is their domestic market that is based on consumption. It is projected that the growth of their middle class size and income will increase to $30 trillion by 2025. As a result, the share of countries amount three-fifths of the 1 billion households' income of greater than $20,000 a year. This is projected to further exacerbate the impact on our planet's ecosystem and increase global EF unless major changes in consumption patterns are adapted (Malik 2013).

HDI is the widely accepted measure for the assessment of a country's progress toward human development. It is interesting to note that the rate of increase of HDI was greater for developing than developed countries. Many factors may have contributed to this phenomenon. For example, the developing countries doubled their economic output within 20 years. They also increased their contribution to the global output from 33% in 1990 up to 50%. The leading eight developing economies (Argentina, Brazil, China, India, Indonesia, Mexico, South Africa and Turkey) were able to increase their GDP from half of that of United States in 2005, where now it equals the GDP of the United States. These efforts played a prudent role in eradicating poverty and increasing the size of the middle class. For example, leading emerging economies such as China, India, and Brazil were able to substantially decrease the percentage of their people who are below the poverty line from 60.2%% of the population in 1990 to 13.1% in 2008, from 49.4% % of the population in 1990 to 32.7% in 2010, and from 17.2% of the population in 1990 to 6.1% in 2009, respectively.

Overall, developing countries were successful in expediting their achievements in both health and education. This is a natural outcome of their spending on education and health. For example, their investment in education increased over the entire period, on average by 658% between 1995 and 2012. For developed countries, the spending increase was lower, on average of 224% over the same period.

It should be emphasized that in term of progress in HDI South Africa was the only country that lagged. This is mainly because of the significant slump in life expectancy observed in South Africa's population due to the HIV/aids pandemic, which is one of the main variables that are used in HDI methodology. Moreover, HDI increase was more substantial for developing over developed countries (CDC 2006).

Significant trends were observed among the four measures studied. For example, a country's increase in GDP/capita is associated with an increase in its EF/W.Biocapacity ratio. However, for G-20 countries GDP/capita may still vary even when they have similar ecological footprints. For example, Japan and USA have a similar GDP/capita ($46,134 and $48,112, respectively), while their EF/W.Biocapacity ratios widely differ (2.343 and 4.039, respectively). These differences are driven by policies that enforce green practices, which encourage reduction in material intensity, increase in rates of recycling/reusing, and adaption of environmentally-friendly technologies (Krantz, Shellaby et al. 2011). In 2013, Japan substantially increased their investment in renewable energy by 80% relative to 2012 levels. This coincided with a global downward trend in world investment in this green practice (Zervos 2014). This underscores Japan's role as a leading country in developing and adapting climate -friendly technologies, and they ranked as one of the top 30 countries based on the Environmental Performance Index (EPI) in 2014. EPI measures a nation's commitment to environmental sustainability. Interestingly, USA is not on this list (Hsu, Emerson et al. 2014).

While, leading developing countries were able to increase their GDP at a pace that is faster than developed countries, their rate of increase in EF/W.Biocapacity ratios was not as fast. It should be recognized that these countries are developing and implementing environmentally-friendly technologies. For example, China is the 4th largest country in the production of wind energy in 2008. It is also the world's largest producer of wind turbines and solar panels. In 2011 and consistent with their national solar mission, India increased their investment in solar energy production by 62%, which is equivalent to $12 billion rendering it the fastest expansion in the renewable energy market. Brazil made an overall investment of $7 billion, an 8% increase over the year before. Similar to the trend observed between GDP/capita and EF/W.Biocapacity ratio, an increase in HDI is associated with increase in GDP per capita. This is consistent with the criteria described earlier. It is interesting to note that high HDI (>0.80) is a prerequisite for countries to be identified as developed, and all such countries have economies that are post-industrial and driven by information technology and service sectors (Malik 2013).

Unlike the trend observed with EF/W.Biocapacity ratio and HDI, increasing HPI is not always associated with an increase in GDP/capita. For example, Mexico (7.088) has a comparable happiness index to that reported for the US (7.082), while its GDP/capita is 5-fold lower than that reported for the US. Many policies adapted by government of Mexico played a prudent role in increasing the people's happiness. In 2003, government of Mexico adapted a public health insurance that ensures access of poor households to comprehensive health care who traditionally been excluded (Frenk, Gómez-Dantés et al. 2009) . Furthermore, the government adopted public education policies that ensured access to lower income for education of reasonable quality (Argyl 2001). Equally important, Mexico has broad social inclusion in its democratic life, which is substantiated by a high voter turnout for the top and bottom 20% of the population (OECD 2013). Overall, Mexico provides a good example of a state with limited resources, yet with good governance body that continues to adopt policies aimed at keeping their people happy.

G-20 countries such as South Africa, China and India have the lowest HPI and GDP capita values. This is thought to be attributed to major differences in income, high unemployment, poor gender equality, and poor governance (Helliwell, Layard et al. 2012).

Indeed, this accentuates the traits of the HPI measure in complementing GDP/capita that has a well recognized limitation as a measure of well-being. Using

HPI provides a better assessment of the progress of countries toward attaining the Sustainable Development Goals proposed by the United Nations. This is mainly attributed to its overall comprehensive methodology discussed earlier.

A strong positive relationship was observed between HDI and EF. One of the main attributes of both indices (the EF and HDI) is their dependence on GDP where an increase in GDP is associated with an increase in the values of these indices as reported in the literature. For example, India and Indonesia reported the lowest GDPs among the G-20 countries and as noted earlier they have the lowest EF/W.Biocapacity and HDI. Only India and Indonesia had an EF/W.Biocapacity < 1 while 11 out the 20 countries had an HDI value higher that the HDI cut-off value (0.80). Indeed, there is no G-20 country that has a high HDI (>0.8) and is ecologically sustainable (EF/W.Biocapacity < 1). The consequences of this trend are dire; present human development is happening at the expense of future generations, a theme that is inconsistent with the principles of sustainability. Furthermore, 2013 HDI report projected that if today's environmental challenges are not addressed with appropriate global policies, this will lead to a devastating impact on agricultural production, improved sanitation and, access to clean water to name a few. Under the "base case" scenario, this will lead to a reduction of 8% of the average global HDI value by 2050. On the other hand and under a more severe "environmental disaster" scenario, the average global HDI value will be even lowered by 15% below the "base case" scenario. Interestingly, both South Asia and Sub-Saharan Africa would realize 22% and 24% reduction in their HDI, respectively. This will undermine the achievement and progress made for human development over the course of decades.

Increasing EF is not always associated with an increase in the HPI. A higher HPI value does not necessarily lead to higher negative impact on the environment. A similar trend is observed between HDI and HPI. Only Australia, Canada, and USA have an HPI value higher than the HPI cut-off value (7.0) and HDI values higher than 0.8. The poor relationship reported between the two indices is attributed to major differences in their methodologies. For example, HDI only relies on assessing the social, economic aspect of the countries, while HPI further integrates the assessment of gender equity, citizen engagement, law and order, religion and ethics and other variables that reflect the quality of life and well-being of the country's constituents (Hicks 1997 ; Helliwell, Layard et al. 2012). These pivotal differences are key drivers for the interest in the HPI as a viable tool to assess progress toward human development.

Our research advocates that the interplay of the three indices discussed earlier, i.e. EF, HDI, and HPI, is necessary in assessing the progress of countries toward achieving the Sustainable Development Goals proposed by the United Nations. It is worth bearing in mind that only three countries (Australia, Canada and USA) achieved the minimum requirements to satisfy developed and happy country criteria, while no G-20 country was able to achieve these requirements and be considered with being ecologically sustainable. Thus, considering this proposal, there is no G-20 country that is sustainable. G-20 countries made major progress toward human development for their constituents. However, many of them failed to demonstrate the same achievements on the environmental and happiness levels. These trend calls for these countries to adapt new policies that will address social inequalities, good governance, minimize their environmental risks.

5.5 Conclusions

The G-20 group will continue to be the driving force for the global economic growth over the next 40 years. This is particularly relevant when considering the proposed Sustainable Development Goals by the United Nations targeting around the same time interval. Therefore, their current policies toward sustainable development could have a detrimental influence on the global human development.

Since World War II GDP, as a measure, has dominated economic decision making and public policy. However, it now presents major drawbacks that are pivotal as a guide in the construction of a viable sustainability index. For example, the GDP methodology does not take into consideration environmental damage. Indeed, it considers ecosystem degradation a profit rather than a cost. Furthermore, GDP focuses on activities that would ultimately add to the economic growth without differentiating between “goods” or benefits and “bads” or the societal cost of pollution to the personal development and well-being. For example, GDP shows the social and environmental damage as economic gain when it goes up, the communities’ well-being goes down, and vice versa. Therefore, to appropriately understand the impact of economic activities of a country on ecological boundaries and relevant progress toward human well-being development, this research outlined a new approach to assess progress made toward overall sustainable development based on measures such as EF, HDI, and HPI. Furthermore, these indices comprehensively assess the countries progress toward the recently proposed goals by UN. Interestingly, no single G-20 country satisfied the minimum criteria for countries to be considered developed, and happy as well as ecologically sustainable. This clearly calls for global institutions to revisit economic drivers, consumption behavior, and identify policies that lead to both human development and economic growth, while living within Earth's boundaries.

CHAPTER 6: System's Sustainability Prosperity Assessment

6.1 Introduction

Chapter 4 identified the strengths and limitations of each of the sustainability indices evaluated. They act as pivotal tools in the assessment of the progress of strategies adapted to attain sustainability. While valid, each evaluated sustainability index has its own disadvantages that limited its use. Table 4.6 lists the attributes that should be considered to develop an index that successfully measures the progress of nations toward environmental, social and economic sustainable development. In this Chapter, a new comprehensive evaluation methodology that assesses both the sustainable development and profitability of a "system" is presented as the sustainable prosperity index (SPI) (Figure 6.1). This index is versatile to be applied to a wide range of systems that is not limited to countries and includes industries, services, and products.

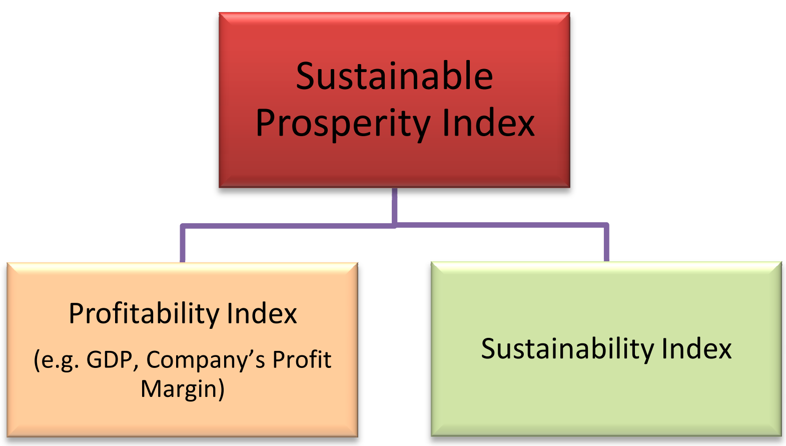


Figure 6.1: Sustainable prosperity index.

The goal is to address the concern that sustainable development is believed by several politicians and policy makers to limit economic progress and prosperity. The aim is to ensure that sustainable progress moves hand in hand with system profitability. Therefore, this tool is structured as a comprehensive index that is based on the aforementioned criteria with keen consideration for system profitability. This leads to the notion that such a measure must be optimized while considering many potentially conflicting criteria and constraints. As outlined in Chapter 4, many of the progress indices treated the three dimensions of sustainability as separate and independent entities, which usually produce a false consensus. Instead, what is required based on the definition of sustainability is a progress measure that integrates the interdependency of the social, economic, and environmental aspects of sustainability. This is based on the concept that there is a constant interaction among these dimensions. The question then is how to appropriately measure sustainability and formalize the desired characteristics of an optimal sustainability index in a mathematically accurate sense.

6.2 System Thinking

System thinking is a principle that is widely used in the study of systems in the medical, environmental, and social fields to name a few; its application in the engineering field was established in 1956 by Professor Jay Forrester from MIT (Aronson 1996). It is a holistic approach to study the inter-relation and dependency of various system's components over time and within the framework of the overall system. It can be defined as "a set of elements mutually related such that the set constitutes a whole having properties as an entity" (Checkland and Scholes 1990). Various entities can be viewed as systems such as, a department in an organization, a company, country, hospital, products such as cars, washing machines and even a nail. A system can be characterized by different attributes (Table 6.1) (Park 1997).

It is noteworthy that the main characteristic of the system is represented by its structure. Here system exists in hierarchy and each sub-system fits in the larger system and has attributes that are unique to it, as illustrated in Table 5.2 (Garner and Keoleian 1995). This renders the system boundaries as an important attribute that should be considered when approaching system sustainability assessment. Overall, this would define the depth and breadth of the assessment to be run to evaluate progress toward sustainable development. For example, researcher can set the boundaries at the top of the hierarchy and then determine if there is a need to further divide the system into smaller sub-components to ensure the quality of the final analysis.

Table 6.1: Attributes of systems as shown in (Park 1997).

Attribute	**Description**
Structure	System that incorporates structures and hierarchy
Boundaries	System that has defined boundaries
Function	System that does a task
Energy	System that requires energy flow
Materials	System that integrates material flow
Equilibrium	Sustainable system requires mass and energy balance
Feedback	Attaining balance requires continuous feedback

Table 6.2: Examples on different system structures i.e. hierarchies (Garner and Keoleian 1995).

Political Entities	**Social Organizations**	**Industrial Organizations**	**Industrial Systems**	**Ecological Systems**
UNEP	World population	ISO	Global human material and energy flows	Ecosphere
U.S. (EPA, DOE)	Cultures	Trade associations	Sectors (e.g., transportation or health care)	Biosphere
State of Michigan (Michigan DEQ)	Communities	Corporations	Corporations/institutions	Biogeographical region
Washtenaw County	Product systems	Divisions	Product systems	Biome landscape
City of Ann Arbor	Households	Product development teams	Life cycle stages/unit steps	Ecosystem
Individual Voter	Individuals/ Consumers	Individuals		Organism

System thinking as an approach has many advantages. For example, it helps in understanding the origin of a problem and why it persists overtime and realizes the inter-relation and linkages among the various systems' components and how they affect the system. It is noteworthy to emphasize that this methodology is different from traditional approaches that are based on de-convoluting the system into various components to better understand their contributions to the system. Thus, instead of identifying smaller parts and their contribution to the system, this approach sees the system as an integrated whole rather than a dissociate collection of elements. This methodology is particularly powerful in effectively studying multifaceted problems that incorporate complexity in their analysis due to significant inter-and intra-dependency among its constituents. Additionally, this approach is widely used when dealing with:

1. Face complex issues which entail multiple components with a goal of understanding the overall picture rather than a section of it.
2. Returning issues that failed to be fixed with previous attempts to solve them.
3. Problems that are affected by the surrounding environment (e.g. natural environment).
4. Issues with no apparent solution.

As discussed in the previous Chapters, sustainability is considered a multidisciplinary, complex and fuzzy concept that is hard to analyze. However, considering current global challenges where environmental conditions are deteriorating and there is a continuous rise in the gap between north and south, a better understanding of sustainability using an approach such as systems thinking is a viable approach. Since it allows investigators and policy makers to understand the origin of a problem, the inter-relation and linkage among various systems' components, and how they affect the sustainability of the whole system in relation to the environment, social and economic systems.

This research contends that to overcome the obstacles that prevent a system from achieving its goal of attaining sustainability, we should have a better understanding of the overall big picture of the various components of system studied with respect to the surrounding environment. Based on that and the fact that sustainability is a complex and fuzzy problem, this research will employ a systems based approach in order to assess the system's sustainability.

6.3 Overview of Guidelines to Scientifically Build an Index

The general guidelines that are adapted to scientifically build an index model are depicted in Figure 6.2 and discussed below in details:

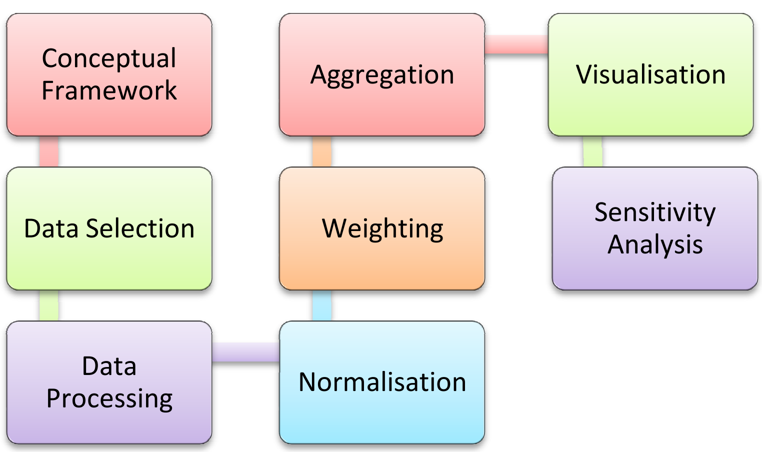


Figure 6.2: Guidelines for a sustainability index model.

6.3.1 Conceptual Framework

The first step of developing a model is identifying the problem studied, defining the key factors, concepts, or variables to be considered. This will also be used to determine the methods to be implemented in building the model. Collectively, this helps in clarifying the model main goal(s) and is used as a guide for data collection and analysis.

SPI is a tool that assesses a system progress (e.g. countries, industries, services, and products) by taking into consideration its sustainability, as reflected by the three pillars of sustainability i.e. economic, social and environmental dimensions and its financial profit.

This dissertation argues that this approach constructs a meaningful assessment of the development toward both system's sustainability and prosperity. It enables decision makers to identify potential improvements in their system that would achieve sustainable development while ensuring system financial profitability. The conceptual framework steps used for constructing the System's SPI that originated from the concepts of life cycle analysis are as follows:

Step 1: Goal Definition and the Identification of the System's Boundaries

The objective of this step is to develop a well defined goal and identify the boundaries of a system to be assessed. The system can be a country, hospital, university, manufacturing plant, a process …etc. As depicted in Figure 6.3, the boundaries have inputs and outputs entering and leaving the system, respectively and they are determined by their selection. Failure to clearly define the boundaries of a given system has major consequences in the overall assessment of system sustainable prosperity. The inputs represent resources such as raw materials used, people (population in a country), and energy consumed…etc. that are used to satisfy system needs/wants and have an ultimate impact on the outcomes of the system studied. They are transformed to become outputs that feed into the sustainability components either as indicators or combined to make indices. When aggregated, they would assess the system's SPI. Therefore, boundaries selection is detrimental in the calculation and reliability of the final score.

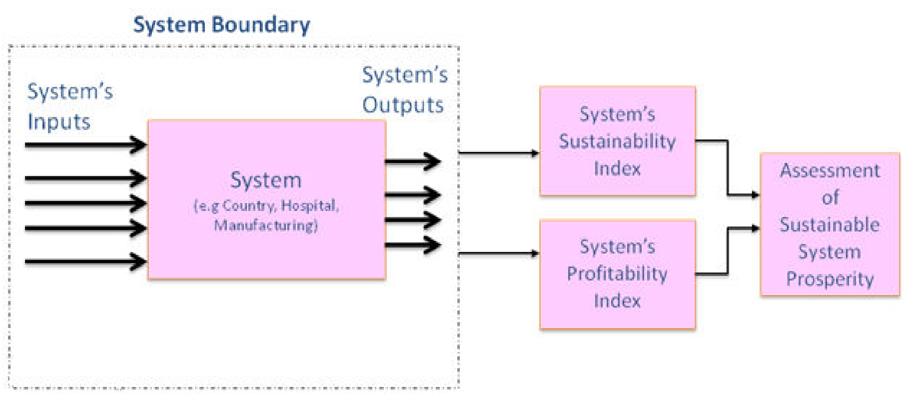


Figure 6.3: the Identification of the System's Boundaries.

Step 2: The Selection of the Factors Considered Critical for Measuring Sustainability

The model discussed in this dissertation is structured to adopt the premise that a system's ability to promote and maintain progress from financial and sustainable development aspects is driven by the interplay of the factors that affect its sustainable prosperity. The goal is to explicitly accentuate the intra and inter-relationships among the social, economic, and environmental dimensions of sustainability as well as the systems' profitability.

The SPI is then calculated through the combination of two dimensions: the Sustainability and Profitability indices that interact with each other to measure the overall system's progress. The Sustainability Index comprises three components, which assess the system's social, economic, and environmental aspects. Moreover, the Profitability Index is composed only of one component that assesses the system's financial progress. It is noteworthy that this work treats the four dimensions as interdependent interacting components. As mentioned earlier, the inputs entering the boundaries of the system are resources that are used to satisfy human needs/wants. They have an ultimate impact on the outcome of most common systems, which are transformed by the system to become outputs that feed into the sustainability components either as indicators or combined to make indices calculated using mathematical equations. All inputs are basically the resources of the system and categorized under the following main categories: materials, transportation, chemicals and oils, energy, technology, and waste. The selection of the inputs within the system boundary is driven by the organization need to establish and maintain sustainable prosperity and the outputs or indicators that should be generated to calculate the overall sustainable development index[26]. Overall, these inputs are presented in a manner that allows them to feed into a mathematical analysis model to generate the system boundaries outputs. These are aggregated to produce the sustainability

[26] This can be achieved through a structured brainstorming session i.e. nominal group technique (NGT), among selected experts or team that represents the organization "system". They would use tools like fishbone diagram to identify potential inputs that are considered critical in the system's sustainability assessment.

assessment index for evaluation. Furthermore, those outputs are based on the set of indicators / indices that are considered as the core elements, which would influence the assessment of the system's SPI. The outputs selection should be relevant to the system to be assessed, reflect its state, identify changes, and satisfy managerial/policy makers' goals, various regulations and laws to ensure system conformity. Finally, inputs and outputs of a given system/subsystem can be expressed in various forms of units, which are determined by the system's needs.

Step 3. Data Acquisition

The most challenging and critical step in developing this measure is collecting appropriate sustainability indicators and measures that will be aggregated together to assess a "system" sustainability performance. In fact, their contribution to the measure would control and influence the ultimate index value and the performance of the system. Thus, the indicators and measures collected should be appropriate, critical, reliable, useful, in measuring sustainable development and adaptable with any system. Moreover, the data for the selected variables should be available and reliable.

This selection methodology is not scientifically rigorous; since it is suggested at the initial or pilot investigation. However, once the preliminary evaluation is performed, it is then followed by more thorough scientific statistical analysis through the use of Principle Component Analysis, Factor Analysis, Uncertainty or Sensitivity Analysis …etc. to define significant and critical outputs (indicators/indices) that should be used in the evaluation.

6.3.2 Data Selection

The goal is to determine the appropriate data type, source, reliability, and suitable procedures in order to obtain a representative sample to collect data for the study defined in step 1. It is a pivotal step that precedes the actual data collection, which requires ample amount of resources and would impact data integrity in supporting the research steps that follow.

This section commences with a discussion of the dimensions and their relevant domains. Each individual step: normalization, the weighting and aggregation procedures, and sensitivity analysis that are used in developing the sustainability index is discussed and justified to ensure that the index has been developed based on scientific approach and not arbitrarily.

Below, the domains and sub-domains selected for each of the three aspects of sustainable development are discussed and depicted in Tables 6.3-6.5.

6.3.2.1 Environmental Sustainability

The concept of environmental sustainability was discussed in Chapter 3. The goal is to assess the consequences and impacts of the “system” consumption on the ecosystem and identify opportunities to improve system’s environmental sustainability score. The set of domains and sub-domains that are used to assess this dimension are outlined in Table 6.3.

Domain	Sub-Domain
System Consumption	Ecological Footprint
Waste	Solid Waste
Water	Water Availability and Usage
	Water Pollution
Environmental Issues	Ozone Depletion
	Greenhouse Effect
Air quality	Air Pollutants

Table 6.3: Domains of environmental sustainability.

System Consumption Domain

As outlined in Chapter 2, the mere driver for countries' economies since the industrial revolution is consumption that is based on linear industrial model. The goal of this domain is to investigate the system's consumption and lifestyles, and examine whether it is achieved within the territory's carrying capacity. Moreover, this would help people to recognize that their over-consumption (if realized) is not sustainable. This should aspire them to modify their lifestyle that is currently consumption based. Below is a discussion of the sub-domains associated with system consumption.

Ecological Footprint Sub-Domain

Ecological Footprint is one of the most widely recognized index in the field of sustainability[27]; since it is effective in measuring the impact of various systems (e.g. country, industry, …, etc.) consumption on the surrounding ecosystem. Therefore, due to its universal application, this research considers it as the cornerstone of the assessment of any system consumption.

Ecological Footprint is used to measure the environmental sustainability of human consumption by determining the bio-productive land needed to produce the

[27] See Chapter 4.

resources to be consumed and assimilate the wastes generated by a given region. It should be noted that the higher the Ecological Footprint values the less sustainable the system is.

Waste Domain

According to the Organization for Economic Co-operation and Development (OECD), waste is defined as "materials that are not prime products (that is, products produced for the market) for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose" (OECD 2001). As discussed in Chapter 2, the current global economy is driven by consumption, which assumes infinite supply of both natural resources and sinks. The ecological ecosystem cannot meet the current rate of aggravated materials extraction, production, consumption, and disposal is associated with an accelerated increase in waste generation. Furthermore, governments, manufacturers, and consumers encourage the production and consumption of goods and services with no significant attention dedicated to the negative consequences of products disposal at the end of their life cycle. This is a problem that continues to grow and negatively affects the environment, which is underscored by the growing amount of solid waste. The major goal of this domain is to track the waste generated by the system. In addition, this is used by policy makers to adapt new/improved measures that address this environmental issue.

Solid Waste Sub-Domain

Solid Waste is the sub-domain to be assessed for any system. This is pivotal since the current economic system has led to the creation of the throwaway society state of mind. This was associated with accelerated increase in the generation of solid waste, where from 1960 to 2010, the per capita waste generation increased from 2.68 to 4.43 Lbs/person/day and the Municipal Solid Waste (MSW) in USA was increased from 88.1 to 249.9 million tons (EPA 2011).

Water Domain

Quality clean water continues to be the cornerstone of the wellbeing of any community. In fact, most of the widely used products and services as well as people require substantial amount of water to exist and functionally operate. In 2008, EPA reported that 400 gallons of water is daily used by an average American family. This is particularly relevant when we realize that many countries such as those in the Middle East and North Africa suffer from water scarcity where they are not able to provide their population with adequate water amounts. This is also accompanied with many environmental crises and global disputes related to inadequate/limited access to, or inappropriate handling of available clean water. These examples clearly underscore and accentuate the importance of fresh water in ensuring the quality of human life (EPA 2008). Thus, water availability and the impact of pollution on available resources are considered the main water sub-domains in this research.

Water Usage Sub-Domain

Water scarcity is an international crisis that continues to negatively influence every continent. Indeed, by 2025, around 1.8 billion people will be living in countries of high water stress (FAO 2012). The goals of this sub-domain are to assess the water usage by the system (studied), raise awareness of the consequence of current policies and their impact on water availability, finally, to advocate for sustainable management of freshwater resources by policy makers.

Water Pollution Sub-Domain

In addition to water availability, it is equally important to assess the quality of the available water resource. Water pollution is defined as any physicochemical or biological alteration in the overall quality of water, which has a detrimental negative impact on the living beings at large. Providing fresh clean water is a major challenge that continues to face people, industries and countries worldwide. In a testament, a UNICEF official noted that "Every day more than 3,000 children die from diarrheal diseases. Achieving this goal will go a long way to saving children's lives." This is a clear outcome of the poor quality of water (HUFFPOST 2012).

Environmental Issues Domain

Environmental Experts and researchers are calling to manage global atmospheric issues related to Climate Change and Ozone Depletion. It is well documented that these issues have negative impact on people wellbeing and the sustainability of ecosystem. Driven by excessive green gas emissions (GHGs), climate change is a significant disruption in the distribution of weather patterns over periods ranging from decades to millions of years. This is an expected outcome of the profound reliance on fossil fuels that have been used excessively in the industrial activities in the past two centuries. Furthermore, this was associated with the depletion of the Ozone layer, which leads to increase in skin cancer, cataracts and other debilitating diseases and harmful effects. This domain is divided into two sub-domains, which are the greenhouse gas emissions (GHG) and ozone depletion.

Greenhouse Gas Emissions Sub-Domain

This is a critical sub-domain to consider in this research. It determines the impact of the system (e.g. industry, country, products) GHGs Emissions on the climate change. Since, it relies heavily on fossil fuels that were associated with massive generation of GHGs that led to present climate change. It resulted in an increase in the global temperature by 0.6 ± 0.2 ºC at a rate of 0.17 ºC per decade since 1950 (Lal 2004). Overall, this was associated with the accumulation of GHGs in the atmosphere and amplification of its effect, which resulted in significant alterations in the Earth's climate.

Ozone Depletion Sub-Domain

Ozone layer envelops the earth and is a concentration of ozone molecules that filters the sun's ultraviolet (UV) radiation. Since the beginning of the industrial revolution there was an accelerated increase in the emission of GHGs. These emissions are critical in diminishing the ozone layer, increasing the amount of UV radiations reaching the earth and are associated with people overexposure to UV rays. This leads to increase in skin cancer, cataracts and other debilitating diseases and harmful effects.

Air Quality Domain

Poor air quality endangers both human health and surrounding environment, if achieved high enough levels. It is an outcome of various natural and human factors such as driving cars, producing products, and burning wood to name a few. Air quality is a critical domain that has been considered by various measures such as ESI (Chapter 4) and UNEP's air quality indicators (UNEP 2003) .

This domain can be assessed toward environmental sustainability by gauging the amount of air pollutants emitted by the system. Therefore, the air-pollutants category is the only sub-domain that is considered in this research.

Air Pollutants Sub-Domain

The air quality is determined by the type and amount of air pollutants that are in the environment. Thus, the system's air quality is gauged by the assessment of the Air Pollutants sub-domain. This sub-domain assesses common forms of air pollutants that are widely used in different measures. Such as: PM10, Non-Methane Volatile Organic Compounds, Sulphur Oxides, Nitrogen oxides, and Carbon Monoxide.

6.3.2.2 Social Sustainability

The vision of sustainability taken by this research is one that focuses on balancing the three dimensions of sustainable development within the system's boundaries. Although, by working towards economic and environmental sustainability, we are indirectly contributing to the social sustainability of the system. Still, social sustainability has a number of standalone domains that should be considered in this measure to ensure that the developed index would support attaining social equity and the satisfaction of equal opportunities for current and future generations, without social discrimination. Furthermore, this would ensure equitable access to shelter, education, health care, job security, etc in order for the system to sustainably function at a defined level of social well being. In conclusion, encompassing this aspect in measuring sustainable development would embody quality of life for all human beings of system investigated.

Unlike environmental and economic sustainability, the assessment of social sustainability is the most problematic of all the sustainability aspects. This aspect has actively encountered scientific debate, on a broad conceptual level since it lacks an agreed on definition consensus exhibited by different nations and thus the identification of adequate indicators as outlined in Chapter 4. Moreover, a major problem with this dimension is data availability and quality since it mostly depends on international sources that are difficult to acquire. Another major limitation to this aspect of sustainability lays in the method of their identification, since the outcomes are usually subjective rather than objective. Consequently, cautions should be taken in selecting the indicators; fail to do this will lead to a questionable results.

As outlined in Chapter 3, to be socially sustainable, people should acquire adequate income, be healthy with good education, and have equitable access to social and health services. Human well being index (HWI) and Millennium Development Goals, which were established following the Millennium Summit of the United Nations in 2000, in addition to the happiness index are the drivers for the assessment of the social sustainability aspect of this index (UN 2008). Since, they track the main domains of social sustainability that actively support the right of current and future generations in a healthy, prosperous, equitable and a good quality of life. Overall, the domains include health and population, wealth, knowledge and culture, community and equity. The domains are discussed below (Table 6.4):

Health and Population Domain

This is the first domain that is integrated in the social sustainability assessment. The sustainability of a system is ensured by the health and wellbeing of its population.

This is driven by its ability to provide its people access to health services that would provide them with healthy, long and prosperous life. The sub-domains enlisted in this section are outlined below:

Health Sub-Domain

This is the first sub-domain of the health and population domain. The main objective is for people to achieve a long and healthy life. In 2003, WHO regarded health as the cornerstone for reducing poverty and improving overall community economic development. In measuring this aspect, the approach adapted in the selection criteria of its indices is based on assessing overall people's health status and measuring the access to this service (WHO 2003).

Population Sub-Domain

This is the second sub-domain of the health and population domain. Population is defined as the total number of people occupying specified area and is considered a key aspect in determining the demand on available resources and the carrying capacity of the surrounding environment. For example, overpopulation occurs when populations need exceeds the carrying capacity of an environment. This is typically associated with enormous burden on the community's economy, infrastructure, and available health and education services, which undermines the commitment toward social sustainability. The opposite is observed when the area is under-populated, which will negatively affect the development of the economic system.

Table 6.4: List of social sustainability domains and sub-domains.

Domain	Sub-Domain
Health and Population	Health
	Population
Knowledge	Communication
	Innovation
	Education Status
	Education Access
Gender Equity	Economic
	Education
	Political
Community	Safety
	Family Security
	Infrastructure
	Political

Knowledge Domain

Knowledge is the second dimension of the social sustainability assessment index. It is a key factor in ensuring quality and wellbeing of humans. In 2000, the Millennium Summit of the United Nations recognized education as one of the main deliverables to be achieved by United Nations member states and internationally recognized organizations by 2015. This is in owe to its pivotal role in building citizens with high self-esteem and empowering them to be independent, physically and mentally fit. These citizens have also responsibility and are committed for the well being of their society. In post-industrial economies, education is the foundation for citizens' knowledge and innovation, which is the basis of these communities production and it is resembled in a form of patents, discoveries and licenses. The presence of communications system combined with innovative and educated population is a key for ensuring the productivity of a society. The sub-domains of this section are discussed below:

Communication Sub-Domain

Effective communication is a key for ensuring the wellbeing of any system. This has been accentuated by the Millennium Development Goals, which were established following the Millennium Summit of the United Nations in 2000 (UN 2008). This sub-domain tracks the system adaption for new information and communication technologies that are believed to play a key role in fostering community and human development.

Innovation Sub-Domain

This is the second sub-domain under knowledge. The ultimate goal of this sub-domain is to stimulate innovation and creativity in the system to ensure that knowledge has been conveyed to its entire people. This will provide a sustainable economic, social and cultural development.

Education Status and Access Sub-Domains

Education is the foundation for people's knowledge. It increases employment opportunities and income levels. It improves the overall health and wellbeing of a system (UN 2000). Therefore, this research considers that education is the cornerstone of a system's progress and sustainable economic development. The higher the education of its community, the more productive and sustainable it is. Therefore, having indices that determine the status and access of education for a system is prudent.

Gender Equity Domain

Equity in the distribution of system resources and services such as health care, education, nutrition, safe water, sanitation, employment, and women representation in executive positions or parliament among people and between genders is a key driver for the system well being and its sustainability. This is the third dimension of social sustainability assessment. It measures equitable distribution of wealth among individuals and/or gender in a system studied. The 2000 Millennium Summit of the United Nations noted that gender equity is a key driver in eliminating poverty from a society. Studies also indicated that when a country provides equal opportunity in education for both girls and boys, the overall economic productivity tends to increase; this is accompanied with improvement in health and educational prospects of next generation. It is also associated with a decrease in both fertility rate as well as maternal and infant mortality (UN 2012).

The sub-domains that are proposed by this research to assess gender equity are:

Economic Equity Sub-Domain

The goal of this sub-domain is to determine whether there is equitable share of employment and average earnings for women in the system assessed.

Education Equity Sub-Domain

This sub-domain measures if there is equal opportunity in the system for women to pursue their education at large.

Political Equity Sub-Domain

This sub-domain assesses the involvement of women in public politics and whether women representation in executive positions or parliament among people exists.

Community Domain

Based on Chapter 4 that reviewed major sustainability measuring indices, certain attributes are needed to achieve socially sustainable community. It embraces the principles of good governance that is based on being equitable and inclusive to all members of the community without compromising the needs of future generations. It ensures the rights of its constituents in having a safe environment that strives to be crime and violence free by promoting community safety efforts. This community provides adequate services and infrastructure facilities that are pivotal for a healthy community. Since failing and/or providing poorly operated/designed systems would compromise the wellbeing of people and negatively impact the environment. Indeed, to ensure sustainable community development, actions must be taken to work towards achieving these aspects and aim to making them a reality.

The sub-domains that are proposed by this research to assess community domain are:

Safety Sub-Domain

A community that is crime, conflict, war and violence free is a main driver for the well being of its constituents. Indeed, crime may lead to loss of life and property, as well as physical pain, post-traumatic stress and anxiety. One of the biggest negative impacts of crime on people’s well-being appears to be through the feeling of vulnerability that it causes.

Family Security Sub-Domain

Family is the cornerstone of any community. There are different forms of families that range from those that are based on two parents, single parents, foster families …etc. Family provides a pivotal source of support and encouragement for its members. It provides a form of financial, and social security, which is a key for the strength of the community at large. Sometimes, families get overwhelmed by what seems like an endless list of challenges and results in conflicts that leads to divorce, which has significant negative consequences that span from economic into social implications that usually take their toll on the kids and their development and wellbeing (Rodgers and Rose 2001; Wolchik 2002). This sub-domain is measured by the divorce rate indicator as outlined in Chapter 6.

Infrastructure Sub-Domain

Infrastructure is the physical and organizational structures that play a pivotal role in securing basic installation of both facilities and services that are essential for the operation of a society (Sullivan and Sheffrin 2003).

Political Sub-Domain

This sub-domain assesses the democracy and the relationship between people and politics in the system.

6.3.2.3 Economic Sustainability

Over the last millennium, there has been a major increase in the overall world economic activities as noted by the significant increase in the global GDP. This was accompanied with an accelerated decay in the environment, which threatens and compromises the ability of humankind to sustain this harmful economic growth. Herman Daly, a leading economist advocated for economic development without growth activity (Daly 1996). Where, it does not grow beyond the carrying capacity of the earth since it is considered a subsystem of the overall ecosystem. In this approach, economic sustainability is only achieved when it considers the finites limits of the earth's ability to provide materials to use and sinks for assimilating generated waste [28] (Figure 6.4). To realize this vision, Daly called for the next industrial revolution that is based on Type III industrial eco-system. As outlined in Chapter 3, this eco-system actively supports the right of both the current and future generations in a sustainable economic development. Its success is based on continuous advancement in human capital and the utilization of more efficient green approaches in resource management and energy consumption (Daly 1996). Below is a more detailed discussion of the domains and relevant sub-domains that should be covered to better assess and track this progress (Table 6.5).

[28] See Chapter 2 for more in-depth discussion on waste and its relation with linear system.

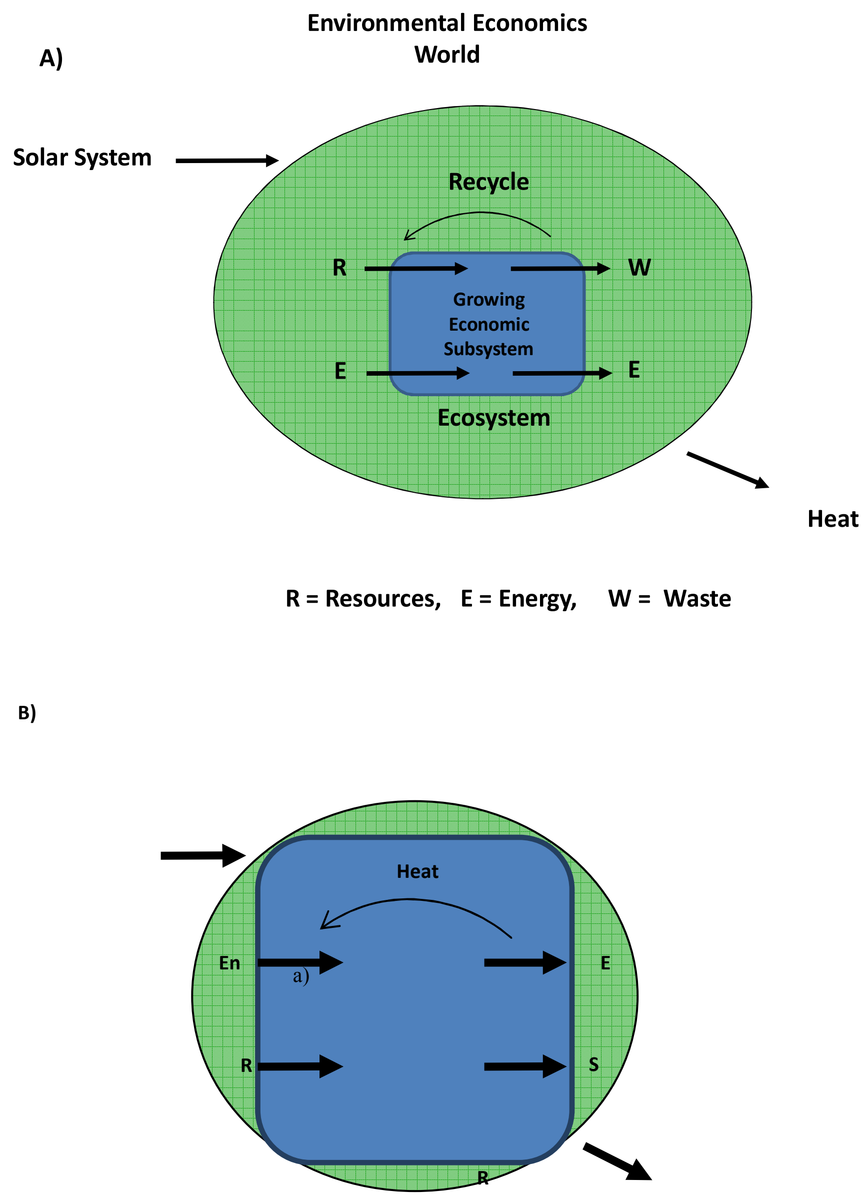


Figure 6.4: The Economy as a Subsystem of the Ecosystem (Daly 1996).

Domain	Sub-Domain
Human Capital	Education
	Health
	Innovation
Resource Depletion	Natural Resources
	Energy
Economy	Status
Sustainability Innovation	Resources
	Energy

Table 6.5: The domains and sub-domains of economic sustainability assessment.

Human Capital Domain

While human capital was covered in the social sustainability dimension, it is also believed to have a prominent role in the sustainability of the economic development. It is defined as the stock of competencies a human should acquire to perform labor that produces economic value (Simkovic 2011). As a result, factors such as investment in providing services that cover health, education, research and development, and infrastructure are the basis for enriching a system's human capital. The sub-domains of this section are as follow:

Education Sub-Domain

This research considers education expenditure as an investment rather than consumption. Since providing an educated workforce is detrimental for the sustainable economic development of any system and increasing the productive capacity of future generations.

Health Sub-Domain

The health and wellbeing of the constituents of any system is another key factor for the success of its economic sustainable development. Investments in human capital health include building and developing healthcare systems infrastructure and ensuring the access to these facilities and services. WHO and other leading institutions considers investments in the physical wellbeing of individuals a pre-requisite for reducing poverty and inducing sustainable socio-economic development (WHO 2003).

Innovation Sub-Domain

This sub-domain complements the one aforementioned in the social dimension of sustainability. It assesses the commitment of the system investigated toward investing in innovation. This is believed to be a prudent driver for economic growth and development. It ensures that knowledge continues to be transferred intra and inter-generations.

Resource Depletion Domain

Natural resources are materials and components that can be found within the environment. Although there are very few resources that are considered renewable and will not run out in foreseeable future, the vast majorities of resources are non-renewable and have a finite quantity. These resources can be depleted if not used efficiently. To be economically sustainable, these resources should not be used beyond their rate of replenishment. Furthermore, renewable alternatives are identified and used at a rate faster than the depletion rate of non-renewable resources. It should be emphasized that natural resource extraction and depletion could be a key driver for building economic wealth and fortune for a given country. This is exemplified in a form of buildings, bridges, equipments, and by investing in human capital and employing people to produce, process, market, transport, and export resources. All of that provided that natural resource extraction is appropriately managed, which continue to be a challenge that faces many of the developing countries. For example, natural resources depletion is associated with social inequity for future generations especially if it is unregulated since it is associated with a sudden inflow of money caused by a resource boom. This typically creates social problems including inflation that harms other industries and compromise the well being of country's citizens. Consequently, to keep this wealth, natural resource extraction and depletion should be kept relatively stable.

Natural Resources Sub-domain

This sub-domain main goal is to track the amount of natural resources that is being depleted as an outcome of the usage and consumption within the system boundaries. In this research, the main natural resources that are considered are forests, minerals, and energy sources i.e. coal, crude oil, and natural gas.

Energy Sub-Domain

Fossil oil continues to be the main driver for the global economic growth. However, the American Petroleum Institute projected that with current rates of energy consumption, the global oil supply will be depleted by 2057 (Appenzeller 2004). This would lead to a devastating impact on global economy and significant increase in the prices of fuel, food and petroleum based products. Therefore, tracking energy depletion and consumption by the system are the focus of this sub-domain.

Economy Domain

The main goal of this domain is to assess the economic status of the system and whether it is profitable as well as sustainable. A system with strong economic status would result in low unemployment and low lay off rate. Its constituents are also well compensated. This would have an indirect positive impact on the social sustainability of this system.

Status Sub-Domain

The economic status of a system can be assessed by measuring its overall saving, accumulated profit, and the economic growth of the system.

Sustainability Innovation Domain

The main theme of this domain is to assess the progress the system is undertaking in investing and utilizing new technologies that maximize the value of renewable materials and energy and reduce the dependence on non-renewable resources. This would also assess the system agility in adapting new practices that eliminate emissions and wastes.

Resources Sub-Domain

This sub-domain reflects the use and investments in technologies and approaches that would achieve, stabilize, and minimize the depletion of natural resources. Indeed, this system would switch to the development of resource cycling and adapting Type III industrial model. Such model is efficient and mimics the natural ecosystems and results in i.e. no waste paradigm. Moreover, increasing the cycling in the system would help in reducing the depletion of raw materials, reduce energy consumption, minimize pollution, and lower carbon footprint. So, it has indirect benefit to both the social and environmental aspects of sustainability. Based on this, recycling and reusing rates achieved in this system are critical factors that should be used in determining the economic sustainability of the system. The higher the rate the better sustainably the system is.

Energy Sub-Domain

This sub-domain reflects the use and investments in technologies and approaches that would reduce the dependence on non-renewable energy resources. According to the Energy Information Administration, in 2007 the major sources of energy consisted of a mix of petroleum 36.0%, coal 27.4%, natural gas 23.0%, rendering fossil fuels as the primary energy source with a total share of 86.4% (EIA 2010). This trend is associated with a devastating impact on the environment. The International Energy Agency (IEA) called for the use of renewable energy is derived from natural processes that are constantly replenished. Renewable energy is directly obtained from the sun or heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, biofuels, and hydrogen derived from renewable resources. Many factors such as climate changes concerns, high oil price, and increasing government support are driving the recent increase in renewable energy legislation and commercialization (Janssen 2002). In 2011, IEA projected that by 2050, most of the world's electricity will be derived from solar power generators, which would significantly reduce GHG and positively impact the environment. Hence, higher rate of renewable energy use is positively correlated with system sustainability. This sub-domain assesses the extent of reliance and investments in energy consumption that relies on renewable sources (Sills Aug 29, 2011). Figure 6.5 shows the domains and sub-domains of the sustainability index.

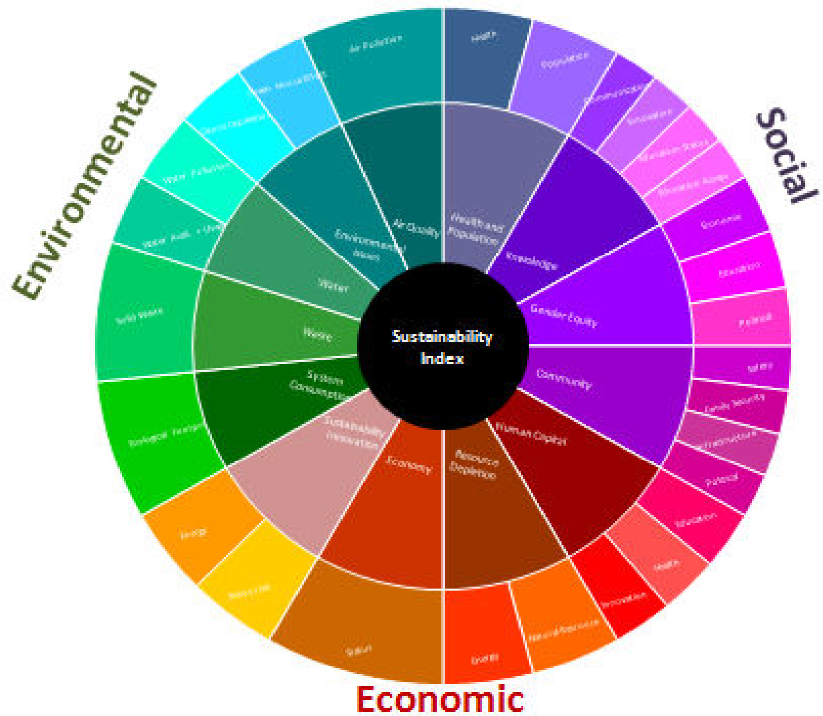


Figure 6.5: The Domains and Sub-domains of the Sustainability Index. Adapted from EPI.

6.3.3 Data Processing

6.3.3.1 Data Imputation

Missing data is a problem that continues to challenge the robustness of the development of composite indicators. In data collection step, there are certain variables that are available only for specific countries that focus on particular measure or only limited for a set of data. To overcome this hurdle, researchers tend to use data imputation to complete the dataset. The approaches that are usually used for data imputation are divided into the following categories:

6.3.3.2 Case Deletion

This is the most commonly used imputation method that does not treat the missing data. It basically deletes the entire records with missing values (for variables, countries, companies, etc) when there is significant number of missing data. The main limitation of this approach is it can generate biased outcomes when the deleted data are not a random sub-sample of the original dataset. In summary, this methodology should not be adapted if the missing data is more than 5% of the overall dataset and one of the approached discussed below should be considered (Little and Rubin 2002).

6.3.3.3 Single imputation

There are two forms of single imputation approach that can be implemented to deal with missing data.

Implicit Imputation

This methodology is adapted when no values are attributed to missing data i.e. only observed values are used in the analysis. This methodology includes:

1. Hot deck imputation: Missing data are imputed from original observed data with similar properties and characteristics.
2. Substitution: Missing data is replaced with values not part of the original observed data set yet with similar characteristics of the missing data.
3. Cold deck imputation: Missing data are imputed from external source preferably from a similar survey completed.

Explicit Imputation

This methodology is adapted when a specific value is attributed to missing data based on a formal statistical model. This methodology includes:

1. Unconditional mean/median/mode imputation, which is substituting variable's mean/median/mode value of the observed values for the missing data.

2. Regression imputation. Regression is used to predict and replace missing data where the dependent variable of the regression is the variable that includes the missing data and the independents are basically those variables that demonstrate high correlation with the dependent variable.
3. Expectation Maximization (EM) imputation this approach focuses on the interdependence between the missing values and the model parameters. The missing data are first predicted based on preliminary estimates of the model parameter values. Then, the process is repeated till they converge to the maximum likelihood estimates (Nardo, Saisana et al. 2005).

Multiple Imputation

This is a general approach that uses the performance "N" sequential random processes that reflects uncertainty and creates N "complete" datasets to impute the missing data. This value is estimated together with their standard errors following running the model multiple times and then averaged. Different models can be used for the most widely used in multiple imputation such as regression. However, Markov Chain Monte Carlo (MCMC) method is most widely used general model.

While data imputation is an important step to treat missing data, it is believed to both dangerous and seductive as noted by Dempster & Rubin (Dempster and Rubin 1983):

"The idea of imputation is both seductive and dangerous. It is seductive because it can lull the user into the pleasurable state of believing that the data are complete after all, and it is dangerous because it lumps together situations where the problem is

sufficiently minor that it can be legitimately handled in this way and situations where standard estimators applied to real and imputed data have substantial bias."

6.3.3.4 Making Variables Comparable

The ultimate goal of the built index is the use of the data variables to compare the selected countries. Thus, it is good practice to take into consideration the differences in the data associated with various systems studied that may be using similar variables but different scales. Thus, it is extremely pivotal to ensure that comparable data are established with respect to time periods, populations, income, populated land area, and among different systems making direct comparisons possible and result in a reliable interpretation.

6.3.4 Normalization

It is adjusting values measured on different scales to a notionally common scale to standardize these values and allow their comparison of corresponding normalized values in a way that eliminates the systematic effects of variations.

One of the main challenges associated with building a composite indicator are the differences observed in data ranges, units and scales that leads to difficulty in data aggregation and further analysis. A preliminary adjustment that renders selected data sustainably comparable is a key step that should precede data normalization. This is accomplished via the application of concepts such as environmental space[29] or by consideration of aspects such as size, population, income, etc, as discussed earlier.

[29] As adapted by this research.

Once completed, data normalization is applied to *avoid adding up apples and oranges*. This is a critical step that transforms the data set into the same measurement unit and scale before proceeding with aggregation and further analysis. It has many advantages, for example, normalization allows for scale adjustment or the transformation of highly skewed indicators where needed. Appropriate selection for normalization technique is driven by close consideration of theoretical framework, inherent data properties, and the other methods that would be implemented in subsequent data analysis to build the comprehensive measure. Below is an overview of the main normalization techniques that are widely considered in literature (Saisana and Tarantola 2002; Freudenberg 2003; Nardo, Saisana et al. 2005; Tarantola and Mascherini 2009):

6.3.4.1 Ranking

This is the simplest normalization technique that is recognized for its independence of outliers. It ranks the systems performance based on their relative positions i.e. ordinal levels. However, unlike other approaches, ranking doesn't provide information or allow judgment on systems performance in absolute levels as information on positions is typically lost. The information and communication technology across countries index adapted this technique to rank order various countries progress (Fagerberg 2001).

6.3.4.2 Percentage of Annual Differences over Consecutive Years

This is a normalization technique that is used when data for a system are available for a number of years. Values are altered to a dimensionless indicator that depicts percentage growth or decline compared to previous year instead of the absolute level. This is calculated using the following formula (Tarantola and Mascherini 2009):

$$Ind_c^t = \frac{X_{qc}^t - X_{qc}^{t-1}}{X_{qc}^t} \times 100$$

Where:

Ind_c^t is the value of the index q for country c at time t.

X_{qc}^t is the value of indicator q for country c at time t.

6.3.4.3 Indicators Above or Below the Mean

This is another simple normalization technique that is not affected by outliers and transforms data according to its position relative to an arbitrarily assigned threshold around the mean. Where values are around the mean that receives a score of 0, while the values above or below the predefined threshold receive scores of 1 and -1 respectively. It is calculated as shown below (Tarantola and Mascherini 2009):

$$If\ x_{qc}^t / x_{qc=\bar{c}}^{t_0} > (1+p)\ \boldsymbol{then}\ I_{qc}^t = 1$$

$$If\ x_{qc}^t / x_{q=\bar{c}}^{t_0} > (1-p)\ \boldsymbol{then}\ I_{qc}^t = -1$$

$$If\ (1-p) < x_{qc}^t / x_{qc=\bar{c}}^{t_0} < (1+p)\ \boldsymbol{then}\ I_{qc}^t = 0$$

Where:

I_{qc}^t is the value of the indicator q for country c at time t.

X_{qc}^t is the value of indicator q for country c at time t.

It should be emphasized that this technique continues to be criticized for three reasons: first, the arbitrariness of the predefined threshold, second: for the slip of the absolute level information, finally: it is usually associated with loss of information in particular around data variance.

6.3.4.4 *Distance to a Reference*

It is a technique that measures the relative position of a system's given indicator with respect to a Reference point. This can be either an external benchmark system, the leader of the group in performance, or the average performer. The Reference can also be a goal to be achieved in a given period of time. This technique is calculated as:

$$I_{qc}^{t} = x_{qc}^{t} / x_{qc=\bar{c}}^{t_0}$$

This method takes the ratios of the indicator $x_{qc}^{t}$for a generic country c and time t with respect to the sub-indicator $x_{qc=\bar{c}}^{t_0}$ for the reference country at time t_0.

Using the denominator $x_{qc=\bar{c}}^{t_0}$, the transformation takes into account the evolution of indicators across time; alternatively one can use the denominator $x_{qc=\bar{c}}^{t_0}$ with running time t.

6.3.4.5 *Categorical Scales*

As the term implies, the indicator values are assigned to preselected categories that can be either quantitative or qualitative. It should be emphasized that each category is given an arbitrary selected score, which is then mapped to each indicator value. Furthermore, the arbitrary scores are usually based on the percentiles of the distribution of the systems' indicator values, e.g. the leading 5% of the systems receive a score of 100 while the less performing ones receive a 0. The key advantage of this technique is when adapting the same percentile transformation, any small change in the indicator definition that could occur over the course of years, will not affect the transformed variable. However, this would limit our ability to track yearly progress. Similar to Indicators above or below the mean technique, the use of categorical scales is usually associated with omission of large amount of information in particular around data variance.

6.3.4.6 Standardization (or Z-Scores)

It is a widely used concept in building composite indices. As outlined in equation below, it is calculated by first determining the average value and the standard deviation across systems evaluated and then converting the values into standard normal distribution scores with a mean zero and a one standard deviation. The normalization formulation is(Tarantola and Mascherini 2009):

$$I_{qc}^{t} = \frac{x_{qc}^{t} - x_{qc=\bar{c}}^{t}}{\sigma_{qc=\bar{c}}^{t}}$$

Where:

X_{qc}^{t} is the value of indicator q for country c at time t.

$x_{qc=\bar{c}}^{t}$ is the average across countries.

$\sigma_{qc=\bar{c}}^{t}$ is the standard deviation across countries.

This will result indicators I_{qc}^{t} that have similar dispersion across countries.

It should be stressed that the use of this technique is desirable if the aim is to recognize exceptional performance i.e. extreme values since they would have a greater impact on the composite index. As outlined in Chapter 4, this method was implemented in building the environmental sustainability index. In recognition of its significance, the WHO index of health system performance was criticized for not using proper normalization technique and standardization was recommended (SPRG 2001).

6.3.4.7 Re-Scaling

This is another commonly used technique that converts the indicator values, using a ratio that is based on the range of the data rather than its standard deviation. It converts the data into normalized scores to ensure that all values have an identical range [0-1]. It is calculated as follows:

Each indicator x_{qc}^{t} for a generic country c and time t is transformed in:

$$I_{qc}^{t} = \frac{x_{qc}^{t} - \min_{c}\left(x_{q}^{t}\right)}{max_{c}\left(x_{q}^{t}\right) - \min_{c}\left(x_{q}^{t}\right)}$$

Where $\min_{c}\left(x_{q}^{t}\right)$ and $max_{c}\left(x_{q}^{t}\right)$ are the minimum and the maximum value of x_{q}^{t} across all the countries c at time t. In this way, the normalized indicators I_{qc}^{t} have values laying between 0 (laggard, $x_{qc}^{t} = \min_{c}\left(x_{q}^{t}\right)$, and I (leader, $x_{qc}^{t} = \max_{c}\left(x_{q}^{t}\right)$.

It should be noted that the minimum and maximum values used in the calculation could be unreliable outliers, and thus have a distortion effect on the normalized scores. Conversely, if the data values exist within a small range, this would extend the transformed range of the normalized values creating a greater impact on the composite index assessed more than what would be observed the standardization (z-scores) method.

6.3.5 Weighting

The process of weighting involves emphasizing the contribution of some factors to a final result, thus they may be given 'more weight' in the analysis than other factors. This would reflect its relative importance based on the objective of the data collection. That is, rather than each variable in the data contributing equally to the final result, some data are adjusted to contribute more than others.

This is a critical step in the process of building a sustainability measure since it has a significant impact on the final results associated with the comprehensive measure and would affect the system's performance. Fundamentally, it involves assigning a number (weight) to each variable (indicator), which would reflect its relative importance and contribution to the final result based on the objective of the theoretical framework. There is no consensus in the literature on a single approach to weight individual indicators. Indeed, multiple approaches were reported for data weighting and each has its own strengths and limitations. Researchers should ensure both transparency in selection process and that the implemented tool meets the measure theoretical framework (Ebert and Welsch 2004). Below is a discussion of various weighting techniques that exist and are: first: equal weights, second: weights based on statistical models e.g. factor analysis, data envelopment analysis, Regression approach, and unobserved components models, and finally: weights derived from opinions: participatory methods such as budget allocation processes, analytic hierarchy processes, public opinion, and conjoint analysis.

6.3.5.1 Equal Weighting

This is the simplest and most widely used weighting technique in building composite indices and does not require significant amount of resources especially when there are no statistical or empirical grounds for choosing a different scheme. It assumes same weight for all variables assessed; this does not mean that no weighting has been applied on the normalized data. Instead, all variables will have equal status to the final measure calculation. Care should be exercised when implementing this technique. For example, when it is applied on dimensions with different numbers of indicators, this would lead to unbalanced weighting on the final composite indicator assessment. Therefore, other techniques should be considered instead. In addition, when applying equal weights on highly correlated indicators this would introduce double counting into the index calculation. Various approaches were reported to address this trend. Researchers opt to first assess the correlation between various indicators using multivariate analysis. Once determined, they either reduce the weight of the highly correlated indicators or only use low correlated indicators for further analysis. Since, positive correlation does always exist especially when large number of indicators studied, researchers usually choose a cut off value beyond which the correlation is considered double counting and an action is required to address it (Tarantola and Mascherini 2009). It should be noted that high correlation indicated by statistical analysis does not necessarily reflect double counting. Indeed, one should also consider the dimension that the indicator aims at capturing and this should be taken into consideration when finally deciding on assigned weighting. Finally, proper normalization of indicators is needed when applying this methodology.

6.3.5.2 Weighting Based on Statistical Models

Researchers adapted four techniques that are based on statistical models to ascertain a proper weighting scheme. While these techniques are considered neutral, they can be biased since they place a higher weight on statistically reliable indicators and penalize the ones that are statistically more challenging to determine.

6.3.5.3 Principal Component Analysis or Factor Analysis

Principal components analysis (PCA) or factor analysis (FA) is used to group individual indicators based on their degree of correlation. It combines variables that are collinear to capture as much common information as possible using the minimum number of indicators.

This technique is associated with disadvantages that limit its use. For example, it is a hard concept to explain to non-statisticians. In addition, weights tend to change as the data change with time. Moreover, weighting assignment using this methodology is based on correlations rather than the importance of the associated indicator. It corrects for the overlap in the information of two or more correlated variables and does not measure the relevance of indicator assessed. As a result, if no correlation among indicators studied exists then no weighting will be assigned. PCA may also result in negative weighting for sub-indicators, which a key factor that led to its exclusion from the construction of an indicator of environmental sustainability (Esty, Levy et al. 2002; Nardo, Saisana et al. 2005).

6.3.5.4 Regression Approach

Regression analysis is a statistical technique that is used for the purpose of prediction and assessment of the relationships among dependent variable (the objective to be attained) and one or more independent variables (indicators). It enables one to estimate the changes in the dependent variable that would be realized if one of the independent variables value varied, while the others are held fixed (coefficients, i.e. weights).

A (usually linear) multiple regression model is defined as

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} \ldots + \beta_p x_{pi} + \varepsilon_i$$

Where:

β_0 = y- intercept or is the estimated constant

β_1= slope of *Y with indicator* x_1 *when* x_2 , x_3 .... x_p *are held constant, Weight of Indicator* x_1

β_2= slope of *Y with indicator* x_2 *when* x_1 , x_3 .... x_p *are held constant , Weights of Indicator* x_2

β_p= slope of *Y with indicator* x_k *when* x_1 , x_3 .... x_{p-1} *are held constant , Weight of Indicator* x_3

e_i = random error in *Y* for observation *i*

This methodology is appropriate for a large number of different types of indicators. The independence of the indicators and the linear behavior of the data tested are basic assumptions of this technique. If not met, and indicators are correlated, estimators will have significant variance, which would undermine the hypothesis, rendering estimates not precise. Also, if a perfect co-linearity among regressors is realized, the model will not be identified.

Regression analysis is a valuable tool even if component indicators are not correlated. Furthermore, this technique is effective in updating or validating the applied set of weights. However, a clear limitation of this approach is that to produce quality results with high statistical properties, regression requires a large amount of data, which may not always be feasible. Another limitation, it provides poor estimates when used with highly correlated indicators. To overcome this issue, it is recommended to combine it with PCA when used.

It should be noted that this approach is not widely used in building composite indicators. An example of its application in this area was reported with Legatum

Prosperity Index (Gamester, Lovo et al. 2012). They used regression analysis to determine the level of importance, or 'weight' that is attributed to a given variable. It also enabled the selection of statistically significant indicators on their dependent variable. Then their data were standardized and multiplied by the weights derived from regression analysis to calculate their index.

Budget Allocation

There are many participatory techniques that can be used to assign weights. Budget allocation, which is considered the most straightforward of the participatory methods, incorporates various experts who are given a budget of *N* points, to be distributed over a number of individual indicators. Each expert can allocate more points for those indicators, which they consider important and want to accentuate while smaller number of points if any is allocated for indicators that they consider not as important(Jesinghaus 1997; Tarantola and Mascherini 2009) . Then Weights are evaluated as average budgets, this process (budget allocation) can be repeated until convergence is achieved (optional).

Munda *et al.* indicated that this technique is feasible when there is a well-defined basis for a national policy with an optimal number of 10-12 indicators (Munda and Nardo 2005). Indeed, if more indicators are used, this may undermine its utility. Since it can give serious cognitive stress to the experts who are asked to allocate the budget and compromise their judgment, which may lead to serious inconsistencies. Furthermore, care should be taken when selecting the experts who will provide their budget allocation. It is pertinent to select experts with broad background, knowledge and experience, which will ensure that meaningful weighting system, is implemented.

In certain conditions, reliability of this technique could be compromised since decisions may reflect the sense of urgency around a particular issue rather than its true importance level.

Public Opinion

This is a widely used participatory technique for weight allocation. It focuses on surveying public opinion, from a particular sample, on concerns that are on the public agenda, and has the same media attention. In 1991, Parker argued that "*public opinion polls have been extensively employed for many years for many purposes, including the setting of weights and they are easy to carry out and inexpensive*" (Parker 1991). The methodology of this tool focuses asking people about their level of "concern" on preselected issues determined by identified indicators. Over the course of years, various methods and techniques were used for opinion polls and ranges from telecommunications to in person-to-person contact. The main limitation of public opinion technique is that it can be associated with results inconsistencies when dealing with high number of indicators.

Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP), which was developed by Thomas L. Saaty in the 1970s, is a powerful structured tool that can be used for multi-attribute decision making (Saaty 1987). This tool has been extensively studied and used in various fields such as healthcare, government, businesses, industry…etc.

AHP is a compensatory tool because alternatives that are efficient with respect to one or more objectives can compensate by their performance with respect to other objectives. It allows decision-makers to derive weights rather than subjectively assigning them. This is accomplished by decomposing the problem into a hierarchical structure. It incorporates the problem quantitative and qualitative dimensions in the assessment process. This will ensure that opinions are methodically extracted via ordinal pair-wise comparisons of attributes.

For the objective assessed, the preference is determined by comparing each pair of indicators to determine which is the more important, and by how much. Then the preference is given a value based on a scale of 1 to 9, the results are then depicted in a comparison matrix that is used for relative weights calculation of each indicator. It should be emphasized that weights calculated using AHP are less sensitive to errors of judgment compared to other methodologies. However, since the methodology of this tool is based on pair-wise matrix comparison, this may result in huge number of comparisons among indicators which would be computationally costly.

Benchmarking with "Distance to the Target"

This is another simple approach to assign weights and was adapted by HDI. Based on systems' performance, targets are set to attain and measure the need or cost for intervention. Where targets can be best performance system, policy goals, or sustainability levels systems' strive to achieve. The weighting is determined by dividing the indicators' values by its associated target values. These dimensionless factors can then be aggregated by a simple average to generate the final score i.e. composite indicator. Overall, policy makers embrace this technique since its weighting principles can be potentially based on their policy targets. However, it is believed that that comparisons among systems are not feasible since such targets i.e. policy goals are either not available or lead to conflicting results.

Data Envelopment Analysis (DEA)

This is a statistical tool that utilizes linear programming to assess an *efficiency frontier* that is utilized as a benchmark to determine the progress i.e. performance of a set of systems i.e. countries, hospitals, industries, products etc. A set of weights are determined for each system based on its relative position (distance) to this *efficiency frontier* where weights are system dependant.

The construction of the *efficiency frontier* depends on the following assumptions, first the weights used are positive, second, systems are not discriminated against i.e. no priorities given and systems are equally ranked; and finally: the feasibility of the linear combination of the best performers i.e. the convexity of the frontier (Nardo, Saisana et al. 2005).

This technique is considered an easy principle to communicate. In addition, it is embraced by policy makers since any another weighting technique would be associated by lower composite scores. This is attributed to the observation that the weights are endogenously determined by the observed performances, which is the result of policy priorities. Instead of its reported merits, DEA has major disadvantages that limit its use and application. For example, due to its methodology that results in endogenously "system-specific" determined weights, some researchers believe that comparisons cross systems is not feasible. This approach is also considered as "incentive generating", which encourages the maintenance of status-quo since its methodology maximizes the problem which leads to higher weights and scores.

$$CI_j = \max \sum_{i=1}^{m} y_{ij} w_i$$

Subject to

$\sum_{i=1}^{m} y_{ik} w_i \leq 1 \qquad \forall k = 1, \ldots, n$ (*Normalization constraint*)

$w_i \geq 0 \qquad \forall i = 1, \ldots, m$ (*Non-negativity constraint)*

6.3.6 Aggregation

Data aggregation is a process where data collected is expressed in a summary form that would enable statistical analysis and representations of findings. This allows better data interpretation and communication. There are three key approaches to aggregate indicators:

1 *Additive methods*

2 Geometric aggregation

3 *Non-compensatory multi-criteria analysis*

6.3.5Additive methods

The most common form of this kind of aggregation is the linear aggregation. That is the summation of weighted and normalized indicators. It is calculated using the equation below:

$$CI_c = \sum_{q=1}^{Q} w_q \times I_{qc}$$

Where :

I_{qc} is the value of the indicator q for country c, w_q is the weighting factor of the indicator q.

$$\sum_{q=1}^{Q} w_q = 1$$

$$0 \leq w_q \leq 1$$

This methodology requires normalization and involves restrictions on the type and nature of indicators and weights calculated. For example, it assumes that the assessed indicators are independent, where their addition will yield an unbiased index.

It's worth noting that this is a challenging condition to realize since various indicators are inter-related, therefore, the addition of their values would underestimate the true value of the aggregated index. Moreover, this approach entails full compensability where a deficit in one indicator can be compensated by a surplus in the other. Rendering this methodology not to be usually a desirable approach (Nardo, Saisana et al. 2005; Tarantola and Mascherini 2009).

Geometric Method

Similar to linear aggregation, it assumes the independency among indicators assessed i.e. no synergy or conflict effects exist. However, unlike linear aggregation, it implies partial compensability that is not constant. Where a poor performance in some indicators of the system can only be compensated when adequately high values are achieved in other system indicators. This is a good approach if the multi-criteria framework requires full non-compensability, where a system e.g. country would have a greater interest in addressing the domains/sub-domains with low scores. Ultimately, this would increase the odd for them to improve their overall ranking (Tarantola and Mascherini 2009).

Non-Compensatory Multi-Criteria Analysis

When different objectives are equally valid and imperative (e.g. social, economic, and environmental dimensions), and the increase in one dimension/indicator cannot be compensated by a loss in another then a non-compensatory approach implantation may be warranted. This methodology does not reward outliers and assumes the absence of preference independence. Using this approach, a pair-wise comparison of systems across all variables is implemented. All systems are then rank-ordered from best to worst using a mathematical model. Interestingly, non-compensatory approach is both scale-free and no normalization is necessary (Tarantola and Mascherini 2009).

6.3.7 Visualization

It is a step that involves graphical visual representations of data that is intended to convey information clearly and effectively through graphical means. The main goal of data graphical representation is creating elegant data visualizations, which communicates information in a manner that enables better comprehension and interpretation by the general public and policy makers. The visualization approach that will be implemented in this research is the Graphical Representation of The Barometer of Sustainability or the Wellbeing Index (Chapter 4). In this representation, the sustainability index is placed on one axis scaled from 0 to 100 measuring progress made toward sustainable development by the system investigated. While on the other axis system's profitability is plotted. Each axis is divided into five bands of 20 points each. They diverge from bad (red) to good (green).   The intersection point of the two indices is plotted in the graph, represented by the egg of sustainable prosperity, to portray the overall sustainable prosperity of the city/country/nation in question. Furthermore, this is considered powerful visual tool enables interested parties to see the system's performance and scores of sustainable development relative to its prosperity (Figure 6.5).

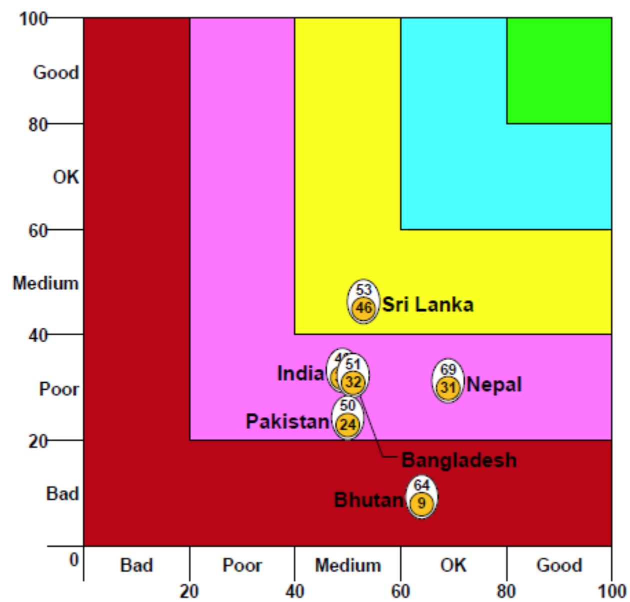


Figure 6.6: The sustainability and prosperity visualization approach.

6.3.8 Sensitivity Analysis

Sensitivity analysis (SA) is "the study of how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation". It is considered a pivotal step in constructing and improving models. According to Nardo et al Composite Indicators can be considered as models (Nardo, Saisana et al. 2005).

SA is used to assess the effect of changes in a certain parameter on the model's final outcome. It also determines and identifies, which parameters are the key drivers and critical factors of a model results. Indeed, this methodology would enable decision makers to consider alternative scenarios of the same model. Overall, it would increase the level of confidence in the model as a useful tool to aid decision-making. Furthermore, another key advantage of SA is its ability to discern the robustness of the composite indicator. This will ensure that the composite indicator is not misguiding policy makers and sending poor policy messages.

It is generally believed that composites indicators construction incorporates several steps i.e. selection of sub-indicators, data quality, data imputation, normalization, weighting and weights' values, and aggregation. Such steps integrate several levels of uncertainty that are simultaneously triggered, which renders composite indicator to be non linear. Therefore, robust, "model-free" sensitivity analysis methodology is ideal for such models. Variance-based techniques for sensitivity analysis are considered the most convenient methodology for the present analysis. A detailed discussion of Variance-based techniques sensitivity analysis can be found in Nardo et al. page 92 (Nardo, Saisana et al. 2005).

CHAPTER 7: System's Sustainability Prosperity Assessment: Country Case

7.1 Introduction

The goal of this research is to develop an index that can be universally applied on various systems such as countries, industries, and products to assess their progress toward sustainable prosperity (Adolphson 2004). Chapter 6 outlined this comprehensive framework along with the overall computational procedure for the assessment of this index. In this Chapter, the countries' case example is presented with discussion of the findings obtained from the application of this index. This model is applied on the G-20 countries that are defined as the top 20 countries that are driving the global economy. This model enables a better assessment and comparison of the progress of these countries toward sustainable prosperity. Furthermore, it also identifies potential gaps that limit the progress of these countries to achieve their goals toward sustainable prosperity. Furthermore, this Chapter has three objectives, First to define the domains, sub-domains and related indicators/indices that will be used to assess progress toward the three dimensions of sustainability, Second, to determine the appropriate weighting, normalization , aggregation techniques applied in the assessment of this case, and Finally to discuss results and findings of implementing this methodology.

7.2 Countries' Selection Rational

G-20 countries were selected to assess the utility of this index in measuring these systems' progress toward sustainable prosperity (Table 6). The selection criterion is based on the Pareto Principle also known as law of the vital few, where 80% of the obtained outcomes are a result of 20% of the causes. Herein, 80% of the global economy is generated by the G-20 countries (Table 7.1). These countries produce 80 % of the gross world product (GWP) and trade. They also have 66% of the world population, and account for 84% of the world's economic growth. Furthermore, in 2010 at the Seoul G20 Summit the countries leaders declared their commitment to 'green growth', where prosperity is realized without compromising Mother Nature. It should be emphasized that the G-20 countries vary in their ability to deliver on this pivotal obligation.

Finally, the overall quality of data obtained for these countries is high and reliable, which would facilitate a better meaningful comparison among these countries that can be extrapolated to other countries if needed.

Table 7-1: List of the G-20 Countries.

G-20 Countries			
United States	Mexico	European Union	Germany
United Kingdom	Japan	China	France
Turkey	Italy	Canada	Saudi Arabia
South Korea	Indonesia	Brazil	Argentina
South Africa	India	Australia	Russia

7.3 Selection of Indicators / Indices

Previous Chapters discussed the three pillars of sustainability and provided a description for each domain and its relevant sub-domains (Table 6.3, 6.4, and 6.5). In this Chapter, a set of indicators/indices that are considered signals in the system were selected for the G-20 countries. They span a time period that extends from 1990 to

2010. Each identified variable was selected in a way that influenced its associated domain/sub-domain (Tables 7.2, 7.3, and 7.4). They provide information on system status and its evolution. Below, is a discussion of these indicators/indices selected for the country's case. It should be noted that the selection criteria for these indicators/indices was based on the review conducted in this research as outlined in Chapters 4 and 6. Furthermore, for all indicators/indices investigated, their definition, units, and data source are included in Appendix A.

7.4 Environmental Sustainability

As discussed earlier, an environmentally sustainable country would ensure that its constituents demand on the environment can be met without compromising the country's carrying capacity and enable its people to live well, at present and in the future. To assess countries progress toward attaining environmental sustainability, this dimension is split into five domains: the system consumption, waste, environmental issues, and water and air quality. Each is divided into one or more sub-domain(s). These are then broken down, if considered necessary, into several indices/indicators that are chosen to assess the state of the country in placing its demands on the environment; as illustrated in Table 7.2.

Table 7.2: List of environmental sustainability indices.

Domain	Sub-Domain	Index
System Consumption	Ecological Footprint	Ecological Footprint
Waste	Solid Waste	Municipal Waste Collected (TONNES Capita)
Water	Water Availability and Usage	Annual Freshwater Withdrawals, Total (% of Internal Resources)
	Water Pollution	Organic Water Pollutant Emissions (kg per 1,000 people per day)
Environmental Issues	Ozone Depletion	Nitrous Oxide Emissions (thousand metric tons of CO_2 equivalent)
	Greenhouse Effect	CO_2 Emissions (Metric Tons Per Capita)
Air quality	Air Pollutants	PM10, Country Level (Micrograms per Cubic Meter)
		Non-Methane Volatile Organic Compounds (Metric Tons Per Capita)
		Sulphur Oxides Emissions (Metric Tons Per Capita)
		Nitrogen Oxides (Metric Tons Per Capita)
		Carbon Monoxide (Gg)

It is worthwhile to keep in mind that the environmental sustainability is one of the deliverables of the Millennium Development Goals that are established following the Millennium Summit of the United Nations in 2000 (targets # 7A and 7B), where countries would incorporate the principles of sustainability into country policies and guidelines; reverse loss of environmental resources and attain significant reduction in the rate of biodiversity loss by 2010 (UN 2000).

7.4.1 System Consumption Domain

The goal of this domain is to investigate the country's consumption and lifestyles, and examine whether it is achieved within the territory's carrying capacity. Moreover, this would help people to recognize that their over-consumption (if realized) is not sustainable. This should aspire them to modify their lifestyle that is consumption based.

The Ecological Footprint was reviewed in detail in Chapter 4. It is the sub-domain as well as the indicator that is used to assess this domain. It is used to measure the environmental sustainability of human consumption by determining the bio-productive land needed to produce the resources to be consumed and assimilate the wastes generated by a given region. The unit used for this measure is Global Hectares of biologically productive land required per capita (gha). This sub-domain is not broken down since it can be used to measure different systems progress toward environmental sustainability. Therefore, it is also applicable on countries. It should be noted that the higher the Ecological Footprint values the less sustainable the country is. Furthermore, to allow comparison among countries, in which, the Ecological Footprint value for each country is compared to the system's predefined 'allowable' limit. This is its total available bio-capacity that has a unit similar to Ecological Footprint i.e. global hectares per capita. Thus, the Ecological Footprint Relative Sustainability Index is calculated for each country using the equation below:

$$EF_{RSI} = \frac{Ecological\ Footprint}{Total\ Biocapacity}$$

It should be noted the data were retrieved from the World Wildlife Fund (WWF) Living Planet Reports, which are published over the years to help countries prosper in a resource-constrained world. These reports can be found at their website

http://www.footprintnetwork.org/en/index.php/GFN/page/publications/ (WWF 2000-2010).

7.4.2 Waste Domain

According to the Organization for Economic Co-operation and Development (OECD), waste is defined as "materials that are not prime products (that is, products produced for the market) for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose" (OECD 2001). Waste is considered one of the major environmental issues and a main outcome of Current Paradigm that is based on linear consumption paradigm (Chapter 2)**.** Under this system, every step is associated with waste generation, which further undermines Mother Nature by altering the environmental sustainability through excessive use of nonrenewable resources on the source side and generation of pollution and waste on the sink side (Goodland 1995). The major goal of this domain is to track the waste generated by the country. This should help in recognizing current consumption patterns and figure out more sustainable practices that would not destabilize the sinks of Mother Nature.

7.4.2.1 Solid Waste Sub-Domain

Solid Waste is the sub-domain to be assessed for any system. This is pivotal since the current economic system has led to the creation of the throwaway society state of mind. This was associated with accelerated increase in the generation of solid waste, where from 1960 to 2010, the per capita waste generation increased from 2.68 to 4.43 Lbs/person/day and the Municipal Solid Waste (MSW) in USA was increased from 88.1 to 249.9 million tons (EPA 2011). The index that is used to capture this sub-domain is the Municipal Waste Collected (TONNES Capita).

7.4.2.1.1 Municipal Waste Collected (TONNES Capita)

This is the waste that is collected by or on behalf of municipalities, by public or private enterprises, includes waste originating from: households, commerce and trade, small businesses, office buildings and institutions (schools, hospitals, government buildings). It includes bulky waste (e.g., white goods, old furniture, mattresses) and waste from selected municipal services, e.g., waste from park and garden maintenance, waste from street cleaning services (street sweepings, the content of litter containers, market cleansing waste), if managed as waste. It is noteworthy that the definition excludes waste from municipal sewage network and treatment, municipal construction and demolition waste. The unit of the municipal waste collected is TONNES Capita.

The data are extracted from the United Nations (UN) Statistics Division (last accessed March, 2013). They can be found on http://unstats.un.org/unsd/environment/municipalwaste.htm. Also, they are derived from UNSD/UNEP Questionnaires on Environment Statistics, Waste section. Eurostat Environmental Data Centre on Waste:

http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/sectors/municipal_waste

OECD Environmental Data Compendium, Waste section. United Nations, Department of Economic and Social Affairs, Population Division, World Population Prospects: The 2008 Revision, New York, 2009 (UN 2009).

7.4.3 Water Domain

Quality clean water continues to be the cornerstone of the wellbeing of any community. It is a primary element that should be considered in measuring the sustainability of any system. Especially, when considering that the world continues to face many environmental crises in addition to national and international disputes related to inadequate/limited access to, or inappropriate handling of available clean water. Therefore, ensuring a minimum amount of fresh clean water that is needed to sustain both human wellbeing and maintain the viability of the ecosystems by applying principles of sustainability is critical. Furthermore, assessing the extent of water pollution is another important aspect that should be considered when assessing the water domain, since it has a harmful impact on any living beings. Overall, assessing water usage and the extent of water pollution are the main themes that are assessed in this domain (GLEICK 1998).

7.4.3.1Water Usage Sub-Domain

Water scarcity is a global problem that negatively influences every continent. Indeed, by 2025, around 1.8 billion people will be living in countries of high water stress (FAO 2012). These are typically developing countries, with significant unsustainable population growth and limited access to safe drinking water and adequate sanitation facilities. This is associated with unconstructive impacts on the overall aspects of economy represented by food availability, security, water supply and sanitation (WWAP 2012).

Thus, to be able to determine the sustainability of water in our planet, we should track the usage of water for each country. The index below, which is the Annual Freshwater Withdrawals, Total (% of Internal Resources) is used for this task.

7.4.3.1.1 Annual Freshwater Withdrawals, Total (% of Internal Resources)

The goal of using this variable is to measure the country's consumption of water relative to available internal resources that would allow comparison among countries. This variable is defined by the WB as "Annual freshwater withdrawals refer to total water withdrawals, not counting evaporation losses from storage basins. Withdrawals also include water from desalination plants in countries where they are a significant source. Withdrawals can exceed 100 percent of total renewable resources where extraction from nonrenewable aquifers or desalination plants is considerable or where there is significant water reuse. Withdrawals from agriculture and industry are total withdrawals for irrigation and livestock production and for direct industrial use (including withdrawals for cooling thermoelectric plants). Withdrawals for domestic uses include drinking water, municipal use or supply, and use for public services, commercial establishments, and homes." The data are extracted from the World Bank (WB), World Development Indicators (WDI) Catalog (1990-2010) that is published annually by WB (last accessed March 18, 2013). They are derived from Food and Agriculture Organization, AQUASTAT data (WDI 2013). The unit of this measure is % of internal water resources.

If the value is less than or equal 100%, this indicates that its consumption is sustainable. On the other hand, if the score is higher than one, this indicates that the country is consuming water at unsustainable levels and the higher the score, the more unsustainable it is.

7.4.4 Climate Change Domain

Climate change is a significant disruption in the distribution of weather patterns over periods ranging from decades to millions of years. For example, CO_2 was balanced in nature where oceans and plants absorbed it and was usually emitted to the atmosphere by natural processes that were in equilibrium. However, current industrial system, which relied heavily on fossil fuels for its industrial activities that included and not limited to energy burned for transportation, heating, and power plants; led to the release of massive amounts of greenhouse gases (GHGs) emissions including CO_2 that disrupted this delicate balance. Furthermore, such activity was associated with the depletion of the Ozone layer, which leads to increase in skin cancer, cataracts and other debilitating diseases and harmful effects. This domain is divided into two sub-domain, which are the greenhouse gas emissions and ozone depletion sub-domains.

7.4.4.1 Greenhouse Gas Emissions Sub-Domain

Current linear consumption system relied heavily on fossil fuels that were associated with massive generation of GHGs, which led to climate change. It resulted in an increase in the global temperature by 0.6 ± 0.2 ºC at a rate of 0.17 ºC per decade since 1950 (Lal 2004). In 2005, the atmospheric methane (CH_4) level, a key contributor GHGs, surpassed the natural range evaluated over the last 650,000 years (Solomon 2007). Overall, this was associated with the accumulation of GHGs in the atmosphere and amplification of its effect, which resulted in significant alterations in the Earth's climate. It is interesting to note that China and USA, the largest two economies, GHGs emissions counted for more than 37.42% of the total global greenhouse emissions. CO_2 Emissions was considered in this sub-domain.

7.4.4.1.1 CO_2 Emissions (Metric Tons Per Capita)

The main cause of global warming and climate change is the global emission of CO_2, which reached a record high of 34 billion tones in 2011. The US continues to be the country with the highest emission with 17.3 tonnes per capita. It is prudent to limit the rise in the average global temperature to only to 2°C above pre-industrial levels, which is the goal that was endorsed by the UN climate negotiations. For that to happen, the cumulative CO_2 emissions should not exceed 1000-15000 billion tones over the period of 2000-2050. The likelihood for that to be accomplished is believed to be low considering global trend of current CO_2 emissions increases (EDGAR 2012). According to WB CO_2 emissions data are those stemming from the burning of fossil fuels and the manufacture of cement. They include CO_2 produced during consumption of solid, liquid, and gas fuels and gas flaring (WB 2013). The data is obtained from the WDI Catalog (1990-2012) that is published annually by WB (available online last accessed March 18, 2013) which has been derived from the Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States (WDI 2013).

7.4.4.2 Ozone Depletion Sub-Domain

Ozone layer envelops the earth and is a concentration of ozone molecules that filters the sun’s ultraviolet (UV) radiation. Since the beginning of the industrial revolution there was accelerated increase in the emission of GHGs. These emissions are critical in diminishing the ozone layer, increasing the amount of UV radiations reaching the earth and are associated with people overexposure to UV rays. This leads to increase in skin cancer, cataracts and other debilitating diseases and harmful effects. The 2006 assessment report documented the continued success of the Montreal Protocol in reducing the atmospheric abundance of ozone-depleting substances (ODSs) (WMO 2007). Moreover, although nitrous oxide (N_2O) is not restricted by the Montreal Protocol , They are deemed the only largest and most significant ozone-depleting free radical emitted through human activities that are currently available (Ravishankara, Daniel et al. 2009). Therefore, N_2O is considered a critical factor for this environmental impact and the only ozone-depleting substance that is considered in this research.

7.4.4.2.1 Nitrous Oxide Emissions (thousand metric tons of CO_2 equivalent)

N_2O is an important ozone-depleting and GHG emission. Its emissions are those that result from agricultural biomass burning, industrial activities, and livestock management. N_2O emissions in energy sector are reported as thousand metric tons of CO_2 equivalent. Indeed, by comparing the Ozone Depletion Potential-weighted anthropogenic emissions of N_2O with those of ozone-depleting substances, Ravishankara et al. (Ravishankara, Daniel et al. 2009) showed that N_2O emissions currently are the single most important emissions of a chemical that depletes ozone. However, N_2O is not controlled by the Montreal Protocol (Ravishankara, Daniel et al. 2009) .

According to WB N_2O emissions are those from agricultural biomass burning, industrial activities, and livestock management (WB 2013). The data is obtained from the WDI Catalog (1990-2012) that is published annually by WB (available online last accessed March 18, 2013). It has been derived from the International Energy Agency (IEA Statistics © OECD/IEA, http://www.iea.org/stats/index.asp) (WDI 2013).

7.4.5 Air Quality Domain

Poor air quality endangers both human health and surrounding environment, if achieved high enough levels. It is an outcome of various natural and human factors such as driving cars and burning wood to name a few. Air quality is a critical domain that has been considered by various measures such as ESI (Chapter 4) and UNEP's air quality indicators (UNEP 2003) .

This domain can be assessed toward environmental sustainability by gauging the amount of air pollutants emitted by the system i.e. country. Thus, the air pollutants is the only sub-domain that is considered in this research.

7.4.5.1 Air Pollutants Sub-Domain

The air quality is determined by the type and amount of air pollutants that are in the environment. Thus, the system's air quality is gauged by the assessment of the Air Pollutants sub-domain. This sub-domain is split into five variables that are considered as common air pollutants and widely used in different measures. Most importantly, it is thought that the combination of these variables will provide a good gauge of the air quality: PM10, Non-Methane Volatile Organic Compounds, Sulphur Oxides, Nitrogen oxides, and Carbon Monoxide. Below is a discussion of each of the variables.

7.4.5.1.1 PM10, Country Level (Micrograms per Cubic Meter)

Particulate matter (PM) is a complicated combination of fine solid particles and liquid droplets suspended in air. These are either naturally occurring particulates such as those originated from volcanoes, dust storms, and forest fires or manmade that originated from burning of fossil fuels, power plants and other related industrial activities. US Environmental Protection Agency (EPA) is concerned about the particulate matter especially ones with a size smaller than 10 microns in diameter (PM10). These can be easily inhaled and are reported to cause major health hazards such as heart disease, lung cancer to name a few. As reported by the WB, data for countries and aggregates for regions and income groups are urban-population weighted PM10 levels in residential areas of cities with more than 100,000 residents. Moreover, the estimates represent the average annual exposure level of the average urban resident to outdoor particulate matter (WB 2013). The data is collected from the WB, WDI Catalog (1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from Kiran Dev Pandey, David Wheeler, Bart Ostro, Uwe Deichmann, Kirk Hamilton, and Katherine Bolt. "Ambient Particulate Matter Concentrations in Residential and Pollution Hotspot Areas of World Cities: New stimates Based on the Global Model of Ambient Particulates (GMAPS)," World Bank, Development Research Group and Environment Department (2006) (WDI 2013). Furthermore, the state of a country's technology and pollution controls is an important determinant of particulate matter concentrations (WB 2013). In summary, appropriate assessment of the contribution of a system i.e. country to the generation of particulate matter is critical for the assessment of the system environmental sustainability.

7.4.5.1.2 Non-Methane Volatile Organic Compounds (Metric Tons Per Capita)

Important ingredients of many products, Non-Methane Volatile Organic Compounds (NMVOCs) are organic compounds (excluding Methane) with low boiling point and high vapor pressure. Similar to the particulate matter, VOCs are either naturally occurring or man-made where they are emitted into the environment from sources such as combustion activities, and various production processes. They are found in indoor and outdoor environments. EPA regulates them especially indoor, where concentrations tend to be the highest. Constant indoor exposure to certain NMVOC types or classes such as benzene and 1,3 butadiene has a reported harmful compounding health effects, hence the keen interest in assessing these emissions. This would offer the trends of the most hazardous NMVOCs produced by the system investigated (EDGAR 2011). Its unit is Metric Tons Per Capita.

The data are drawn from European Commission, Joint Research Centre (JRC)/PBL Netherlands Environmental Assessment Agency. Emission Database for Global Atmospheric Research (EDGAR), release version 4.2 (EDGAR 2011).

7.4.5.1.3 Sulphur Oxides (SO_x) Emissions (Metric Tons Per Capita)

It is one of the common air pollutants that negatively affect the air quality. The two main forms of SO_x are Sulphur dioxide (SO_2) and Sulphur trioxide (SO_3). However, for the quality of data availability, SO_2 variable has been considered for this study. It is a colorless gas with a pungent, irritating odor and taste. It is highly soluble in water forming weakly acidic sulphurous acid. SO_2 is used in many industrial processes such as chemical preparation, refining, pulp-making and solvent extraction. SO_2 is also used in the preparation and preservation of food because it prevents bacterial growth and the browning of fruit. SO_2 can harm crops and trees, textiles, building materials, animals, and people either as a result of exposure to long-term low concentrations or short-term high concentrations. It turns leaves yellow and decreases the growth rate of crops. SO_2 corrodes metal, and causes building materials and textiles to deteriorate and weaken. Sulphur dioxide irritates the throat and lungs and, if there are fine dust particles in the air, can damage a person's respiratory system. Sulphur oxides combine with other substances in the air to produce a haze that reduces visibility. SO_2 is a major contributor to acid deposition. The data are drawn from European Commission, Joint Research Centre (JRC)/PBL Netherlands Environmental Assessment Agency. Emission Database for Global Atmospheric Research (EDGAR), release version 4.2 (EDGAR 2011).

7.4.5.1.4 Nitrogen Oxides (Metric Tons Per Capita)

Nitrogen oxides emission is mainly realized from electric power plants that are generated by the combustion of fossil fuels, waste incineration, agricultural burning, and other relevant industrial processes (ATSDR 2002; EPA 2013). It has two main forms, which are Nitrogen Dioxide and Nitric Oxide and is usually in the form of smog or particles.

It is associated with significant negative impact on human health. For example, it plays a key role in deteriorating asthmatic conditions and other respiratory relevant conditions. This is partially attributed to its reaction with air oxygen and the production of ozone, which is known to be irritant. This is also accompanied with the formation of nitric acid that once dissolved in water would result in the formation of nitric acid. This is the basis of acid rain that has harmful impact on ecosystems by undermining plants growth. It also destroys buildings and other infrastructures (ATSDR 2002). The data are drawn from European Commission, Joint Research Centre (JRC)/PBL Netherlands Environmental Assessment Agency. Emission Database for Global Atmospheric Research (EDGAR), release version 4.(EDGAR 2011).

7.4.5.1.5 Carbon Monoxide (Gg)

Carbon monoxide (CO) is a colorless, odorless, tasteless, poisonous gas that results from incomplete combustion of fuels, i.e. coal, heating oil, or any combustible materials.

When CO enters the body, it inhibits the blood from absorbing oxygen; thus, the heart and brain are not going to function appropriately. A person exposed to high levels of CO may die, or just complain of heart pains, headache, nausea fatigue, poor vision and concentration if just exposed to small amounts (CARB 1994; EPA 2012). The data are drawn from European Commission, Joint Research Centre (JRC)/PBL Netherlands Environmental Assessment Agency. Emission Database for Global Atmospheric Research (EDGAR), release version 4.2 (EDGAR 2011).

7.5 Social Sustainability

Social Sustainability is the second dimension of measuring sustainable development as discussed in Chapter 3. The conceptual framework was established for this pillar in

Chapter 6. It should be noted that many of the selected indices that are shown in Table 7.3 are based on both the well being index (Chapter 4) and Millennium Development Goals which were established following the Millennium Summit of the United Nations in 2000 (UN 2008). A discussion of each index is discussed below as follows:

Table 7-3: List of Social Sustainability Indices.

Domain	Sub-Domain	Index
Health and Population	Health	Physicians (per 1,000 people)
		Life expectancy at birth, total (years)
		Mortality rate, under-5 (per 1,000 live births)
	Population	Fertility rate, total (births per woman)
		Population growth (annual %)
Knowledge	Communication	Mobile Cellular Subscriptions (Per 100 People)
		Telephone Lines (Per 100 People)
		Internet Users (Per 100 People)
	Innovation	Patent Applications, Nonresidents
		Patent Applications, Residents
		Researchers In R&D (Per Million People)
		Scientific And Technical Journal Articles
	Education Status	School Enrollment, Primary (% Net)
		School Enrollment, Secondary (% Net)

		School Enrollment, Tertiary (% Gross)
		Literacy Rate, Adult Total (% Of People Ages 15 And Above)
	Education Access	Pupil-teacher Ratio, Primary
Gender Equity	Economic	Ratio of average male and female earnings.
		Share of women employed in the nonagricultural sector (% of total nonagricultural employment)
	Education	Ratio of female to male tertiary enrollment (%)
		Ratio of female to male secondary enrollment (%)
		Ratio of female to male primary enrollment (%)
	Political	Proportion of seats held by women in national parliaments (%)
Community	Safety	Intentional homicides (per 100,000 people)
		Losses due to theft, robbery, vandalism, and arson (% sales)
	Family Security	Divorce Rate
	Infrastructure	Passenger cars (per 1,000 people)
		Road density (km of road per 100 sq. km of land area)
		Roads, paved (% of total roads)
		Vehicles (per km of road)
		Improved sanitation facilities (% of population with access)
		Improved water source (% of population with access)

	Political	Political stability and security
		Political freedom Average of indexes of political and civil liberties

7.5.1 Health and Population Domain

As discussed in Chapter 6, healthy population is another prudent factor that ensure the sustainability of a community (UN 2012). Thus, a sustainable country would offer its people access to health services that would provide them with healthy and long life. This would help them in achieving their goals in having a prosperous life. For the Health sub-domain the following indicators/indices were integrated in the measure:

7.5.1.1 Health Sub-Domain

This is the first sub-domain of the health and population domain. The indicators that are considered are:

1. Life expectancy at birth, total (years)
2. Physicians (per 1,000 people)
3. Mortality rate, under-5 (per 1,000 live births)

Below is a discussion of each indicator:

7.5.1.1.1 Life Expectancy at Birth

Life Expectancy at Birth is defined as "the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout his/her life" (WB 2013). Based on the research conducted, it is considered as one of the core measure of the status of health in a country. Since it is an indicator of the overall health conditions and infrastructure of the country (e.g. availability of sanitation, diet, clean water, etc.). It has been used as one of the factors in measuring the WI and the HDI. This variable is measured in years.

The data is drawn from the WDI Catalog (1990-2012) that is published annually by WB (WDI 2013). Furthermore, the extracted data was taken from: United Nations Population Division, World Population Prospects; United Nations Statistical Division, Population and Vital Statistics Report; Census reports and other statistical publications from national statistical offices; Eurostat: Demographic Statistics; Secretariat of the Pacific Community: Statistics and Demography Programme; U.S. Census Bureau: International Database.

It is interesting to note that the world average life expectancy at birth in 2010 was 67.2, however, it was only 64.5 years in 1999 (CIA 2013). Furthermore, in the Millennium Summit of the United Nations in 2000, officials set a goal that all countries should achieve a life expectancy of 75 years by 2015 (UN 2000) .

7.5.1.1.2 Mortality Rate, Under-5 (Per 1,000 Live Births)

This is another indicator that is considered in this dissertation to measure the health status of country's population. It is also one of the Millennium Development Goals (MDGs) of reducing child mortality rate by two-thirds by 2015 (UN 2000). It is defined by the WB that under-five mortality rate is "the probability per 1,000 that a newborn baby will die before reaching age five, if subject to current age-specific mortality rates"(WB 2013). The data is obtained from the WDI (WDI) Catalog (1990-2012) that is published annually by WB (available online last accessed March 18, 2013) (WDI 2013). Moreover, these extracted data estimates are developed by the

UN Inter-agency Group for Child Mortality Estimation (UNICEF, WHO, WB, UN DESA, and UNPD). The world average has been reduced from 87 (8.7%) in 1990 to 51 (5.1%) in 2011 (UN 2012).

7.5.1.1.3 Physicians (Per 1,000 People)

This indicator is included as a measure of direct access of general public in a country to health services. It is defined as "Physicians include generalist and specialist medical practitioners" who are working in the country in any medical practice per 1,000 of the population (WB 2013). The WHO reported that at least 2.3 health workers, which include physicians, nurses, and midwives per 1,000, would be needed to achieve primary health care coverage in a country. The data is obtained from the WDI Catalog (1990-2012) that is published annually by WB (available online last accessed March 18, 2013) and WHO, Global Atlas of the Health Workforce. San Marino has the highest number of physicians per 1,000 people with a value of 47.35. Whereas, the country with least number of physicians per 1,000 people is Tanzania with a value of 0.01(Barrientos 2013).

7.5.1.2 Population Sub-domain

This is the second sub-domain of the health and population domain. The index that is considered is the Fertility rate, total (births per woman), Below is a discussion of the index:

7.5.1.2.1 Fertility Rate, Total (Births per Woman)

Together with population growth rates, this indicator gives an assessment of the country population growth and its age structure. It is an indicator on whether a country population is growing at demographically sustainable rate. According to the WB it is defined as "Total fertility rate represents the number of children that would be born to a woman if she were to live to the end of her childbearing years and bear children in accordance with current age-specific fertility rates." It is an important measure for the prospective for population change in a country. To avoid population decline e.g. Italy, Japan, and Germany, and ensure stability in the structure of its population a replacement rate of two children per woman is needed. Furthermore, lower or higher rates than this target is associated with negative consequences on the overall sustainability of the country (TJ, JC et al. 2003).

The data is collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (available online last accessed March 18, 2013). Moreover, these extracted data estimates are derived from United Nations Population Division. World Population Prospects, United Nations Statistical Division. Population and Vital Statistics Report (various years), Census reports and other statistical publications from national statistical offices, Eurostat: Demographic Statistics, Secretariat of the Pacific Community: Statistics and Demography Programme, and U.S. Census Bureau: International Database (WDI 2013).

7.5.2 Knowledge Domain

As discussed in Chapter 6, knowledge is the second dimension of the social sustainability index. It is a pivotal factor in ensuring the wellbeing and development of a community. It is measured by assessing education, communication, and innovation. The three sub-domains are detrimental in ensuring the productivity of a society by sharing, transferring and growing knowledge among individuals. Knowledge has been one of the critical aspects that are included in major global measures such as HDI and WI. Moreover, UN recognized education as one of the major goals of MDGs to be achieved by its member states and internationally recognized organizations by 2015.

7.5.2.1 Communication Sub-Domain

The indicators that are chosen to monitor the progress in this sub-domain; are the ones that are used by UN as a measure to monitor progress toward achieving goal # 8 of MDGs (UN 2008)**.** This is to extend the global partnership for development by making the benefits of new technologies in particular information and communications based. With a goal to create an environment that fosters development and eliminates poverty at the national and global levels. The three indicators used in this assessment are:

1. Mobile Cellular Subscriptions (per 100 people)
2. Telephone lines (per 100 people)
3. Internet users (per 100 people)

7.5.2.1.1 Mobile Cellular Subscriptions (Per 100 People)

According to the WB this indicator is defined as the number of "subscriptions to a public mobile telephone service using cellular technology, which provide access to the public switched telephone network. Post-paid and pre-paid subscriptions are included" (WB 2013). The data is collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from

International Telecommunication Union, World Telecommunication/ICT Development Report and database, and WB estimates (WDI 2013).

The country with the highest subscriptions is Macao SAR, China, with a value of 206.30. On the other hand, the country with the lowest value is Myanmar, with a value of 1.24 (Barrientos 2013).

7.5.2.1.2 Telephone Lines (Per 100 People)

According to the WB, this indicator is defined as the number of "fixed telephone lines that connect a subscriber's terminal equipment to the public switched telephone network and that have a port on a telephone exchange. Integrated services digital network channels and fixed wireless subscribers are included" (WB 2013). The data is collected from the WB, WDI Catalog (1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from International Telecommunication Union, World Telecommunication/ICT Development Report and database, and WB estimates (WDI 2013).

The country with the highest subscriptions is San Marino, with a value of 68.81. On the other hand, the country with the lowest value is Dem. Rep. Congo, with a value of 0.06 (Barrientos 2013).

7.5.2.1.3 Internet Users (Per 100 People)

According to the WB, this indicator is defined as the number of "people with access to the worldwide network" (WB 2013). The data is collected from the WB, WDI Catalog (1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from International Telecommunication Union, World

Telecommunication/ICT Development Report and database, and WB estimates (WDI 2013).

7.5.2.2 Innovation Sub-Domain

This is the second sub-domain under education and culture. The ultimate goal of this sub-dimension is to stimulate innovation and creativity of countries to ensure that knowledge has been conveyed to the general public. This will provide a sustainable economic, social and cultural development. The four indicators that are used in this assessment and would assess the nation's progress toward research and development are:

1. Patent Applications, Nonresidents
2. Patent Applications, Residents
3. Researchers in R&D
4. Scientific and Technical Journal Articles

7.5.2.2.1 Patent Applications, Nonresidents

According to the WB this indicator is defined as "the number of patent applications that are filed through the Patent Cooperation Treaty procedure or with a national patent office for nonresidents in a country, for exclusive rights for an invention, a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years" (WB 2013).

The data is collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from World

Intellectual Property Organization (WIPO), World Intellectual Property Indicators and www.wipo.int/econ_stat (WDI 2013). The US filed the largest numbers of patents in the world with a value of 248,249 patents while the lowest was for is Uganda, with a value of 1 patent (Barrientos 2013).

7.5.2.2.2 Patent Applications, Residents

Similar to the previous indicator, this variable is defined as "the number of patent applications that is filed through the Patent Cooperation Treaty procedure or with a national patent office for residents in a country, for exclusive rights for an invention, a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years" (WB 2013).

The data is collected from the WB, WDI Catalog (1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from WIPO, World Intellectual Property Indicators and www.wipo.int/econ_stat (WDI 2013). It is interesting to note that China filed the highest value in the world with a value of 293,066 and the lowest was for is Trinidad and Tobago, with a value of 1 (Barrientos 2013).

It should be noted that both indicators are included to ensure that all patents filed in a specific country has been captured.

7.5.2.2.3 Researchers in R&D

This is another indicator that is retrieved from the WDI Catalog to assess the progress of innovation in a country. The WB defines Researchers in R&D as "professionals engaged in the conception or creation of new knowledge, products, processes, methods, or systems and in the management of the projects concerned" (WB 2013). The data are collected from the WB, WDI Catalog (1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from UNESCO, Institute for Statistics. It should be noted that postgraduate PhD students (ISCED97 level 6) engaged in R&D are included (WDI 2013).

Finland has the highest value in the world in the number of Researchers in R&D, which accounted for 7,647.36 per million people. Conversely, Niger has the lowest value in the world in the number of Researchers in R&D, which accounted for 7.77 per million people (Barrientos 2013).

7.5.2.2.4 Scientific and Technical Journal Articles

In academic publishing, a scientific journal is a periodical publication that aims to advance scientific knowledge by reporting new research. According to WB, the index of scientific and technical journal articles refer to "the number of scientific and engineering articles published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences" (WB 2013). The data are collected from the WB, WDI Catalog (1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from National Science Foundation, Science and Engineering Indicators (WDI 2013). In 2009, the country with the highest number of scientific and technical published articles in the world is US, with a value of 208,600.80. While, the country with the lowest value in the world is St. Lucia, with a value of 0.00.

7.5.2.3 Education Status and Access Sub-Domains

Education is the foundation for citizens' knowledge. It has a pivotal role in ending the global poverty. It increases employment opportunities and population income levels. Education improves both maternal and child health as well as the overall health of a community. In addition, regions with solid educations are associated with lower crime rate, improved social services and opportunities for economic growth (UN 2000).

Providing universal primary education is one of the pivotal targets in MDGs, which focuses on the completion of a full course of primary schooling. In addition, literacy rate has also been considered to ensure that the whole community including adults is able to read and write at a basic level (UN 2000). However, this research argues that education is the cornerstone of a country's progress and sustainable economic development. The higher the education of a community, the more productive and sustainable the community is. Therefore, the indicators that are considered in this dissertation reflect not only the primary education and literacy rate (consistent with MDGs), but equally important it includes those that assess secondary and tertiary education. The indicators that are used in the countries case assessment to measure country's education status are:

1. School enrollment, primary
2. School enrollment, secondary
3. School enrollment, tertiary
4. Literacy rate, adult total (% of people ages 15 and above)

The indicator that is used in the countries cases assessment to measure country's education access is:

1. Pupil-teacher ratio, primary

7.5.2.3.1 School Enrollment, Primary

This is one of the indicators that are used to measure the attainment of MDGs (UN 2000). It calls for ensuring that by 2015, all children worldwide will be able to complete a full course of primary education. Moreover, primary education is the education that "provides children with basic reading, writing, and mathematics skills along with an elementary understanding of such subjects as history, geography, natural science, social science, art, and music." Furthermore, WB defines "Net enrollment ratio as the ratio of children of official school age based on the International Standard Classification of Education 1997 who are enrolled in school to the population of the corresponding official school age" (WB 2013). Consequently, the net enrollment ratio cannot exceed 100%. If it does, then it indicates that there is discrepancy between population and enrolment data. Thus, UNESCO Institute for Statistics adjusts the value using a capping factor. A high ratio designates a high degree of enrolment ratio in primary education by the official school-age population. The data are collected from the WB, WDI Catalog (1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from UNESCO Institute for Statistics (WDI 2013).

7.5.2.3.2 School Enrollment, Secondary

As mentioned above, this indicator is not used to monitor education achievement by MDGs. However, it is used here since this research argues that the higher the education of the population the more productive the community is. Moreover, Secondary education is the education that “completes the provision of basic education that began at the primary level, and aims at laying the foundations for lifelong learning and human development, by offering more subject- or skill-oriented instruction using more specialized teachers.” furthermore, the WB defines “Net enrollment ratio as the ratio of children of official school age based on the International Standard Classification of Education 1997 who are enrolled in school to the population of the corresponding official school age” (WB 2013). Consequently, the net enrollment ratio cannot exceed 100%. If it does then it indicates that there is discrepancy between population and enrolment data. Thus, UNESCO Institute for Statistics adjusts the value using a capping factor. A high ratio designates a high degree of enrolment ratio in primary education by the official school-age population. The data are collected from the WB, WDI Catalog (1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from UNESCO, Institute for Statistics (WDI 2013).

7.5.2.3.3 School Enrollment, Tertiary

This research assesses the last stage of education level through this indicator. Similar to the previous indicator, it is not used by MDGs. Moreover, tertiary education is the education that, “whether or not to an advanced research qualification, normally requires, as a minimum condition of admission, the successful completion of education at the secondary level.” Furthermore, the WB defines “Gross enrollment ratio (GER) as the ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the level of education shown” (WB 2013).

Consequently, it is worth noting that underdeveloped countries usually have a low GER, which indicates that their youth lacking the knowledge and skills needed to prosper. This is attributed to the low standard of living, the inaccessibility to schools and a low gross domestic product per capita. The data are collected from the WB, WDI Catalog (1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics (WDI 2013).

7.5.2.3.4 Literacy Rate, Adult Total (% of People Ages 15 and Above)

This is the last index that completes the assessment of the education status in a country. It assesses the "percentages of people ages 15 and above who can, with understanding, read and write a short, simple statement on their everyday life" (WB 2013). Additionally, this indicator also encompasses 'numeracy', which is the capability to make simple arithmetic calculations. It is measured by calculating the ratio of the number of literates aged 15 years with respect to the corresponding age group population multiplied by 100. This is one of the indicators that are used to measure the attainment of the education goal of MDGs and in a commonly used indices e.g. HDI (UN 2000).

The data are collected from the WB, WDI Catalog (1990-2012) that is published annually by WB (last accessed March 18, 2013), that are derived UNESCO, Institute for Statistics (WDI 2013). Democratic Republic of Korea has the highest literacy rate of 100% while; Afghanistan has the lowest literacy rate of 18.16% (Barrientos 2013).

7.5.2.3.5 Pupil-Teacher Ratio, Primary

Primary school pupil-teacher ratio is the number of pupils enrolled in primary school divided by the number of primary school teachers (regardless of their teaching assignment) (WB 2013). The data are collected from the WB, WDI Catalog (1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from UNESCO, Institute for Statistics (WDI 2013).

To ensure quality of education, the lower the pupil-teacher ratio the better it is for pupils. Since this would provide individual students more access to their teachers, which would result in better overall performances.

7.5.3 Gender Equity Domain

As discussed in the previous Chapter, promoting gender equality and empowering women is one of the eight MDGs and deliverables, which was identified in the Millennium Summit of the United Nations in 2000 (UN 2000). They noted that gender equity is a key driver in eliminating poverty from a society. This research ascertains that assessing gender equity should be evaluated from four aspects/ sub-domains: economic, education, innovation, and political dimensions. These pillars are measured by indicators depicted in Table 7.3, which were used by different leading organizations such as UNDP who established the Gender Inequality Index.

However, while reviewing the literature, it was noted that in 2006 the World Economic Forum established a new index, which is the Global Gender Gap Index. This measure provides a framework for determining gender-based inequalities worldwide. Consistent with this research scope, this index provides ranking in term of countries progress toward overcoming gender gaps from economic, political, education, and health-based standards. This enables meaningful comparison across regions over time (Hausmann, Tyson et al. 2012). This research incorporates this index in its calculation as a representative for Gender Equity. The data is collected from the World Economic Forum, for the years between 2006 and 2010. They are published annually as reports by the World Economic Forum (Hausmann, Tyson et al. 2006-2012).

7.5.4 Community Domain

To achieve socially sustainable community certain principles should be achieved. For example, the community should embrace the principles of good governance that is based on being equitable and inclusive to all members of the community without compromising the needs of future generations. It ensures the rights of its constituents in having a safe environment that aims to be crime and violence free by promoting community safety efforts. This community provides adequate services and infrastructure that are pivotal for a healthy community. Indeed, to ensure sustainable community development, actions must be taken to work towards achieving these aspects and aim to making them a reality.

In order to assess the social sustainability of a community, the measure should incorporate four sub-domains which are outlined below:

1. Safety
2. Family security

3. Infrastructure
4. Political freedom

7.5.4.1 Safety Sub-Domain

Having a safe and peaceful environment that strives to be crime, conflict, war, and violence free by promoting community safety efforts is pivotal for the well-being of individuals in the community. It largely reflects the risks of people being physically assaulted or falling victim to other types of crime. Crime may lead to loss of life and property, as well as physical pain, post-traumatic stress and anxiety. One of the biggest negative impacts of crime on people's well-being appears to be through the feeling of vulnerability that it causes.

Peace is notoriously difficult to define. Perhaps the simplest way of approaching it, is in terms of harmony achieved by the absence of war or conflict. Applied to nations, this would suggest that those not involved in violent conflicts with neighboring states or suffering internal civil wars have achieved a state of peace.

In this research, the progress of a country toward safety is measured using global peace index

7.5.4.1.1 Global Peace Index

This research uses the Global peace index as a measure to assess the safety and peacefulness of a country. This index has been first launched by Institute for Economics and Peace in 2007, and then is yearly published. Consistent with this research scope, this index provides a ranking in term of countries progress according to their peacefulness. This index enables meaningful comparison across regions over time. It assesses the extent of the country's involvement in both domestic and international conflict. Furthermore, using 23 broad indicators, global peace index measures the internal harmony of the country by assessing its crime rate, the extent of terrorist attacks and violent demonstration, the relationship between the country and its neighboring states, and the proportion of populations that are displaced as refugees. Overall, these indicators will provide the global peace index that measures the peacefulness of the country. The data is collected from Economist Intelligence Unit, for the years between 2007 and 2010. They are published annually as reports by Institute for Economics and Peace (IEP) (IEP 2007-2012).

7.5.4.2 Family Security Sub-Domain

Family is the cornerstone of any community. There are different forms of families that range from those that are based on two parents, single parents, foster families …etc. Family provides a pivotal source of support and encouragement for its members. It provides a form of financial, and social security, which is a key for the strength of the community at large. Sometimes, families get overwhelmed by what seems like an endless list of challenges and results in conflicts that leads to divorce, which has significant negative consequences that span from economic into social implications that usually take their toll on the kids and their development and wellbeing (Rodgers and Rose 2001; Wolchik 2002). This sub-domain is measured by the divorce rate indicator, see below for more information.

7.5.4.2.1 Divorce Rate

Divorce is the final termination of a marital union and cancellation of all relevant legal responsibilities of marriage between involved parties. While, divorce laws are different between countries and regions around the world, they usually require court endorsement to be legally accepted. Indeed, divorce is considered one of the major devastating events in a person life. It negatively impacts people finance, living arrangement, schedule and many more. Furthermore, kids for divorce parents usually suffer from more behavioral issues relative to those for married couples. In addition, they tend to have lower academic achievement and tend to discontinue their higher education and college (Rodgers and Rose 2001; Wolchik 2002) . One measure of divorces is the divorce rate, which is the number of divorces per 1,000 population. It provides an overview of marriage in an area, but it does not take people who cannot marry into account. For example, it would include young children who are clearly not of marriageable age in its sample.

UN Statistics Division is responsible for collecting data on divorce rate from the national statistical offices of over 200 countries and areas on an annual basis through the Demographic Yearbook data collection system. They calculate relevant indicators on divorce rate such as the crude divorce rates and publish it in their annual Demographic Yearbook. Furthermore, data on marriage and divorce are also made available to Member States, for international comparisons, as well as to scholars and academia, Non Governmental Organizations (NGOs) and the public-at-large (UN 2013).

7.5.4.3 Infrastructure Sub-Domain

Infrastructure is the physical and organizational structures that play a pivotal role in securing basic installation of both facilities and services that are essential for the operation of a society (Sullivan and Sheffrin 2003). It includes many sectors such as:

Public utilities: power, telecommunications, piped water supply, sanitation and sewerage, solid waste collection and disposal.

Public works: roads, major dam, and canal work for irrigation and drainage.

Other transport sectors: urban and interurban railways, urban transport, ports, and water ways and airports.

WB considers well designed infrastructure as a key for a long-term prosperity of a country. Furthermore, WB believes that infrastructure is a critical factor in ensuring economic growth and abolishing poverty and accomplishing environmental sustainability (WB 1994). The key indicators that are used to assess this sub-domain are listed below:

1. Passenger Cars (Per 1,000 People)
2. Road Density (km of Road per 100 Sq. km of Land Area)
3. Roads, Paved (% of Total Roads)
4. Improved Sanitation Facilities (% of Population with Access)
5. Improved Water Source (% of Population with Access)

Below is a discussion of these indicators:

7.5.4.3.1 Passenger Cars (Per 1,000 People)

Nowadays, car ownership is a critical factor in determining people's mobility. It is determined by many variables such as individual income, interest rates, car prices and demographic trends. The most widely used index to measure car ownership is the passenger cars per 1,000 people is defined by WB as “road motor vehicles, other than two-wheelers, intended for the carriage of passengers and designed to seat no more than nine people (including the driver)" (WB 2013). The per capita vehicle ownership rates tend to increase with economic development to a point. Eventually, it peaks and this is determined by public policies e.g. fuel and parking prices, roadway supply, the quality of alternative modes, and land use policies (LITMAN 2012).

The data on passenger cars per 1,000 people are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from International Road Federation, World Road Statistics and data files (WDI 2013). The country with the highest value in the world is Monaco, with a value of 771.00. The country with the lowest value in the world is Central African Republic, with a value of 0.29 (Barrientos 2013).

7.5.4.3.2 Road Density (km of Road per 100 Sq. km of Land Area)

Road Transport is a pivotal contributing factor to the country's economy. For example, it is a reflection of the connectivity among transport routes within a country. Road transport would improve the movement of goods and people since it reduces costs and improve country's competitiveness. Therefore, it is pivotal for country's development, social integration and security needs. WB defined road density as is "the ratio of the length of the country's total road network to the country's land area. The road network includes all roads in the country: motorways, highways, main or national roads, secondary or regional roads, and other urban and rural roads" (WB 2013). The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013), that are derived from International Road Federation, World Road Statistics and data files (WDI 2013).

The country with the highest value in the world is Monaco, with a value of 3,850. The country with the lowest value in the world is Niger, with a value of 1.00 (Barrientos 2013).

7.5.4.3.3 Roads, Paved (% of Total Roads)

This is another indicator that is used in this research to assess the progress of infrastructure among the countries. Paved roads according to the WB "are those surfaced with crushed stone (macadam) and hydrocarbon binder or bituminized agents, with concrete, or with cobblestones, as a percentage of all the country's roads, measured in length" (WB 2013). It is another indicator that reflects the development of the country since it facilitates human activity and improves the quality of life and wellbeing of individuals. It is expressed as % of total road. The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013), that are derived from International Road Federation, World Road Statistics and data files (WDI 2013).

7.5.4.3.4 Vehicles (Per km of Road)

According to the WB "Vehicles per kilometer of road include cars, buses, and freight vehicles, but do not include two-wheelers. Roads refer to motorways, highways, main or national roads, secondary or regional roads, and other roads. A motorway is a road specially designed and built for motor traffic that separates the traffic flowing in opposite directions" (WB 2013). This indicator is used as an imperfect surrogate to analyze traffic in countries. However, there is a disconnect that is usually reported between national and urban areas especially for developing countries. The country with the highest value in the world is Monaco, with a value of 387.00. The country with the lowest value in the world is Togo, with a value of 1.00.

The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from International Road Federation, World Road Statistics and data files (WDI 2013).

7.5.4.3.5 Improved Sanitation Facilities (% of Population with Access)

It is widely accepted that access to safe drinking water and clean sanitation facilities is a common measure that is used to assess country progress toward eliminating poverty and disease. Indeed, this is considered a human right rather than a privilege for people (CDC). The percent of population with access to improved sanitation facilities has increased since 1990 in all regions. However, in 2008, around 40% of world population still had no access to improved hygienic sanitation facilities which mounts to an estimated 2.5 billion people. In fact, the population with access to improved facilities is particularly low in Sub-Saharan Africa (30 %), but the largest proportion of population without access is in South Asia (59%). This is attributed to both a slow progress in providing this needed infrastructure as well as high population growth (CDC). This is also a leading cause for the 1.5 million children death that is reported every year. It is noteworthy that the MDGs set a target to reduce by half the share of people with no access to basic sanitation by 2015. Overall, the progress made thus far is slow and is unlikely to meet this goal by that deadline (UN 2008) .

The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from World Health

Organization and United Nations Children's Fund, Joint Measurement Programme (JMP) (http://www.wssinfo.org/) (WDI 2013).

7.5.4.3.6 Improved Water Source (% of Population with Access)

Access to an improved water source indicator refers to the percentage of the population with reasonable access to an adequate amount of water from an improved source, such as a household connection, public standpipe, borehole, protected well or spring, and rainwater collection. Reasonable access to safe drinking water sources is defined as the accessibility of no less than 20 liters for a person a day from a source within one kilometer of the dwelling (CDC).

In 2010, around 89% of world's population used drinking water, which was obtained from improved sources such as piped connections (54%). Only 780 million people lacked access to these sources (WHO and UNICEF 2012). MDGs set a target goal to reduce the proportion of people with no adequate access to improved sources of safe drinking water in half by 2015 (UN 2008). So far, significant progress has been made, where more than 2 billion people got access to good drinking water source from 1990 to 2010.

The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from World Health Organization and United Nations Children's Fund, Joint Measurement Programme (JMP) (http://www.wssinfo.org/) (WDI 2013).

7.5.4.4 Political Sub-Domain

This sub-domain assesses the democracy and the relationship between people and politics in the country. It is assessed by the following indicators:

1. Political stability and security
2. Political freedom average of indices of political and civil liberties

Next is a discussion of these indices.

7.5.4.4.1 Political Stability and Security

The common indicators that are used in assessing the countries stability and security are included in the Global Peace Index, which was included earlier under the safety of the community. Hence, it was not repeated to avoid redundancy.

7.5.4.4.2 Political Freedom Average of Indexes of Political and Civil Liberties

A sustainable democratic society is based on protecting and embracing the pillars of liberty, which include political freedom (e.g. freedom of speech and no hindrance for political action), civil liberties, and human rights. This Sub-domain has been assessed using the average of indexes of political and civil liberties. Freedom House's flagship publication is an annual standard-setting comparative assessment for 195 countries and 14 related and disputed territories that assesses political rights and civil liberties. It is used by politicians, global agencies, and human rights defenders to evaluate trends and progress toward attaining and maintaining freedom and democracy worldwide.

This organization divides countries into three categories depending on their commitment toward securing their people rights and freedom:

- Free country is the one that provides a climate that fosters open political competition, secures respect for civil liberties, where significant independent civic life and media are realized.
- Partly free country is the one that provides a limited climate for political rights and civil liberties. It usually experiences the dominance of single political parties which is associated with corruption and weak rule of law.
- Not free country is the one that lacks basic political rights and basic civil liberties are deliberately denied.

Each country is provided a numerical rating from 1 to 7 for both political rights and civil liberties, with 1 representing the most free and 7 the least free. The average of the two scores which is also known as the freedom rating determines the country's status where: Free (1.0 to 2.5), Partly Free (3.0 to 5.0), or Not Free (5.5 to 7.0). The data for this variable have been collected from the *Freedom in the World* data and reports that are available on the Freedom House website at http://www.freedomhouse.org/report-types/freedom-world (Freedom.House 2013).

7.6 Economic Sustainability

Economic Sustainability is the third dimension of assessing the sustainability of a system. In Chapter 6, the conceptual framework that includes the domains has been established and discussed. Sub-domains and selected indices are shown in Table 7.4 that is followed by a discussion of each of them. This advocates that the economics of a country does not only involve the country's consumption i.e. GDP, but also the investment made to render the economic system more sustainable (Pigou 1928).

Table 7-4: List of Economic Sustainability Indices.

Domain	Sub-Domain	Index
Human Capital	Education	Education expenditure
	Health	Health expenditure, public (% of GDP)
	Innovation	Research and development expenditure (% of GDP)
Resource Depletion	Natural Resources	Adjusted savings: net forest depletion (% of GNI)
		Adjusted savings: natural resources depletion (% of GNI)
		Adjusted savings: mineral depletion (% of GNI)
	Energy	Adjusted savings: energy depletion (% of GNI)
		Electricity production from renewable sources (Kwh)
Economy	Status	Inflation
		Gross Domestic Savings
		GDP per capita growth (annual %)
Sustainability Innovation	Resources	% Recycling and Reusing Rates
		Investment in Sustainable Resources
	Energy	Electricity production from renewable sources (Kwh)
		Investment in Sustainable Energy

7.6.1 Human Capital Domain

Human Capital was first discussed by Arthur Cecil Pigou who called for investment in both human and material capital (Pigou 1928). It is widely accepted that human capital development has a pivotal role in the economic development of a country. It includes both investments in productivity growth as well as innovation. As discussed in Chapter 4, Human Development Index (HDI) that is used by UN to assess the human capital in nations, has used three focal indices in their calculations of this important domain, which are: "Life Expectancy Index", "Education Index" and "Income Index”. This suggests that the assessment of the progress of a country toward human capital investment should involve assessment for health, education and standard of living. Thus, under this domain, this research focuses on the assessment of investments made in Education, Health and Innovation. However, standard of living, which this research believes is equally as important, will be reflected by the indices under the economic status of the nation. Below is a discussion of each sub-domain and its associated indices.

7.6.1.1 Education Sub-Domain

As mentioned earlier, education is the basis of the Human Capital. This research deems that investment in country’s education is critical in the sustainability of its economic system. Since, it creates more productive capacity of future generations, which leads to more opportunities for the country’s economic growth. The index that is used to assess this sub-domain is:

7.6.1.1.1 Education Expenditure

Unlike GDP methodology, this research considers education expenditure as an investment in human capital rather than consumption. Education expenditure refers to the current operating expenditures in education, including wages and salaries and excluding capital investments in buildings and equipment. It is expressed as % of GNI (WB 2013).

The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013). They are based on WB staff estimates using data derived from the United Nations Statistics Division's Statistical Yearbook, and the UNESCO Institute for Statistics online database (WDI 2013). Country's assurance of a quality education to its people is crucial in achieving equitable economic growth. This is particularly important to poor countries that have usually limited opportunities to attain sustainable economic growth. This is in part attributed to their inability to adequately invest in science and technology unlike knowledge and innovation driven economies. Most of the poor countries income is spent on providing basic needs such as food and shelter with minimal investment in future. Therefore, for these countries to achieve accelerated economic growth, investment in a combination of base infrastructure and human capital will lead to an educated workforce that will be a key driver for eliminating poverty (Mingat and Winter 2002). The country with the highest value in the world is Cuba, with a value of 13.37%, while the country with the lowest value in the world is Myanmar (0.84%) (Barrientos 2013).

7.6.1.2 Health Sub-Domain

Human capital and economic development are interconnected by investments in the health of people, because healthy people are essential for the economic development of a nation. The human capital health investment includes factors like the development of the healthcare system, good hospitals, and easy access to healthcare facilities. An example of how a lack of investment in the health of people may affect economic development can be seen in a situation where there is a high rate of mortality among the general population due to lack of adequate healthcare facilities (Ejim 2013). The WHO considers investments in the physical wellbeing of individuals a pre-requisite for reducing poverty and inducing sustainable socio-economic development (WHO 2003). The indicator that is used to assess this sub-domain is:

7.6.1.2.1 Health Expenditure, Public (% of GDP)

Public health expenditure consists of recurrent and capital spending from government (central and local) budgets, external borrowings, and grants (including donations from international agencies and nongovernmental organizations), and social (or compulsory) health insurance funds. It is expressed as % of GDP (WB 2013).

The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from WHO/National Health Account database (see http://apps.who.int/nha/database for the most recent updates) (WDI 2013). The country with the highest value in the world is Cuba, with a value of 10.99%. The country with the lowest value in the world is Zimbabwe, with a value of 0.00% (Barrientos 2013).

7.6.1.3 Innovation Sub-Domain

Innovation is another major driver of economic growth, development, and in providing better jobs. This economic aspect innovation sub-domain complements the social dimension one discussed earlier. The ultimate goal of this sub-domain is to ensure that the country continues to invest in the area of innovation. It would guarantee that knowledge would be transferred from current to future generations. It will provide a sustainable economic, social, and environmental development. The indicator that is used in this research to assess investment in innovation is research and development expenditure (% of GDP) as discussed below.

7.6.1.3.1 Research and Development Expenditure (% of GDP)

Gross research and development (R&D) expenditure provides an indication of the expenditure patterns relating to promoting knowledge. It includes experimental development, basic and applied research. It encompasses current and capital expenditures (both public and private) in inventive work that is methodically undertaken to improve knowledge such as that of humanity, culture and society, and the use of knowledge for new applications (WB 2013). Furthermore, technological, pharmaceutical, and health care companies reinvest significant amount of their profit back into the R&D, since it is generally believed that this is a key for their continued growth.

Expenditure on research and development (R&D) is one of the most widely used measures of innovation inputs. R&D expenditure as a percentage of GDP is used as an indicator of an economy's relative degree of investment in generating new knowledge.

To focus decisions and public funding on investment in building new knowledge, policy makers in many countries adapted this indicator. It is interesting to note that Israel stands out in term of their investments in research where Israel has the highest R&D investments, which accounts for more than 4% of GDP (OECD 2011).

R&D expenditure unit is % of GDP. The data is obtained from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013), that are derived from United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics (WDI 2013).

7.6.2 Resource Depletion Domain

Resource depletion is considered one of the original drivers behind the call for sustainability. Since natural nonrenewable resources depletion by mining, petroleum extraction, and forestry has substantial negative consequences on the sustainability of Mother Nature. Once extracted, they cannot be restored. Many reports were published to document these devastating outcomes as discussed in the sub-domains.

Collectively, global organizations such as UN continued to encourage countries to sustain their natural resources and attain sustainable economic development by recovering their hidden value and extending their usefulness by reusing and recycling. The sub-domains that will be included in this domain are discussed below:

7.6.2.1 Natural Resources Sub-Domain

Consumption oriented economies combined with development in technology have been joined with an accelerated rate of depletion of natural resources. These are usually finite in supply and their unsustainable extraction has dreadful impact on current and future generations. For example, in 2005, more timber was removed from forests than ever reported. This is partially to expand soybeans implantation in South America to mainly increase meat production that hit a record 276 million tons in 2006. Moreover, climate change is altering the migration routes of fish, increasing sea levels leading to coastal erosion. Also, ocean acidity is increased since oceans absorbed half of the CO_2 released by human beings in the previous two centuries. These changes in the ocean environment are associated with a major increase in seafood consumption. It is worthwhile to keep in mind that on average we realized a 3 fold increase in the seafood consumption per person relative to that reported in 1950. Furthermore, around 100 million people were affected by weather related disasters. In addition, steel production hit a record of 1.24 billions tons in 2006. On the other hand, aluminum production hit a record of 33 millions tons the same year. Interestingly, aluminum production is responsible for 3% of global energy consumption (Shapley 2007).

In this research, the main natural resources that are considered are forests, minerals, and energy sources i.e. coal, crude oil, and natural gas. The index that is used in the calculation and reflects the depletion of these critical resources in the country is:

7.6.2.1.1 Adjusted Savings: Natural Resources Depletion (% of GNI)

As outlined earlier, consumption oriented economy is resulting in the depletion of earth's precious natural resources. This index determines the amount of depleted natural resource in the country by measuring the sum of net forest depletion, energy depletion, and mineral depletion. Net forest depletion is the unit resource rents times the excess of round wood harvest over natural growth. Energy depletion is the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at

25 years). It includes coal, crude oil, and natural gas. Mineral depletion is the ratio of the value of the stock of mineral resources to the remaining reserve lifetime (capped at 25 years). It includes tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite, and phosphate (WB 2013).

The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013), that are principally WB staff estimates based on sources and methods in WB's "The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium" (2011) (WDI 2013).

7.6.2.2 Energy Sub-Domain

It is projected that the global oil supply will be depleted by 2057 as noted by the American Petroleum Institute (Appenzeller 2004). This is consistent with the accelerated rate of energy consumption that is happening at a rate that is significantly faster than its replenishment. Consequently, this is a major concern that is leading to a major increase in the prices of fuel, mainly petroleum derived products, and food worldwide.

Oil is an important source for energy, which our lives continue to depend on. Therefore, we need to be efficient in oil use and rely on more renewable energy sources. This sub-domain has been evaluated using three indices:

1. Adjusted Savings: Energy Depletion (% of GNI)
2. GDP per unit of energy use (PPP $ per kg of oil equivalent)

7.6.2.2.1 Adjusted Savings: Energy Depletion (% of GNI)

It is defined by WB as" Energy depletion is the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years). It covers coal, crude oil, and natural gas." (WB 2013). This indicator has already been incorporated in the previous index (i.e. Adjusted Savings: Natural Resources Depletion (% of GNI)). Therefore, it was omitted from further consideration to avoid redundancy.

The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from International Energy Agency (IEA Statistics © OECD/IEA, http://www.iea.org/stats/index.asp), and WB PPP data (WDI 2013).

7.6.3 Economy Domain

As discussed in Chapter 6, this reflects the economic system in a certain region; the main goal is to assess the status of the economy of the nation and ensure that it is sustainable and offers wealth, comfort and necessities to its people. Furthermore, it reflects the standard of living of the people, which, as mentioned earlier, is one of the main focal indices considered in the Human Development Index (HDI). This associated with higher as income, availability of employment, less poverty rate, less inflation rate … etc, which are linked to a higher level of the quality of life and wellbeing that the people enjoy in their country.

7.6.3.1 Status Sub-Domain

Three indicators have been used to assess the status of the country's economic system:

1. Inflation, consumer prices (annual %)

2. Gross domestic savings
3. GDP per capita growth (annual %)

Below is a review of each one of them.

7.6.3.1.1 Inflation, Consumer Prices (Annual %)

Inflation is the increase in the prices of goods and services in a country over a period of time (the December-to-December change in the U.S). Inflation results in a reduction in the purchasing power of country constituents. As a result, each unit of money buys less goods and services. This would harm the average workers wallet, since their wages lag, cost of living rises, and average families struggle to keep up with the increase in the goods and services prices (Blanchard 2000). One of the worst inflations is the food inflation. It may lead to revolutions by the people. This was a major driver for the demonstrations that happened in Tunisia, Egypt, and Syria and may as well spread to other countries in the Middle East and North Africa (AFP 2011). Inflation would definitely affect the security of the country, which has a negative impact on the social sustainability of the country as discussed earlier.

Inflation, Consumer Prices (Annual %) index is the indicator that is used in this research to measure and compare inflation in the countries studied. The WB defines it as "the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. The Laspeyres formula is generally used" (WB 2013).

The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013), that are derived International Monetary Fund, International Financial Statistics and data files (WDI 2013).

7.6.3.1.2 Gross Domestic Savings

Gross domestic saving (GDS) is a savings rate that refers to the percentage of the country GDP savings by households in a country. It indicates the country financial state and growth, as household saving is the main source of government borrowing to fund public services. It varies among countries and is influenced by various factors such as retirement age, borrowing constraints, income distribution over lifetime, demography and welfare state (OECD 2013). For example, a country that pays retirement pensions generated from tax levied on people of working age will have lower national saving rate (NSR) compared to countries where people have to save to personally provide for their retirement.

According to the WB, GDS is calculated as GDP less final consumption expenditure (total consumption) (WB 2013).

The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013), that are derived from WB national accounts data, and OECD National Accounts data files (WDI 2013) .

7.6.3.1.3 GDP Per Capita Growth (Annual %)

Economic growth is primarily the rise in the amount of the goods and services produced by a country over a period of time. It is calculated as the annualized percentage growth rate in GDP. However, when the focus is on standard of living, which is the focus of this research, then the index GDP per capita growth (annual %) is used. This is fundamentally economic growth that is expressed on a per capita basis, i.e. annual percentage growth rate of GDP divided by midyear population. It is interesting to note that over long periods of time; even small increase in the arte would have a huge outcome. This is mainly attributed to the power of compounding. The WB defines GDP per capita growth (annual %) as "annual percentage growth rate of GDP per capita based on constant local currency. GDP per capita is gross domestic product divided by midyear population. GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources" (WB 2013).

The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013), that are derived from WB national accounts data, and OECD National Accounts data files (WDI 2013).

7.6.4 Sustainability Innovation Domain

This domain focuses on the country investments and its implementation and utilization of new clean technologies and strategies that harness renewable materials and energy sources with a goal of significantly reducing the use of non-renewable natural resources. It also assesses the country's ability to adopt new technologies that would eliminate emissions and wastes. Moreover, this approach would increase the sustainability of the country and improve the wellbeing of its people now and in the future. It also plays a key role in creating new job opportunities that require skilled and well trained people to new approaches.

Below is a discussion of the sub-domains and their relevant indicators.

7.6.4.1 Resources Sub-Domain

This sub-domain reflects the use and investments in technologies and approaches that would significantly reduce the use of non-renewable natural resources and eliminate associated emissions and wastes. The 2 indicators that are used to assess this sub-domain are:

1. %Recycling and Reusing Rates
2. Investment in Sustainable Resources

7.6.4.1.1 % Recycling and Reusing Rates

Recycling is a key component of modern waste reduction and is the third component of the "Reduce, Reuse, Recycle" waste hierarchy (Jaafar, Venkatachalam et al. 2007). Recycling is a material recovery process because of its transformation of returned products into valuable resources. It manages solid waste, reduces the consumption of fresh raw materials, reduces air and water pollution by decreasing the need for "conventional" waste disposal, and conserves energy. Recycling is good for the environment as well as the economy! Since it has twice the economic impact of disposal. For example it generates $10 billion worth of taxable economic activity each year in California alone (CIWMB 2005).

The recycling data are collected from Yale Center for Environmental Law and Policy. These are used in the calculation of Environmental Sustainability Index (from 1980-

2000). This is annually published by the website of Socioeconomic Data and Applications Center (SEDAC) that is hosted by CIESIN at Columbia University (last accessed March, 2013). These data are derived from OECD and United Nations Human Settlement Programme (UNHABITAT), plus country data (Esty, Levy et al. 2002).

7.6.4.1.2 Investment in Sustainable Resources

This index focuses on the amount of investments each country invest as a percentage of its GDP in adopting cleaner production and implementation of new technologies that involve those focused on the utilization of renewable natural resources. However, for the lack of data, this variable has been omitted from the index.

7.6.4.2 Energy Sub-Domain

A good cause that is driving the need for adopting this philosophy is our reliance on oil, which is a major global source that is used as fuel and to generate electricity. For example, around 40% of the European Union's energy resource originates from oil. As a result, adapting new approaches that expand the utility of renewable energy such as the use of solar, wind, and nuclear energy would play a key role in extending the shelf life of available oil reserves beyond year 2057. The 2 indicators that are used to assess this sub-domain are:

1. Electricity Production from Renewable Sources (Kwh)
2. Investment in Sustainable Energy

7.6.4.2.1 % Electricity Production from Renewable Sources

This index assesses the extent of the nation's reliance on producing energy from renewable sources. Therefore, as the nation's dependence on non-renewable energy sources decreases so the negative impacts on the environment. This index is the ratio of the amount of electricity production from renewable sources (kWh) divided by the total of electricity production (kWh) in the country.

Electricity production is measured at the terminals of all alternator sets in a station. In addition to hydropower, coal, oil, gas, and nuclear power generation, it covers generation by geothermal, solar, wind, tide and wave energy, as well as that from combustible renewable and waste. Production includes the output of electricity plants that are designed to produce electricity only as well as that of combined heat and power plants (WB 2013).

The data are collected from the WB, WDI Catalog (from 1990-2012) that is published annually by WB (last accessed March 18, 2013). They are derived from International Energy Agency (IEA Statistics © OECD/IEA, http://www.iea.org/stats/index.asp), Energy Statistics and Balances of Non-OECD Countries, Energy Statistics of OECD Countries, and Energy Balances of OECD Countries (WDI 2013).

7.6.4.2.2 Investment in Sustainable Energy

This index focuses on the amount of investments each country makes as a percentage of its GDP in adopting renewable energy. However, for the lack of data, this variable has been omitted from the index. It should be emphasized that this indicator is indirectly reflected in the previous index Electricity production from renewable sources (Kwh).

7.7 Implemented Sustainability Prosperity Index Methodology

7.7.1 Data Imputation

In the previous Chapter, the main data imputation approaches that are widely used in the literature were reviewed. While missing data have not been a major issue, in this research, missing data were imputed mainly using two approaches which are:

1. Substitution: where missing data is replaced with values not part of the original observed data set yet with similar characteristics of the missing data. For example, this is the technique used to fill the missing data for South Africa and Argentina where the average of the rest of the BRICS countries was used. For Saudi Arabia missing data United Arab Emirates data was used.
2. The mean imputation: where the variable's mean of the observed values over the years replaces the missing data. This approach was used for all other missing data.

7.7.2 Making Variables Comparable

To effectively compare among the G-20 group, this research ensured the use of various methodologies to render the variables comparable. Herein, the data were adjusted with respect to populations, income (i.e. per capita …etc.). Also, some variables measurement units were transformed into the same unit, prior to normalization, weighting and aggregation. This made direct comparisons among the G-20 countries feasible and resulted in a reliable interpretation.

7.7.3 Reverse Transformation

Reverse transformation was applied on a set of indicators where high values before transformation are associated with poor sustainable development. This ensures that high values translate to sustainable development. It enables better assessment of progress toward sustainable development. Table 7-5 summarizes the indicators that underwent reverse transformation and reverse transformation justification. The methods used to transform the three dimensions are as follow. All environmental variables were transformed using the principle of distance to reference, which was discussed in Chapter 6. For economic variables, only natural depletion and inflation consumer prices percentages were reverse transformed by subtracting their values from 100%. Finally, for social indicators, inverse transformation was applied on pupil to teacher ratio, divorce rate, and global peace index. As for mortality rate, it was subtracted from 1000. For fertility rate, the value was first divided by 2.33[i], if the resulted value was higher than 1, then inverse transformation was applied, While, if the resulted value was lower than 1, the value was used as is. Finally, for freedom index, the index was divided 7, which is the highest reported freedom index, and then multiplied by 100%. The obtained value was then subtracted from a 100.

Table 7.5: Variables that underwent reverse transformation, their dimensions and justifications.

Dimension	Variable	Justification
Environmental	All	The higher the indicator the worse the situation. Therefore, the inverse was applied.
Economic	Adjusted Savings	This is based on the view of sustainable consumption that is biased in part on Hicksian notions of living within limits that allow individuals or nations to remain "as well-off"
	Inflation, consumer prices (annual %)	It measures changes in the price level of a market based of consumer goods and services purchased by households. An increase in the inflation is an indication of the real value of wages, salaries, and for deflating monetary magnitude. Thus the higher the inflation% the worse it is for the economic sustainability of the country i.e. social security and healthcare in USA.
Social	Mortality rate, under-5 (per 1,000 live births)	high values in infant mortality rates reflect poor health status
	Fertility rate, total (births per woman)	A population that maintained a TFR of 3.8 over an extended period of time without a correspondingly high death or emigration rate would increase rapidly, whereas a population that maintained a TFR of 2.0 over a long time would decline, unless it had a large enough immigration
	Pupil-teacher Ratio, Primary	the higher the ratio the worse it is for pupils since this will not enable them to have access to their teachers and would result in worse education performance
	Divorce Rate	the higher the arte the worse it is for the community
	Freedom Index	Based on its calculation methodology the higher the less freedom in the country thus should be reversed
	Global Peace Index	The higher the Global Peace Index the worse the situation. Therefore, the inverse was applied.

7.8 The Sustainability Index Weighting, Normalization, and Aggregations Methods Used

This research compares the progress toward sustainable development of the G-20 countries. A key factor that is considered is the implementation of a weighting scheme that is easy to communicate and comprehend. Therefore, DEA was chosen for this task. Indeed, one of the key attributes of this approach that makes it appealing to policy makers is its weights that are rather country specific. The details of this methodology are outlined below.

Moreover, DEA can handle multiple inputs and outputs that have very different units, and without an assumption of a functional form relating inputs to outputs. Consequently, in this research, no normalization method on the data used was implemented.

Finally, data aggregation is a process where data collected is expressed in a summary form that would enable statistical analysis and representations of findings. This allows better data interpretation and communication. For this reason, employing DEA as a weighting method requires that additive aggregation to be used to construct this sustainability index (Nardo, Saisana et al. 2005). The detail of additive aggregation is discussed in Chapter 6.

7.8.1 Data Envelopment Analysis (DEA)

7.8.1.1 Background and History of DEA

DEA is a non-parametric tool for assessing comparative efficiencies of homogeneous decision making units (DMUs) using several inputs consumed to produce several outputs. While its roots can be traced back to 1957 when Farrel used linear programming techniques for measuring the efficiency in U.S. agriculture (Farrell 1957). This technique's initial development was in 1978 by Charnes, Cooper and Rhodes, when they introduced the first model and was named as CCR after their initials (Charnes, Cooper et al. 1978). This technique can be successfully applied in various evaluation scenarios to measure the efficiency of different systems e.g. hospitals, industries, products, not-for-profit organizations, business firms, manufacturing sites, banks and others, including the performance of countries, regions etc.

DEA utilizes linear programming to construct an *efficiency frontier,* that is utilized as a benchmark to determine the progress i.e. performance of a set of DMUs i.e. countries, hospitals. A set of input and output weights, that maximize the collective output input ratio for every DMU, are determined for each system based on its relative position (distance) of its either the vertical (output orientation) or horizontal (input orientation) to this *efficiency frontier* where weights are system dependant.

It should be emphasized that the set for both input and output weights are neither assigned by the user, nor measured using the same units. Indeed, they are determined by the program to illustrate each unit in its superlative outcome to maximize each DMU's efficiency relative to those of others investigated. Overall, these are major attributes that differentiae DEA form other known approaches (PEDRAJA-CHAPARRO, SALINAS-JIMENEZ et al. 1997).

The construction of the *efficiency frontier* depends on the following assumptions, first the weights used are positive, second, systems are not discriminated against i.e. no priorities given and systems are equally ranked; and finally, the feasibility of the linear combination of the best performers i.e. the convexity of the frontier (Nardo, Saisana et al. 2005).

7.8.1.2 Concept of Efficiency

Efficiency is a relative, measurable concept that can be simply determined by the ratio of output to input. The absolute or optimum efficiency can be attained by any unit if and only if neither its inputs nor its outputs can be improved without degenerating any of its other inputs, outputs, new technology, or modification in the system (Koopmans 1951).

In DEA, the concept of efficiency can be defined as a measure of performance between 0 and 1within a group of homogeneous DMUs that is evaluated relative to a best performer which is accounted a score of 1. It is worth noting that within the same set of DMUs there can be more than 1 best performer (Andersen and Petersen 1993). For a DMU to be considered efficient, it should have a score of 1 and as a minimum one nonzero weight in its inputs and one nonzero weight in its outputs. Otherwise, the DMU is considered as inefficient.

DEA would identify a “frontier" composed of best performers, which DEA uses to benchmark other DMUs against those best producers (efficient). Figure 7.1 shows a graphical representation of the method. Units P1, P2, P3 and P4 were identified as best performers and considered efficient. These units are connected with a line that is called "envelopment surface" where it envelopes all the inefficient DMUs that are not on the line and shows the difference between their performance and the "best performer" (100% efficient) units to which they have been compared.

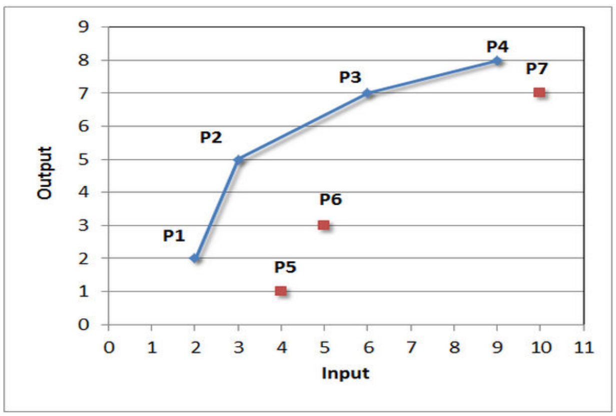


Figure 7.1: A graphical representation of the Data Envelopment Method (DEA).

7.8.1.3 Mathematical Formulation

The mathematical formulation of the DEA model was originally proposed by Charnes et al.(Charnes, Cooper et al. 1978) to solve for maximizing the relative efficiency of a set of decision-making units (DMUs) in the form of a ratio of a weighted sum of the outputs to a weighted sum of the inputs. If there are *n* decision-making-units, each producing *s* different outputs using *r* different inputs. The efficiency ratio for the decision making unit *o* is being represented by a fractional program as follows:

$$Max\ Z_o \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}}$$

$$s.t.: \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, j = 1, \dots \dots, n$$

$$v_i, u_r \geq 0, \qquad \forall i, r$$

Where:

Z_o *is relative efficiency of the DMU o*

s is the number of outputs

r is the number of inputs

y_i *= the* i^{th} *output produced by the DMU*

x_j *= the* j^{th} *input employed by the DMU*

u_i *= s x 1 vector of output weights*

v_j *= r x 1 vector of input weights..*

i runs from 1 to s

j runs from 1 to r.

The constraints that are added to the model are to ensure the positivity of the weights and that the relative efficiency is between 0 and 1.

The previous efficiency score is being measured using a nonlinear program in the form of fractional programming, in order to make it easier to solve, it has to be transformed into a linear programming as done by Charnes et al. (1978) (Charnes, Cooper et al. 1978). It is achieved by dividing the objective function (i.e. the ratio term) in the fractional program into two parts, the nominator would be the objective function of the linear program and the denominator is transformed into a constraint that is equal to 1. On the other hand, the fractional constraint is transformed into a linear constraint in the linear program. These two constraints would ensure that the objective function would be less than or equal to 1. Finally, to ensure the positivity of the weights, non-negativity constraints are also added as the original program.

The efficiency ratio for the decision making unit *o* is being represented by the linear program as follows:

$$Max\ Z_o \sum_{r=1}^{s} u_r y_{ro}$$

$$s.t.: \quad \sum_{i=1}^{m} v_i x_{io} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} \leq \sum_{i=1}^{m} v_i x_{ij}, j = 1, \ldots \ldots, n$$

$$v_i, u_r \geq 0, \qquad \forall i, r$$

Solving the above DEA model results in the efficiency for the specific DMU along with its associated inputs and outputs optimal weight combination. To calculate the efficiencies for all DMUs a separate linear program needs to be solved for each of them.

7.8.1.4 Constant Returns to Scale versus Variable Returns to Scale

Using the original CCR model, DMU's are compared based on the assumption that there is a constant return-to scale (CRS) relationship between the inputs and the outputs as discussed in the previous section. CRS refers to that there is a proportional relationship between inputs and outputs, where a decrease/increase in inputs is associated with a proportional decrease/increase in output values. It is interesting to note that this model disregard the notion that various DMU's could be operating at different scales. Banker and co-workers developed a novel model (the BCC model) to overcome this limitation by taking into consideration variable returns to scale (VRS) (Banker, Charnes et al. 1984). Unlike CRS, in this model the changes in the inputs will not be associated with the same proportional change in the output. Additionally, VRS can be further categorized into either decreasing returns to scale (DRS); where the output level increases less than the input level, or increasing returns to scale (IRS) if the output level increases more than the input level.

$$Max\ Z_o\ \frac{\sum_{r=1}^{s} u_r y_{ro} -\ u_o}{\sum_{i=1}^{m} v_i x_{io}}$$

$$s.t.: \frac{\sum_{r=1}^{s} u_r y_{rj} -\ u_o}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, j = 1, \dots \dots ., n$$

$$v_i, u_r \geq 0, \qquad \forall i, r$$

$$u_o\ is\ unestricted$$

7.8.1.5 Input-Output Orientation

DEA models can also be determined by the orientations of their inputs and outputs. For example, Output-orientated model is the one where the inputs are fixed while the amount by which outputs can be proportionally increased. On the contrary, an input-orientated model is the one where the outputs are fixed while the amount by which inputs can be proportionally reduced. It is worth noting that efficient and inefficient DMU's will be maintained regardless, data set were solved using input and output models separately treated. However, the efficiency scores of the output oriented model in CRS models will be 1 divided by the efficiency score resulted from the input oriented model. Alternatively, in VRS models, scores of inefficient DMUs will be different for each type.

The input-orientated model can be represented mathematically as:

$$Max\ Z_o = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}}$$

$$s.t.: \quad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \quad j = 1, \dots \dots, n$$

$$v_i, u_r \geq 0, \qquad \forall i, r$$

On the other hand, the output-orientated model can be represented mathematically as:

$$min\ Z_o = \frac{\sum_{i=1}^{m} v_i x_{io}}{\sum_{r=1}^{s} u_r y_{ro}}$$

$$s.t.: \quad \frac{\sum_{i=1}^{m} v_i x_{ij}}{\sum_{r=1}^{s} u_r y_{rj}} \leq 1 \quad j = 1, \dots \dots, n$$

$$v_i, u_r \geq 0, \qquad \forall i, r$$

7.8.1.6 Strengths and Weaknesses of DEA

This technique is considered an easy principle to communicate. In addition, it is embraced by policy makers since any another weighting technique would be associated by lower composite scores. This is attributed to the observation that the weights are endogenously determined by the observed performances, which is the result of policy priorities. Instead of its reported merits, DEA has major disadvantages that limit its use and application. For example, due to its methodology that results in endogenously "system-specific" determined weights, some researchers believe that comparisons cross systems is not feasible. This approach is also considered as "incentive generating" which encourages the maintenance of status-quo since its methodology maximizes the problem which leads to higher weights and scores.

Furthermore, one of the most critical drawbacks of DEA is its inability to discriminate among efficient DMUs. This is usually reported when the number of DMUs being analyzed is small relative to the total number of input and output variables used in the analysis. Another contributing factor is the unrealistic weighting scheme that assigns more weights to variables with less importance, and less or (even zero) weights to crucial variables.

7.8.1.7 Methods for Increasing Discrimination in DEA

7.8.1.7.1 Weight Restrictions and Effects

As mentioned in section 6.3.5.9, DEA's initial development was in 1978 by Charnes, Cooper and Rhodes, when they introduced the first model and was named as CCR after their initials (Charnes, Cooper et al. 1978). The original model utilizes linear programming to construct an efficiency frontier. This is utilized as a benchmark to determine the performance of DMUs. It is worth noting that this model does not integrate any weights restrictions on the inputs and outputs. They are allowed to vary freely and determine the optimal set of weights that would maximize the efficiency score of each DMU (Cooper, LEWIN et al. 1995). Indeed, unconstrained DEA model would aim at generating the highest efficiency score possible for each DMU investigated. This is accomplished by assigning either a large or a minimal (or sometimes zero) weight to particular inputs and outputs depending on their performance so as to appear efficient (HALME, JORO et al. 1999) . This renders the outcome of the model of not being realistic which continues to be a major limitation for this methodology (ALLEN, ATHANASSOPOULOS et al. 1997). It should be stressed that this problem is especially paramount consider since in this research the way the model is developed we believe that all variables are important and should all be considered. Incorporation of reasonable input and output weights restrictions into the standard DEA model would generate more reliable and realistic results for the purpose of this study.

The major goal of weight restrictions is to add limits to the generated weights while maintaining some flexibility on the true value of weights. This approach will reduce the number of efficient DMUs which will increase and improve its discrimination.

7.8.1.7.2 Approaches to Incorporate Weights Restrictions into Standard DEA Model

There are several methods that are presented in the literature for placing restrictions on input and output weights in DEA. Below is a discussion of some of the main methods that can be implemented. For more in depth discussion on weight restriction methods the reader is referred to(ALLEN, ATHANASSOPOULOS et al. 1997; Pedraja-Chaparro, Salinas-Jimenez et al. 1997; Angulo-Meza and Lins October 2002,).

7.8.1.7.2 Direct Weight Restrictions

This is a widely implemented weight restrictions approach that was developed by Dyson and Thanassoulis (DYSON and THANASSOULIS 1988).

It impose numerical limits on the weights, which is pivotal in limiting the unrealistic weighting scheme that assigns more weights to variables with less importance, and less or (even zero) weights to crucial variables, while maintaining some flexibility to the true value of weights. It is interesting to note that the numerical limits imposed are usually dependant on the framework as well as expert opinion. Moreover, such limits are imposed following an understanding of the analysis obtained from the original unrestricted DEA analysis.

The number of weight restrictions added is as the number of weights to the original linear program as follows:

$$l_i \leq v_i \leq U_i \quad for\ inputi\ weight$$

$$l_r \leq u_r \leq U_r \quad for\ output\ r\ weight$$

Where *l* is the lower numerical limit and *U* is the upper numerical limit.

7.8.1.7.3 Ranking Weight Restrictions Method

Another widely used approach for weights restrictions in DEA is the ranking weight restrictions method. This method is based on rank ordering weights to illuminate their relevance and significance in the analysis (DYSON and THANASSOULIS 1988) .

There are two forms of ranking, it can be either basic or weighted ranking. The weight restrictions added to the original linear program are as follows:

Basic ranking where weights are ranked as follows:

$$v_1 \leq v_2 \leq v_3 \leq \cdots \leq v_i$$

Or weighted ranking where weights are ranked as follows:

$$2v_1 \leq 4v_2 \leq 6v_3 \leq \cdots \leq 100v_i$$

7.8.1.7.4 Variables Reduction using PCA-DEA

As discussed in the previous section, the selection of variables (indicators) for the countries case was based on the goal of comprehensively measuring the sustainable prosperity of these countries and ensuring that each sub-domain has been incorporated in this assessment. DEA, which is a data oriented, non-parametric and non-statistical method was used to discriminate among countries toward their progress to achieve sustainable prosperity. While the variable selection is unhindered, high number of variables expressed as inputs and outputs using DEA would distort the output efficiency. This further undermines the quality of the analysis and the ability to achieve an efficient differentiation among countries in their progress toward achieving sustainable development (Jenkins and Anderson 2003; Adler and Yazhemsky 2010; Nataraja and Johnson 2011). Indeed, when DEA was implemented alone and considering the large number of inputs and outputs utilized (a total of 49 variables), this methodology fell short of discriminating among the G-20 countries, where all countries investigated were considered sustainable (efficiency score of 1). To overcome these limitations, principle component analysis (PCA) was used to transform the possibly correlated original inputs and outputs collected in this research into a set of values that are uncorrelated linear combinations of original inputs and outputs termed principle components. PCA also captures most of the original variance of the data and reduces the dimensionality of the production function.

Research groups reported that combining DEA and PCA methodologies resulted in more stable estimation results compared to using DEA alone. For example Fu et al demonstrated the utility of combining PCA and DEA to improve the accuracy of the

Chapter 8: Countries' Case: Results and Discussion

8.1 Introduction

The Sustainable Prosperity Index (SPI) is based on a framework that is used as a comprehensive evaluation methodology that assesses both the sustainable development and prosperity of a "system". Indeed, this index is versatile to be applied to a wide range of systems that includes industries, services, and products. The goal is to address the concern that sustainable development is believed by some politicians and policy makers to limit economic progress and undermine prosperity. The aim is to ensure that sustainable progress moves hand in hand with system profitability and encourage policy makers to adopt policies that successfully achieve both dimensions.

The methodology of the countries' case was presented in Chapter 7. This model was applied on the G-20 countries which are the top 20 countries that drive the global economy. Chapter 8 provides an overview of the index countries' case results with discussion of the findings obtained from the development and application of this index.

8.2 Scenario 1 - SPI Results Using Conventional Normalization and Weighting Techniques

The first approach that was implemented to calculate the Sustainability Index leg of SPI was adapted from the Human Development Index[30] (HDI) methodology. This is a widely used index that is developed by United Nations (UN), accepted by the general public, and adapted by policy makers. Its methodology is based on re-scaling normalization technique, which converts the variable values, using a ratio that is based

[30] See Chapter four for more information and background of this index.

on the range of the data rather than its standard deviation, into normalized scores. This ensures that all values have an identical range [0-1], and the averaging weighting method[31].

When implemented the maximum and minimum values used were identified for each given variable across all the countries over the course of years investigated [1990-2012]. Tables 8.1, 8.2, and 8.3 summarize the results of the Sustainability Index, Wealth Index scores, and Sustainable Prosperity Index scores obtained using this methodology, respctively. The Sustainable Prosperity Index was calculated using the following equation:

$$SPI = \sqrt{Sustinablity\ Index^2 + Wealth\ Index^2}$$

All developed countries that are part of G-20 group had an overall sustainability index that is higher than 0.60 over the course of 23 years. None of the developing countries had this trend, suggesting that their adapted practices and policies are still lagging behind those implemented by developed countries. When sustainability score in 2012 compared with 1990, all developed countries maintained a constant ratio that is around [0.90 – 1]. On the other hand, countries such as China, Argentina, Brazil, and Saudi Arabia realized 1.34, 1.07, 1.03, and 1.02 folds increase in their overall scorers, respectively. India and Indonesia observed a decrease in their scores to 0.83 and 0.88 fold of their scores in 1990, which is the lowest compared to other countries investigated. Figures 8.1 and 8.2 depict the average rescaling SPI scores for developed and developing countries between 1990-2012, respectively. Interestingly, the SPI

[31] See Chapter six for more information and background of these methods.

scores for these countries didn't change significantly over the course of time. For example, Saudi Arabia and Canada had the lowest and highest ranking in 1990 and 2012, respectively. Despite the major changes in policies implemented in the economic, social, and environmental areas over the 23 years. Furthermore, there are no major intra-country changes over the course of the years. Indeed, if pursued, this approach doesn't offer policy maker any incentive to adapt and implement policies that would increase sustainable prosperity. This is a key drawback for the implementation of this methodology (see Table 4.7).

Figure 8.3 illustrates the SPI visualization for the G-20 countries for the year of 2012 using the principles discussed in Chapters 6 and 7. The wealth index is placed on the x-axis scaled from 0 to 1 measuring progress made toward wealth accumulation by the system investigated. While on the y-axis system's sustainability index is plotted. Each axis is divided into five bands of 0.20 points each. They diverge from bad (red, Unsustainable Prosperity) to good (green, Sustainable). The intersection point of the two indices is plotted in the graph, to portray the overall sustainable prosperity of the G-20 countries. Interestingly, no countries based on this methodology was shown to be sustainable. Both Canada and USA had the best outcome and were considered "Almost Sustainable". India and Indonesia were considered "Unsustainable Prosperity".

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
South Africa	0.30	0.31	0.32	0.31	0.29	0.30	0.27	0.29	0.30	0.32	0.30	0.27	0.26	0.27	0.27	0.26	0.26	0.23	0.21	0.23	0.23	0.23	0.22
United States	0.64	0.63	0.64	0.63	0.64	0.62	0.64	0.63	0.65	0.65	0.66	0.65	0.67	0.66	0.68	0.66	0.66	0.65	0.63	0.64	0.62	0.60	0.61
Canada	0.79	0.78	0.77	0.77	0.76	0.75	0.74	0.75	0.74	0.74	0.75	0.72	0.76	0.75	0.75	0.76	0.76	0.76	0.73	0.74	0.74	0.75	0.75
Mexico	0.28	0.29	0.31	0.33	0.34	0.32	0.32	0.33	0.31	0.33	0.35	0.34	0.34	0.33	0.37	0.33	0.33	0.32	0.32	0.33	0.32	0.33	0.32
Brazil	0.46	0.45	0.44	0.44	0.44	0.43	0.47	0.43	0.44	0.37	0.39	0.38	0.39	0.39	0.41	0.39	0.43	0.43	0.45	0.45	0.46	0.46	0.46
Argentina	0.41	0.44	0.45	0.47	0.48	0.46	0.46	0.45	0.47	0.46	0.48	0.45	0.41	0.39	0.40	0.40	0.41	0.44	0.45	0.46	0.44	0.45	0.46
China	0.19	0.19	0.19	0.19	0.20	0.19	0.19	0.20	0.23	0.25	0.22	0.19	0.20	0.20	0.17	0.17	0.18	0.18	0.20	0.21	0.18	0.21	0.25
Japan	0.63	0.64	0.62	0.62	0.62	0.61	0.60	0.60	0.60	0.62	0.62	0.61	0.60	0.59	0.60	0.58	0.57	0.56	0.56	0.56	0.55	0.54	0.56
South Korea	0.45	0.46	0.46	0.46	0.46	0.45	0.45	0.44	0.42	0.43	0.45	0.47	0.48	0.49	0.49	0.50	0.52	0.52	0.53	0.48	0.47	0.49	0.50
India	0.25	0.23	0.22	0.21	0.21	0.21	0.19	0.20	0.22	0.25	0.21	0.20	0.19	0.20	0.16	0.18	0.19	0.17	0.16	0.17	0.16	0.15	0.17
Indonesia	0.18	0.18	0.18	0.18	0.18	0.18	0.20	0.17	0.13	0.18	0.17	0.15	0.16	0.16	0.17	0.15	0.17	0.17	0.16	0.19	0.18	0.18	0.19
Russia	0.49	0.49	0.48	0.49	0.47	0.47	0.45	0.47	0.43	0.42	0.38	0.37	0.40	0.41	0.42	0.44	0.47	0.49	0.48	0.49	0.45	0.47	0.51
Turkey	0.33	0.33	0.34	0.35	0.34	0.31	0.31	0.32	0.32	0.30	0.31	0.30	0.32	0.32	0.32	0.31	0.34	0.33	0.34	0.35	0.34	0.34	0.34
European Union	0.55	0.56	0.56	0.55	0.55	0.56	0.55	0.55	0.54	0.54	0.55	0.54	0.55	0.56	0.58	0.57	0.57	0.58	0.58	0.58	0.57	0.56	0.57
Germany	0.60	0.58	0.59	0.57	0.57	0.58	0.58	0.57	0.58	0.57	0.57	0.56	0.56	0.57	0.58	0.56	0.57	0.58	0.58	0.60	0.57	0.60	0.60
France	0.64	0.63	0.63	0.63	0.63	0.64	0.64	0.63	0.63	0.63	0.63	0.64	0.64	0.66	0.67	0.66	0.66	0.67	0.66	0.65	0.62	0.63	0.63
United Kingdom	0.55	0.54	0.54	0.54	0.54	0.54	0.53	0.54	0.53	0.54	0.55	0.56	0.58	0.59	0.60	0.61	0.61	0.62	0.60	0.60	0.59	0.59	0.59
Italy	0.53	0.52	0.53	0.52	0.51	0.51	0.52	0.51	0.52	0.50	0.51	0.52	0.53	0.53	0.55	0.54	0.55	0.55	0.55	0.53	0.49	0.52	0.51
Saudi Arabia	0.28	0.25	0.23	0.24	0.23	0.22	0.21	0.22	0.27	0.27	0.27	0.27	0.26	0.25	0.25	0.25	0.25	0.26	0.24	0.25	0.22	0.24	0.24
Australia	0.73	0.72	0.71	0.71	0.71	0.70	0.68	0.72	0.71	0.68	0.69	0.70	0.71	0.71	0.74	0.72	0.75	0.74	0.75	0.75	0.75	0.76	0.74

Table 8.1: The numerical results of the sustainability index scores obtained using conventional normalization and weighting techniques (Scenario 1).

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
South Africa	0.73	0.74	0.73	0.81	0.72	0.72	0.70	0.72	0.75	0.73	0.71	0.72	0.72	0.69	0.69	0.73	0.72	0.68	0.66	0.68	0.66	0.72	0.73
United States	0.77	0.76	0.75	0.78	0.75	0.75	0.75	0.73	0.75	0.75	0.76	0.76	0.76	0.75	0.73	0.74	0.74	0.73	0.73	0.74	0.71	0.74	0.74
Canada	0.73	0.74	0.73	0.72	0.74	0.73	0.73	0.74	0.74	0.73	0.73	0.74	0.75	0.74	0.73	0.75	0.73	0.73	0.76	0.74	0.72	0.73	0.73
Mexico	0.70	0.70	0.71	0.79	0.72	0.70	0.70	0.72	0.74	0.75	0.74	0.75	0.76	0.72	0.72	0.72	0.71	0.71	0.71	0.69	0.68	0.69	0.69
Brazil	0.76	0.75	0.73	0.75	0.72	0.72	0.70	0.71	0.72	0.72	0.72	0.70	0.71	0.65	0.65	0.68	0.70	0.68	0.69	0.71	0.68	0.70	0.69
Argentina	0.71	0.71	0.73	0.70	0.74	0.73	0.72	0.75	0.75	0.73	0.72	0.72	0.68	0.65	0.63	0.65	0.64	0.62	0.64	0.64	0.63	0.66	0.67
China	0.57	0.58	0.59	0.59	0.59	0.59	0.60	0.65	0.69	0.68	0.65	0.67	0.68	0.62	0.61	0.63	0.63	0.59	0.60	0.64	0.62	0.64	0.65
Japan	0.70	0.68	0.69	0.73	0.69	0.69	0.70	0.68	0.69	0.69	0.68	0.69	0.69	0.67	0.65	0.65	0.65	0.67	0.66	0.64	0.64	0.66	0.66
South Korea	0.68	0.68	0.68	0.70	0.67	0.68	0.68	0.69	0.68	0.69	0.68	0.68	0.68	0.66	0.64	0.67	0.65	0.63	0.63	0.62	0.61	0.62	0.62
India	0.57	0.56	0.57	0.62	0.56	0.53	0.52	0.57	0.60	0.57	0.55	0.56	0.58	0.54	0.54	0.57	0.57	0.52	0.50	0.55	0.52	0.55	0.55
Indonesia	0.54	0.53	0.54	0.53	0.54	0.56	0.56	0.50	0.52	0.56	0.56	0.55	0.54	0.52	0.50	0.51	0.50	0.52	0.53	0.52	0.53	0.50	0.50
Russia	0.52	0.54	0.54	0.60	0.52	0.53	0.48	0.55	0.50	0.43	0.44	0.49	0.50	0.43	0.50	0.55	0.56	0.55	0.55	0.52	0.49	0.52	0.53
Turkey	0.55	0.55	0.54	0.51	0.50	0.50	0.50	0.49	0.46	0.49	0.52	0.51	0.52	0.51	0.49	0.49	0.51	0.51	0.53	0.52	0.50	0.53	0.53
European Union	0.53	0.54	0.55	0.57	0.50	0.49	0.49	0.52	0.52	0.52	0.56	0.55	0.56	0.55	0.52	0.54	0.53	0.53	0.51	0.54	0.53	0.56	0.56
Germany	0.50	0.55	0.56	0.59	0.56	0.54	0.56	0.56	0.56	0.53	0.54	0.55	0.52	0.56	0.54	0.54	0.53	0.56	0.55	0.55	0.54	0.54	0.55
France	0.62	0.58	0.61	0.62	0.60	0.59	0.56	0.56	0.56	0.54	0.56	0.54	0.58	0.56	0.58	0.58	0.55	0.55	0.56	0.58	0.57	0.55	0.55
United Kingdom	0.54	0.53	0.55	0.58	0.53	0.51	0.53	0.54	0.55	0.55	0.56	0.55	0.56	0.54	0.54	0.55	0.53	0.54	0.52	0.53	0.52	0.52	0.53
Italy	0.55	0.53	0.45	0.47	0.51	0.54	0.53	0.53	0.53	0.54	0.52	0.53	0.53	0.53	0.53	0.52	0.51	0.50	0.50	0.50	0.48	0.49	0.49
Saudi Arabia	0.37	0.37	0.36	0.29	0.33	0.32	0.32	0.35	0.37	0.37	0.38	0.37	0.38	0.37	0.35	0.38	0.35	0.34	0.33	0.34	0.36	0.39	0.38
Australia	0.46	0.46	0.46	0.41	0.44	0.45	0.44	0.44	0.47	0.45	0.44	0.45	0.46	0.43	0.44	0.46	0.43	0.40	0.43	0.42	0.42	0.43	0.44

Table 8.2: The numerical results of the wealth index scores obtained using conventional normalization and weighting techniques (Scenario 1).

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
South Africa	0.78	0.80	0.80	0.86	0.78	0.78	0.75	0.78	0.80	0.80	0.77	0.77	0.76	0.74	0.74	0.77	0.76	0.72	0.69	0.71	0.70	0.76	0.76
United States	1.00	0.99	0.98	1.00	0.98	0.97	0.98	0.96	0.99	0.99	1.00	1.00	1.01	1.00	1.00	0.99	0.99	0.97	0.96	0.98	0.94	0.95	0.96
Canada	1.08	1.08	1.07	1.05	1.07	1.05	1.03	1.05	1.05	1.04	1.05	1.03	1.07	1.06	1.05	1.06	1.05	1.05	1.05	1.05	1.04	1.05	1.05
Mexico	0.75	0.76	0.78	0.86	0.80	0.78	0.77	0.79	0.81	0.82	0.82	0.83	0.83	0.79	0.80	0.79	0.79	0.78	0.78	0.77	0.75	0.76	0.76
Brazil	0.89	0.88	0.85	0.87	0.85	0.84	0.84	0.83	0.84	0.81	0.82	0.80	0.81	0.76	0.77	0.79	0.83	0.81	0.83	0.84	0.82	0.83	0.83
Argentina	0.82	0.84	0.86	0.84	0.88	0.86	0.85	0.87	0.88	0.87	0.87	0.85	0.79	0.75	0.75	0.76	0.76	0.76	0.78	0.79	0.77	0.80	0.81
China	0.60	0.61	0.62	0.62	0.62	0.62	0.63	0.68	0.73	0.73	0.69	0.70	0.71	0.65	0.63	0.65	0.65	0.62	0.63	0.67	0.65	0.67	0.69
Japan	0.94	0.93	0.93	0.96	0.93	0.92	0.92	0.91	0.92	0.92	0.92	0.92	0.91	0.89	0.88	0.87	0.86	0.87	0.86	0.86	0.84	0.85	0.87
South Korea	0.82	0.82	0.82	0.83	0.81	0.81	0.81	0.82	0.80	0.82	0.82	0.82	0.83	0.82	0.81	0.83	0.83	0.82	0.82	0.79	0.77	0.79	0.80
India	0.62	0.60	0.61	0.66	0.60	0.57	0.55	0.60	0.64	0.62	0.59	0.59	0.61	0.58	0.56	0.60	0.60	0.55	0.52	0.58	0.54	0.57	0.58
Indonesia	0.57	0.56	0.57	0.56	0.57	0.59	0.59	0.53	0.54	0.59	0.59	0.57	0.56	0.55	0.53	0.53	0.53	0.54	0.56	0.56	0.56	0.53	0.54
Russia	0.72	0.73	0.72	0.77	0.70	0.71	0.66	0.72	0.66	0.60	0.58	0.61	0.64	0.60	0.65	0.70	0.73	0.73	0.73	0.72	0.67	0.70	0.73
Turkey	0.64	0.64	0.64	0.62	0.61	0.59	0.59	0.58	0.56	0.57	0.60	0.59	0.61	0.61	0.59	0.59	0.61	0.61	0.63	0.62	0.61	0.63	0.63
European Union	0.76	0.78	0.79	0.80	0.75	0.74	0.74	0.75	0.75	0.75	0.78	0.77	0.79	0.79	0.78	0.79	0.78	0.79	0.77	0.79	0.78	0.80	0.80
Germany	0.78	0.80	0.81	0.82	0.80	0.80	0.81	0.80	0.81	0.78	0.78	0.78	0.77	0.79	0.79	0.78	0.78	0.80	0.80	0.82	0.79	0.81	0.81
France	0.89	0.86	0.87	0.88	0.87	0.87	0.86	0.84	0.84	0.82	0.84	0.83	0.86	0.86	0.89	0.88	0.86	0.87	0.86	0.87	0.85	0.83	0.84
United Kingdom	0.77	0.76	0.77	0.80	0.76	0.74	0.75	0.76	0.76	0.77	0.79	0.78	0.81	0.80	0.81	0.82	0.81	0.82	0.79	0.80	0.79	0.79	0.79
Italy	0.76	0.74	0.70	0.70	0.73	0.74	0.74	0.74	0.74	0.74	0.72	0.74	0.75	0.75	0.77	0.75	0.75	0.74	0.75	0.72	0.69	0.72	0.71
Saudi Arabia	0.46	0.45	0.43	0.37	0.41	0.39	0.38	0.42	0.45	0.46	0.46	0.46	0.46	0.45	0.43	0.45	0.44	0.43	0.41	0.42	0.42	0.46	0.45
Australia	0.86	0.85	0.84	0.82	0.83	0.83	0.81	0.84	0.85	0.82	0.81	0.83	0.84	0.83	0.86	0.85	0.86	0.84	0.86	0.86	0.86	0.87	0.86

Table 8.3: The numerical results of the SPI index scores obtained using conventional normalization and weighting techniques (Scenario 1).

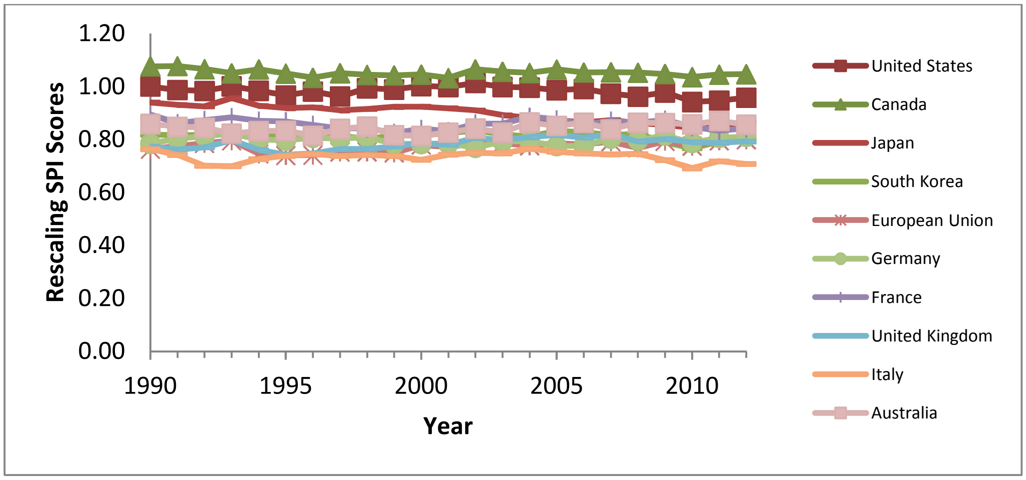


Figure 8.1: The rescaling SPI scores for developed countries between1990-2012.

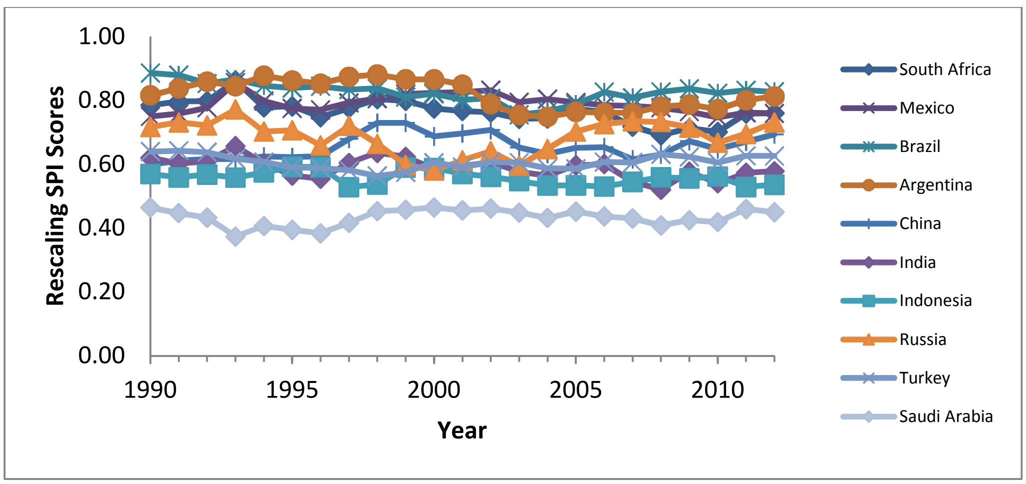


Figure 8.2: The rescaling SPI scores for developing countries between1990-2012.

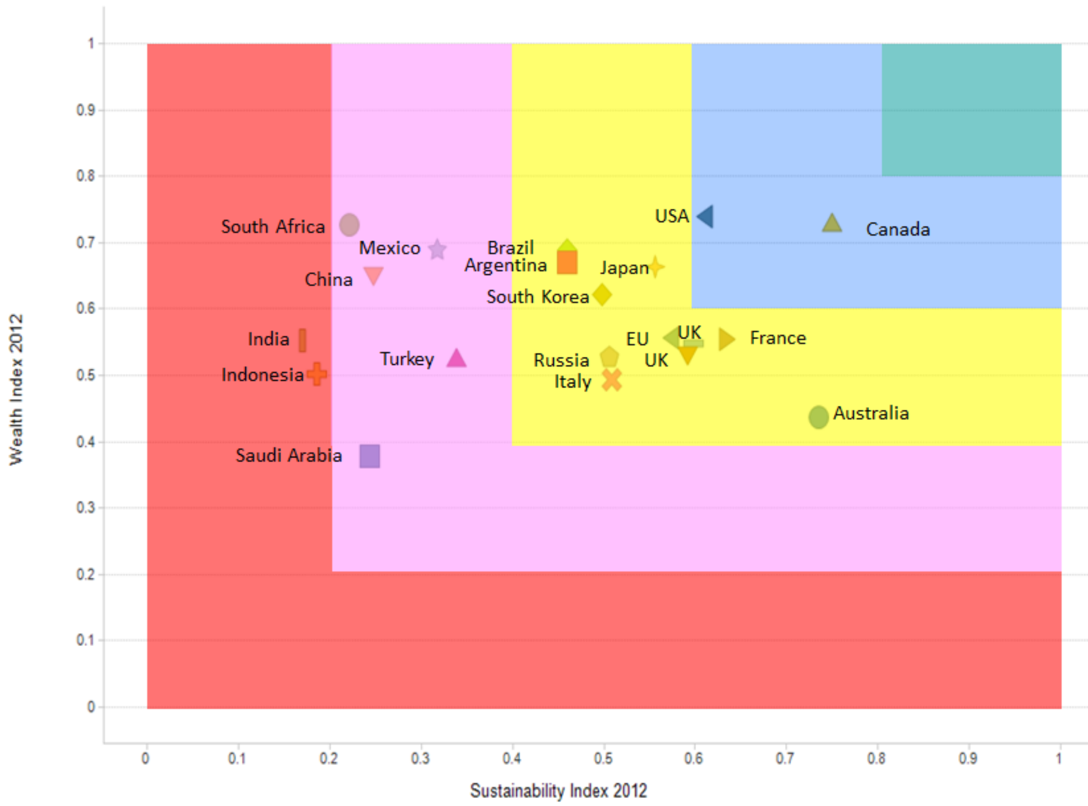


Figure 8.3: The SPI visualization for the G-20 countries for the year of 2012 using conventional normalization and weighting techniques (Scenario 1).

8.3 Scenario 2 - Improving the SPI Method by Using Conventional Data Envelopment Analysis (DEA)

This section provides data analysis of the original 44 input variables selected and discussed in Chapter 7, using standard input-oriented- DEA model run for the 20 countries examined by this research. As discussed in Chapters 6 and 7, DEA analysis incorporates the use of inputs and outputs to calculate the efficiency score i.e. Sustainable Prosperity Index. It should be noted that the inputs are the selected variables discussed in Chapter 7; on the other hand, the outputs chosen are based on the wealth of nations concept discussed below.

8.3.1 The Wealth of G-20 Countries Variables:

As discussed earlier, GDP is the traditional indicator that measures the flow of money in the country and determines if the economy is growing within a time frame. This index is based on the notion that higher GDP results from higher amount of money spent in the country by producing and/or consuming more goods and services. Its advocates believe that it creates wealth in the country, which leads to better welfare and standard of living. However, its opponents make a good argument on the limitations of GDP where its methodology fell short of considering the impact of economic practices on environment (Chapter 4).

Therefore, this dissertation advocates that focusing only on practices that will either achieve sustainable development without maintaining the prosperity and wealth of the country or vice versa is unsustainable. In that regard, the wealth measure should be based on maintenance of capital, or keeping capital stock least unchanged. Actually, there are four main forms of capital: natural capital, social capital, built capital, and financial capital.

In fact, the wealth assessment (output in this scenario) was mapped to the conceptual framework of the sustainability discussed in Chapters 6 and 7 and are consistent with the wealth definition proposed by Dasgupta (Dasgupta 2010) . The dimensions, domains, and indices that are pivotal in the assessment of country's wealth are summarized in Table 8.4.

Dimension	Domain	Variable
Social	Infrastructure	Gross Fixed Capital Formation
	Knowledge & Skills	Researchers In R&D
		Graduates from tertiary
		Physicians
Economic	Natural Resources	Natural Resources Depletion
	Health	Health expenditure, public (% of GDP)
	Education	Adjusted savings: education expenditure (% of GNI)
Environmental	System Availability	Total Biocapacity
	Air quality	Co_2 Damages
	Water	Renewable internal freshwater resources

Table 8.4: Output measures used in DEA Analysis Scenario 2.

It is worth noting that a constant-returns-to-scale input-oriented model was implemented where each country's performance is measured by maximizing outputs given the same level of inputs. The linear programming equivalent is illustrated below,

$$Max\ Z_o \sum_{r=1}^{s} u_r y_{ro}$$

$$s.t.: \quad \sum_{i=1}^{m} v_i x_{io} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} \leq \sum_{i=1}^{m} v_i x_{ij}\ , j = 1, \dots \dots, n$$

$$v_i, u_r \geq 0, \qquad \forall i, r$$

Where:

Z_o is relative efficiency of the DMU o

s is the number of outputs

r is the number of inputs

y_i = the i^{th} output produced by the DMU

x_j = the j^{th} input employed by the DMU

u_i = s x 1 vector of output weights

v_j = r x 1 vector of input weights.

i runs from 1 to s

j runs from 1 to r.

8.3.2 Standard DEA Model Results

Table 8.5 summarizes the sustainability index for the G-20 countries obtained using a standard DEA model without any modification (Scenario 2). As illustrated using this methodology, no discrimination among the countries investigated was observed. The outcomes of the analysis of Scenario 2 clearly illustrate the typical challenges encountered when implementing standard DEA model to calculate DMUs efficiency scores. The results depict the inability of this model to discriminate among efficient DMUs. This is not unexpected and usually reported when the number of DMUs being analyzed is smaller than the total number of input and output variables used in the analysis. In our case, there was large number of inputs and outputs utilized (a total of 54 variables) versus 20 DMUs. Thus, this methodology fell short of discriminating among the G-20 countries, in which they were all considered efficient and got a score of 1 (Table 8.5) suggesting that they all are sustainable. Another contributing factor is the unrealistic weighting scheme that assigns more weights to variables with less importance and less (or even zero) weights to crucial variables. This is captured in Table 8.6 that summarizes the weights obtained for 2007. It is worth noting that similar trends where observed when assessing other years.

Country	Efficiency Index 1990-2012
South Africa	1
United States	1
Canada	1
Mexico	1
Brazil	1
Argentina	1
China	1
Japan	1
South Korea	1
India	1
Indonesia	1
Russia	1
Turkey	1
European Union	1
Germany	1
France	1
United Kingdom	1
Italy	1
Saudi Arabia	1
Australia	1

Table 8.5: the efficiency score for G-20 countries for the years 1990-2012 (All scores =1).

	in1	in2	in3	in4	in5	in6	in7	in8	in9	in10	in11	in12	in13	in14	in15	in16
South Africa	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
United States	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Canada	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mexico	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Brazil	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.60E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Argentina	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-01
China	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.40E-02	0.00E+00
Japan	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
South Korea	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
India	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.80E-02	0.00E+00
Indonesia	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E-01	0.00E+00	0.00E+00	0.00E+00	1.00E-02	0.00E+00	0.00E+00
Russia	0.00E+00	5.63E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
European Union	0.00E+00	0.00E+00	5.46E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.93E-04	4.94E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Germany	0.00E+00	0.00E+00	1.62E-01	0.00E+00	0.00E+00	0.00E+00	1.62E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	0.00E+00	0.00E+00	0.00E+00
France	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-03	0.00E+00	0.00E+00	0.00E+00
United Kingdom	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.78E-05	9.00E-03	0.00E+00	0.00E+00	0.00E+00
Italy	0.00E+00	0.00E+00	7.83E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.14E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	0.00E+00	0.00E+00	0.00E+00
Saudi Arabia	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Australia	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

in17	in18	in19	in20	in21	in22	in23	in24	in25	in26	in27	in28	in29	in30	in31	in32
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.15E+02
0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.98E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.44E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-03	0.00E+00	0.00E+00
2.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.14E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	2.56E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.50E-02	2.16E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	1.10E-02	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	0.00E+00	0.00E+00	3.15E+03
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

in33	in34	in35	in36	in37	in38	in39	in40	in41	in42	out1	out2	out3	out4	out5	out6	out7
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-02
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.14E-04	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.50E-05	3.60E-02	0.00E+00	0.00E+00	8.58E-06	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.29E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.33E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.54E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.31E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.66E-04	0.00E+00	0.00E+00	2.18E-05	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	3.79E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.34E+00	0.00E+00	0.00E+00	2.96E-04	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		2.20E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-01
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.32E-04	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.67E-01
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.03E-05	1.39E-04	8.00E-03
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.44E-05	0.00E+00	0.00E+00	0.00E+00	2.40E-05	5.71E-05	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.82E-06	1.70E-02	1.60E-02		2.16E-05	1.10E-05	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	0.00E+00	0.00E+00	2.10E-05	9.16E-06	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.10E-02	0.00E+00	0.00E+00	5.00E-02	1.96E-05	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-01
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.09E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.80E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 8.6: All Countries input and output variables weights assigned by the standard DEA model for the year of 2007.

8.4 Scenario 3 - Using Principal Component Analysis (PCA) -DEA Analysis

As discussed in the previous section, DEA, which is a data oriented, non-parametric method is used to discriminate among countries toward their progress to achieve sustainable prosperity. While the goal is to comprehensively measure the sustainable prosperity of these countries, using high number of variables (a total of 54 variables), as inputs and outputs, the major outcome of Scenario 2 was the lack of discrimination and distortion with the output efficiency i.e. Sustainability Index values.

To overcome this challenge, principle component analysis (PCA) was used to reduce the number of variables and transforming the original inputs and outputs into principle components with minimal loss of information (capturing most of the original variance of the original data)[32].

The implementation of PCA led to the reduction of the number of variables as inputs and outputs into 17 total variables while maintaining around (80-85%) of total cumulative variation (Appendices B, C, D, and E). Consistent with reports in the literature when PCA is combined with DEA, it provides a similar impact to that of weight restrictions addition, without the need of an additional opinion that should be provided by policy makers/experts rendering it more objective (Adler and Yazhemsky 2010). When, PCA-DEA was initially implemented with the use of all the PCA data that contain 80-85% of the variation, improvement in the discrimination among countries was observed compared to using conventional DEA (Table 8.7). However, still discrimination was not satisfactory. One of the approaches that is highlighted in the literature is the significance of the number and combinations of inputs and outputs

[32] Principle component analysis (PCA) was discussed in chapter 7.

and their impact on the efficiency score. For example, Poladru and Roots indicated that the efficiency score is sensitive to these variables. Where, the efficiency score and number of efficient countries tend to increase with the increase of the number of principle components used. However, the discrimination suffers, which undermines the utility of PCA-DEA. This trend is consistent with what we have observed over the years studied in this work. Table 8.7 highlights the impact of different case scenarios of number PCA inputs and outputs used and their combinations for the years of 1990, 2000, and 2012 on the number of efficient countries, portion of countries deemed inefficient, average SPI score, minimum SPI score, and standard deviation. In considering the results obtained in Table 8.7, it is important to emphasize when all the PCA inputs and outputs (dimensionality) were used, in 2012, the number of countries considered efficient was 5. As the number of inputs and outputs decreased to 4, the number of efficient countries was reduced to 1 and the discrimination among countries investigated was increased. This clearly demonstrates the profound impact of dimensionality on the overall model performance. This outcome is consistent with the findings of (Põldaru and Roots 2014), who indicated that the use of one PC in inputs and one PC in outputs provided the best results. In our case, we ensured to have one PC for each dimension of sustainability i.e. economic, social, and environmental and one PC in the outputs for the wealth dimension (a total of four) i.e. PCA-DEA 1111 model. This renders our index capable of comprehensively assessing the progress toward attaining sustainable prosperity from the four dimensions, which is a key attribute of our novel index. It is prudent to emphasize that while the number of inputs and outputs was only 4, still these captured 50% of the variability of the data. This is also another aspect that should be highlighted when implementing this methodology were a balance should be obtained in capturing the variability and effectively increasing the discrimination among systems investigated. Ultimately, the goal is to differentiate between the countries.

Employing PCA resulted in negative data. This is a limitation that would challenge the functionality of DEA since it assumes the non-negativity of all variables used in the model. Therefore, negative data have to be handled. One approach that is used in the literature is adding a subjective large number to all values of a given variable that will transform all negative data into positive.

A)

Member	Conventional DEA 1990	All Inputs And Outputs 1990	PCADEA2433 1990	PCADEA1222 1990	PCADEA1111 1990
South Africa	1	1	1	0.946	0.349
United States	1	1	1	0.937	0.856
Canada	1	1	1	1	0.829
Mexico	1	1	1	0.928	0.335
Brazil	1	1	1	1	0.677
Argentina	1	1	1	0.932	0.394
China	1	1	1	1	0.513
Japan	1	1	1	1	1
South Korea	1	1	1	0.849	0.689
India	1	1	1	1	0.15
Indonesia	1	1	1	1	0.215
Russia	1	1	1	0.952	0.582
Turkey	1	0.994	0.992	0.939	0.407
European Union	1	0.985	0.983	0.894	0.789
Germany	1	1	1	0.951	0.901
France	1	1	1	0.936	0.871
United Kingdom	1	1	0.975	0.846	0.739
Italy	1	1	1	1	0.99
Saudi Arabia	1	1	1	0.975	0.531
Australia	1	1	1	1	0.838
Number Of PCA Inputs And Outputs	**54**	**17**	**12**	**7**	**4**
Number Of Efficient Countries	**20**	**18**	**17**	**8**	**1**
Proportion Of Countries Deemed Inefficient	**0**	**0.1**	**0.15**	**0.6**	**0.95**
Average SPI Score	**1**	**0.99895**	**0.9975**	**0.95425**	**0.63275**
Minimum SPI Score	**1**	**0.985**	**0.975**	**0.846**	**0.15**
Standard Deviation	**0**	**0.00354631**	**0.006700353**	**0.049060516**	**0.258995402**

B)

Member	Conventional DEA 2000	All Inputs And Outputs 2000	PCADEA2433 2000	PCADEA1222 2000	PCADEA1111 2000
South Africa	1	1	0.975	0.925	0.261
United States	1	1	1	1	1
Canada	1	1	1	1	0.716
Mexico	1	1	1	1	0.508
Brazil	1	1	1	1	0.342
Argentina	1	1	0.976	0.911	0.458
China	1	1	1	1	0.28
Japan	1	1	1	1	0.99
South Korea	1	1	1	0.907	0.644
India	1	1	1	1	0.117
Indonesia	1	1	1	1	0.172
Russia	1	1	1	1	1
Turkey	1	1	0.977	0.971	0.368
European Union	1	0.996	0.948	0.946	0.69
Germany	1	1	1	1	0.752
France	1	1	0.989	0.989	0.719
United Kingdom	1	1	0.905	0.905	0.696
Italy	1	1	1	1	0.755
Saudi Arabia	1	1	1	1	0.511
Australia	1	1	1	0.931	0.844
Number Of PCA Inputs And Outputs	**54**	**17**	**12**	**7**	**4**
Number Of Efficient Countries	**20**	**19**	**14**	**12**	**2**
Proportion Of Countries Deemed Inefficient	**0**	**0.05**	**0.3**	**0.4**	**0.9**
Average SPI Score	**1**	**0.9998**	**0.9885**	**0.97425**	**0.59115**
Minimum SPI Score	**1**	**0.996**	**0.905**	**0.905**	**0.117**
Standard Deviation	**0**	**0.000894427**	**0.02399013**	**0.037414991**	**0.272879244**

C)

Member	Conventional DEA 2012	All Inputs And Outputs 2012	PCADEA2433 2012	PCADEA1222 2012	PCADEA1111 2012
South Africa	1	0.295	0.295	0.295	0.295
United States	1	0.765	0.684	0.684	0.586
Canada	1	1	0.984	0.769	0.745
Mexico	1	0.419	0.419	0.41	0.41
Brazil	1	0.65	0.65	0.416	0.398
Argentina	1	0.442	0.442	0.41	0.41
China	1	0.455	0.455	0.455	0.455
Japan	1	1	1	0.609	0.537
South Korea	1	1	1	0.458	0.454
India	1	0.17	0.17	0.148	0.148
Indonesia	1	0.885	0.885	0.642	0.642
Russia	1	0.577	0.577	0.462	0.462
Turkey	1	0.406	0.406	0.391	0.391
European Union	1	0.561	0.557	0.557	0.498
Germany	1	0.673	0.648	0.596	0.514
France	1	0.691	0.667	0.667	0.588
United Kingdom	1	0.558	0.541	0.541	0.439
Italy	1	0.718	0.616	0.616	0.555
Saudi Arabia	1	1	1	1	0.876
Australia	1	1	1	1	1
Number Of PCA Inputs And Outputs	**54**	**17**	**12**	**7**	**4**
Number Of Efficient Countries	**20**	**5**	**4**	**2**	**1**
Proportion Of Countries Deemed Inefficient	**0**	**0.75**	**0.8**	**0.9**	**0.95**
Average SPI Score	**1**	**0.66325**	**0.6498**	**0.5563**	**0.52015**
Minimum SPI Score	**1**	**0.17**	**0.17**	**0.148**	**0.148**
Standard Deviation	**0**	**0.257170612**	**0.255039233**	**0.209844328**	**0.191517287**

Table 8.7: The Sustainable Prosperity Score of G-20 countries measured in 1990 (A), 2000 (B), and 2012 (C) using different PCA combinations, respectively(the scheme of this table was adapted from (Põldaru and Roots 2014)) .

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	**average**
South Africa	0.35	0.32	0.31	0.25	0.24	0.28	0.29	0.29	0.31	0.27	0.26	0.24	0.24	0.30	0.34	0.35	0.38	0.39	0.37	0.39	0.37	0.36	0.30	**0.313**
United States	0.86	0.79	0.78	0.81	0.80	0.77	0.84	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.80	0.79	0.70	0.64	0.59	**0.874**
Canada	0.83	0.76	0.71	0.58	0.59	0.62	0.67	0.78	0.77	0.74	0.72	0.73	0.75	0.79	0.84	0.88	0.93	0.94	0.88	0.85	0.88	0.79	0.75	**0.773**
Mexico	0.34	0.35	0.38	0.38	0.36	0.27	0.30	0.39	0.44	0.44	0.51	0.52	0.51	0.52	0.52	0.54	0.57	0.56	0.53	0.47	0.44	0.45	0.41	**0.443**
Brazil	0.68	0.38	0.55	0.44	0.40	0.41	0.43	0.48	0.46	0.35	0.34	0.32	0.31	0.32	0.33	0.36	0.39	0.42	0.44	0.45	0.51	0.51	0.40	**0.421**
Argentina	0.39	0.43	0.49	0.49	0.49	0.46	0.50	0.58	0.61	0.51	0.46	0.42	0.27	0.31	0.36	0.39	0.43	0.46	0.46	0.44	0.45	0.46	0.41	**0.447**
China	0.51	0.37	0.39	0.48	0.35	0.48	0.30	0.28	0.26	0.26	0.28	0.30	0.33	0.35	0.36	0.36	0.38	0.40	0.40	0.49	0.47	0.47	0.46	**0.380**
Japan	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.92	0.86	0.86	0.85	0.83	0.76	0.71	0.62	0.69	0.63	0.59	0.54	**0.863**
South Korea	0.69	0.70	0.69	0.59	0.58	0.68	0.75	0.74	0.56	0.58	0.64	0.61	0.66	0.68	0.65	0.65	0.67	0.71	0.60	0.56	0.54	0.59	0.45	**0.633**
India	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.14	0.13	0.12	0.12	0.14	0.14	0.15	0.16	0.16	0.17	0.19	0.17	0.18	0.18	0.18	0.15	**0.150**
Indonesia	0.22	0.21	0.21	0.22	0.22	0.22	0.24	0.48	0.26	0.15	0.17	0.17	0.26	0.19	0.28	0.38	0.57	0.23	0.24	0.35	0.30	0.40	0.64	**0.287**
Russia	0.58	0.45	0.52	0.52	0.51	1.00	1.00	0.56	0.94	1.00	1.00	1.00	1.00	1.00	0.62	0.46	0.47	0.49	0.48	0.56	0.57	0.52	0.46	**0.683**
Turkey	0.41	0.38	0.38	0.41	0.32	0.34	0.35	0.40	0.45	0.35	0.37	0.27	0.31	0.37	0.44	0.49	0.52	0.53	0.48	0.42	0.44	0.44	0.39	**0.403**
European Union	0.79	0.74	0.74	0.66	0.65	0.66	0.71	0.75	0.78	0.74	0.69	0.69	0.72	0.80	0.81	0.80	0.82	0.85	0.77	0.73	0.65	0.59	0.50	**0.723**
Germany	0.90	0.87	0.92	0.85	0.84	0.86	0.90	0.89	0.91	0.84	0.75	0.73	0.73	0.79	0.79	0.74	0.76	0.78	0.73	0.71	0.65	0.61	0.51	**0.785**
France	0.87	0.81	0.80	0.74	0.71	0.71	0.76	0.77	0.80	0.77	0.72	0.73	0.75	0.84	0.86	0.85	0.87	0.90	0.84	0.85	0.73	0.67	0.59	**0.780**
United Kingdom	0.74	0.66	0.64	0.57	0.56	0.57	0.62	0.72	0.78	0.74	0.70	0.70	0.74	0.77	0.80	0.76	0.78	0.82	0.66	0.61	0.54	0.49	0.44	**0.670**
Italy	0.99	0.93	0.93	0.74	0.71	0.68	0.78	0.82	0.86	0.81	0.76	0.77	0.85	0.97	1.00	0.97	0.98	1.00	0.92	0.87	0.78	0.70	0.56	**0.843**
Saudi Arabia	0.53	0.56	0.55	0.51	0.42	0.44	0.46	0.52	0.55	0.52	0.51	0.52	0.52	0.56	0.61	0.82	0.81	0.92	0.95	0.95	0.93	1.00	0.88	**0.654**
Australia	0.84	0.75	0.70	0.64	0.66	0.70	0.76	0.84	0.84	0.82	0.84	0.82	0.86	0.91	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.868**

Table 8.8: The G-20 countries numeric results of the efficiency scores using PCA-DEA for the years of 1990-2012.

Table 8.8 summarizes the G-20 countries numeric results of the efficiency scores using PCA-DEA for the years of 1990-2012. To rank the G-20 countries, the average value of the SPI score is used (1990-2012). As depicted in the table 8.8, USA had the highest average SPI score with a value of 0.874. On the other hand, the lowest ranking is the SPI score for India with a value of 0.150. If we considered an average SPI of 0.70 to be sustainably prosperous, 8 countries which are USA, Canada, Japan, EU, Germany, France, Italy and Australia meet this criterion.

Figure 8.4 depicts the average SPI scores using PCA-DEA for developed and developing countries between 1990-2012. Developed countries among the G-20 group had higher average SPI scores compared to developing countries over the period investigated. However, between 2008 to 2012, developed countries realized a reduction in the overall average SPI scores from ≈0.8 to 0.6. This trend was not observed with the developing countries. This is the time period that followed the 2008 financial meltdown, which threatened the total collapse of large financial institutions and was prevented by the bailout of banks by national governments. Interestingly, the GDP growth in 2009 was mainly limited to the developing countries, while developed countries had poor GDP growth if any. Indeed, this phenomenon was captured in the 2013 human development report titled “The Rise of the South”. It contends that during 2008-2009 when this collapse happened; the developing countries kept on economically growing. This phenomenon is partially attributed to the investments these countries made in human development (Malik 2013). To further substantiate these findings, the weights of input principle components associated with the three aspects of sustainability in the final PCA-DEA model were examined. It was observed that significant weight was assigned to the social dimension in most of the G-20 countries using PCA-DEA.

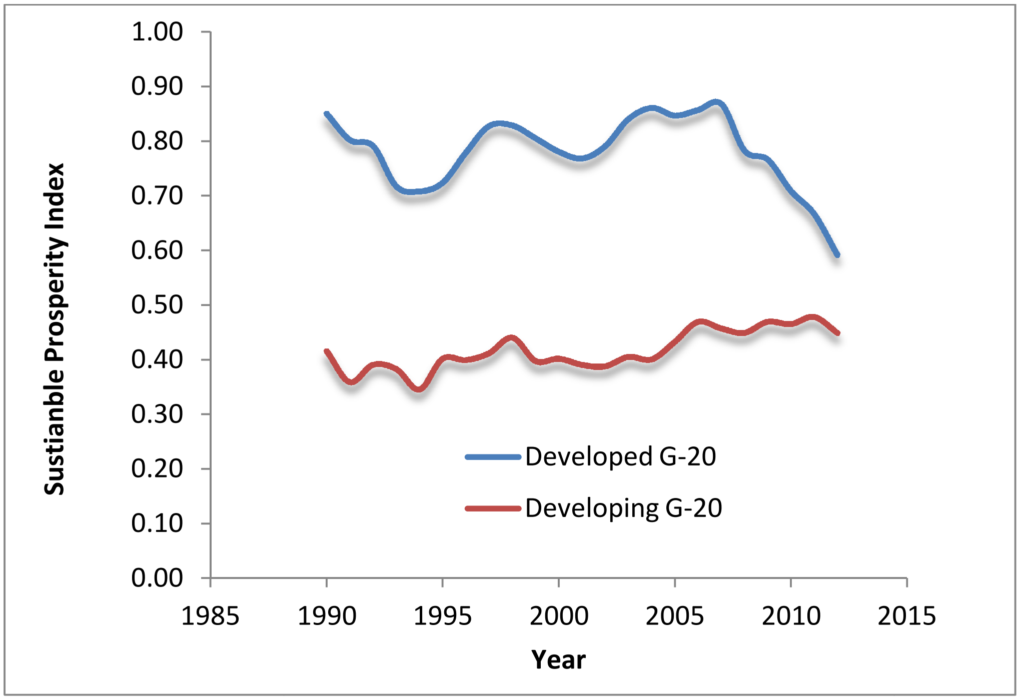


Figure 8.4: The average developed and developing G-20 countries SPI results using PCA-DEA (1111) for the years of 1990-2012.

Many factors contributed to this observation, first, this research selected the domains and sub-domains of the social dimension based on the well being index and United Nations Millennium Development Goals in 2000. It has been reported that many of the United Nations goals were achieved three years ahead of the 2015 deadline. This testifies to the significant global investments in particular by the developing countries in human development relevant areas. For example, developing countries such as Turkey, China, and Saudi Arabia demonstrated major improvements in their return of investments in their people as shown in the increase in the life expectancy at birth and tertiary school enrollment. This was significantly higher than that shown for developed countries such as USA, France and United Kingdom (Figures 8.5 and 8.6).

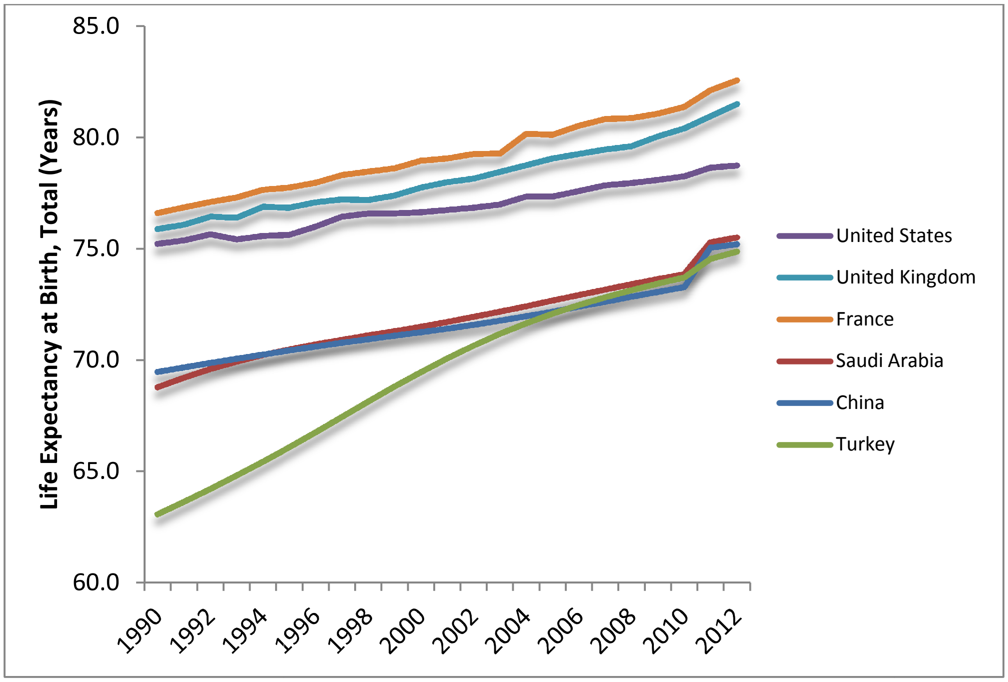


Figure 8.5 the Life Expectancy at Birth, Total (Years) of USA, UK, France, Saudi Arabia, China and Turkey between 1990 – 2012.

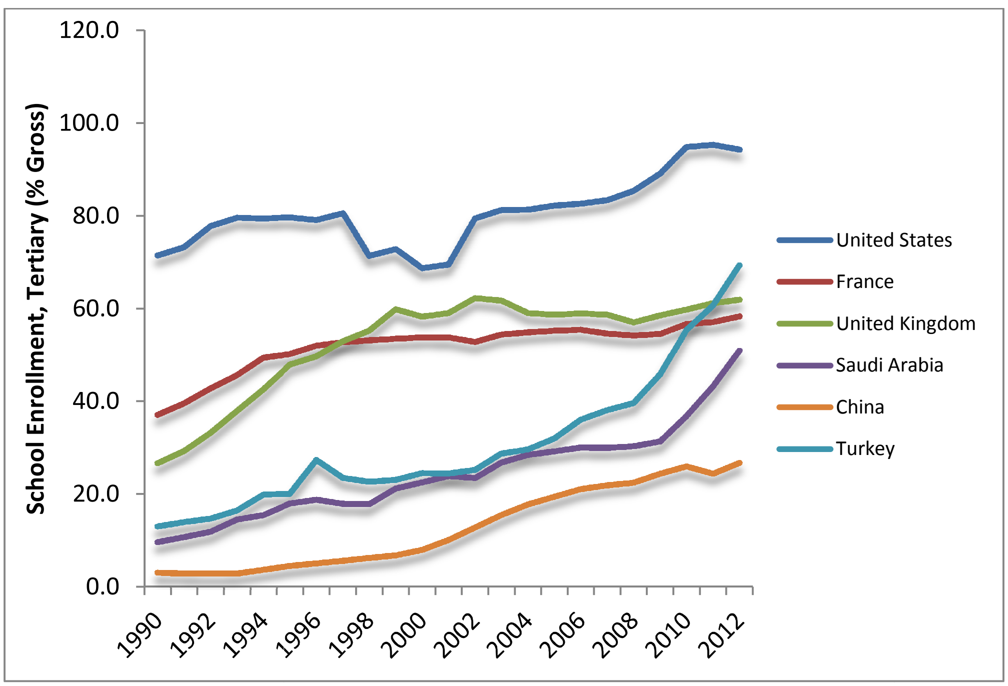


Figure 8.6 the Tertiary School Enrollment (% Gross) of USA, UK, France, Saudi Arabia, China and Turkey between 1990 – 2012.

Second, this research chose DEA as a methodology because unlike other tools, it is not western biased and it assigns weights based on endogenous country specific priorities. This makes it favored by policy makers and believed not to be biased.

One question is why Saudi Arabia is considered sustainably prosperous and its SPI scores are higher than 0.70 between the years of 2005-2012. Saudi Arabia is the world's leading oil producer and controls the second largest oil reserves. It is also the only Arab country that is part of the G-20 Group. Being a high income country, the Saudi policy makers maximized the value of the oil exports returns by making major investments in gross domestic savings, infrastructure, renewable energy resources, health and education expenditures and human development shown by growing education and health expenditures. Figure 8.7 illustrates the gross domestic saving of US and Saudi Arabia between 1990-2012. It is clear that US had a steady gross domestic saving that is averaging around 18% between 1990 to 2012. Indeed, it decreased to 78% of its original value in 1990 (20% of GDP) by 2012. However, Saudi Arabia demonstrated steady increase in their gross domestic average from 24.1% in 1990 to 49.9% in 2012. Consistent with these findings, Saudi Arabia was able to increase their Gross fixed capital formation ~ 7 folds from 1990 to 2012. However, USA gross fixed capital formation only increased by 2.4 folds over the same period. Gross fixed capital formation is used to capture investments in infrastructure i.e. lands, plant, machinery, construction of roads, railways, schools, hospitals …etc. Similar trends were observed with variables in different aspects and domains were Saudi Arabia made major strides in improving their economic infrastructure and the wellbeing of people. In addition, Saudi Arabia made major policy changes that focus on embracing sustainable practices and shift their reliance on meeting their energy needs by adapting renewable energy resources. For example, Saudi Arabia sets a goal to produce a total of 24 GW of renewable energy by 2020 and 54 GW by 2032 (Policy 2013). Saudi Arabia's HDI increased from 0.653 to 0.782 between the years of 1990 to 2012. This is the results of the major investments that Saudi Arabia made in improving and upgrading health services, education infrastructure, and providing a decent standard of living for its constituents. For example, the life expectancy at birth increased 6.7 years for Saudi Arabia while it only increased 3.5 years for the USA between 1990-2012. Furthermore, a major increase in Tertiary School enrollment by 41% for Saudi Arabia while it only increased by 23% for the USA between 1990-2012 (Figures 8.5 and 8.6). Overall, these investments do not only affect the health and education aspects, but also impacts the social well-being of its people at large.

Moreover, between 2000 and 2012, there was an exponential growth in the number of internet users and mobile subscribers that surpassed 30% per year. These services gave the Saudi people access to valuable resources and information and enabled them to more actively participate in the global society. Taken together, these strides underscore the improvement noted in Saudi Arabia SPI score.

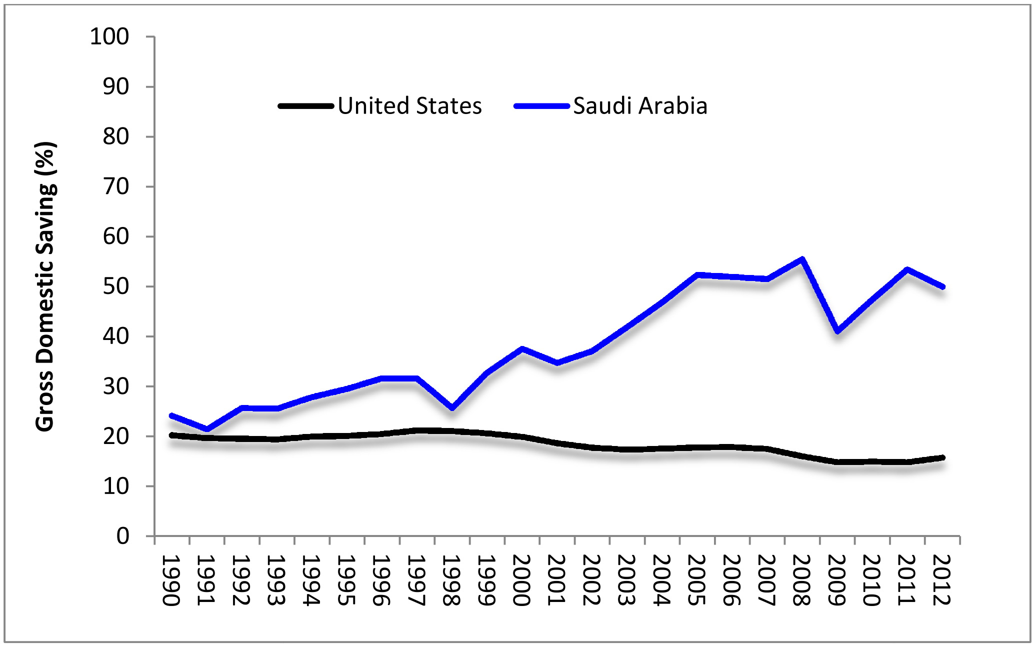


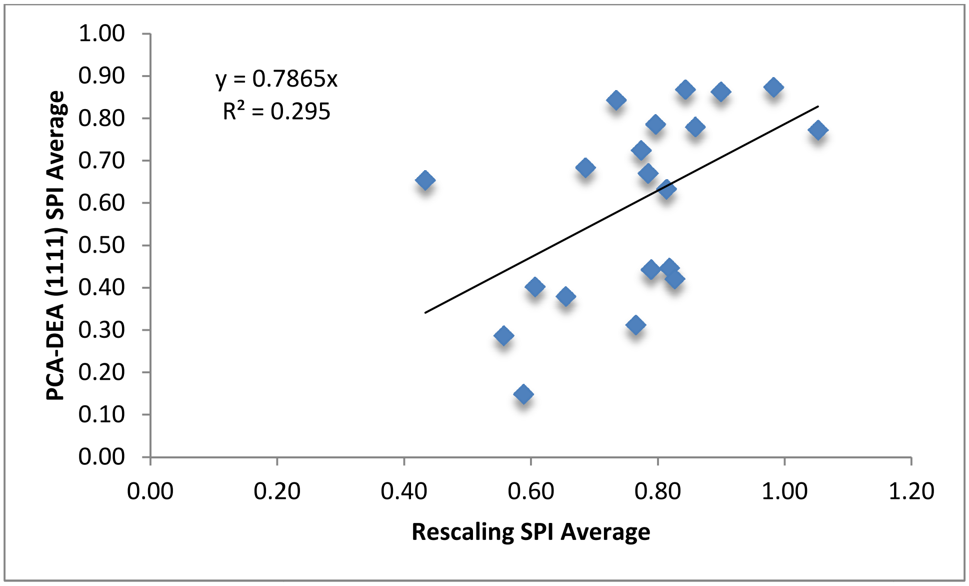
Figure 8.7: The relationship of the gross domestic saving (%) for United States and Saudi Arabia between 1990 to 2012.

8.5 Comparison between PCA_DEA and Rescaling Models

As outlined earlier, rescaling model methodology is based on the HDI methodology, which used the averaging of the various rescaled variables of all dimensions to calculate the score. Interestingly, this puts equal weight for each variable and dimension. This is a major drawback of this methodology, since the components calculated in such an aggregated index may cancel each other and compromise the assessment of the progress toward sustainable prosperity. In addition, unlike PCA-DEA methodology, the rescaling model did not provide significant intra country discrimination over time (Figures 8.1, 8.2, and 8.4). If implemented this may send the wrong message to policy makers leading them to believe in the perception that adapting policies toward sustainable development would compromise the progress toward economic prosperity, which is a major drawback and inconsistent with the traits of good measure (Table 4.7). Table 8.9 depicts the rescaling country score average, PCA-DEA (1111) score average between 1990-2012, and countries ranking based on the two methodologies. Figure 8.8 depicts the relationship between the average scores using the rescaling model and PCA-DEA (1111) model for the G-20 countries. As shown, there is a major difference in the ranking order between the two methodologies. For example, India and United States had the worst and best rank using PCA-DEA (1111) methodology, respectively. On the other hand, Saudi Arabia and Canada had the worst and best ranking using rescaling methodology. Thus, a poor correlation between the two methodologies was observed a (R^2 = 0.295, P-value = 0.01). Therefore, this clearly suggests that there is a significant difference between the two methodologies.

Number	Country	Rescaling Average	*Rescaling Rank*	DEA Average	*DEA Rank*
1	Argentina	0.82	7	0.45	13
2	Australia	0.84	5	0.87	2
3	Brazil	0.83	6	0.42	15
4	Canada	1.05	1	0.77	7
5	China	0.66	16	0.38	17
6	European Union	0.77	12	0.72	8
7	France	0.86	4	0.78	6
8	Germany	0.80	9	0.79	5
9	India	0.59	18	0.15	20
10	Indonesia	0.56	19	0.29	19
11	Italy	0.73	14	0.84	4
12	Japan	0.90	3	0.86	3
13	Mexico	0.79	10	0.44	14
14	Russia	0.69	15	0.68	9
15	Saudi Arabia	0.43	20	0.65	11
16	South Africa	0.77	13	0.31	18
17	South Korea	0.81	8	0.63	12
18	Turkey	0.61	17	0.40	16
19	United Kingdom	0.78	11	0.67	10
20	United States	0.98	2	0.87	1

Table 8.9: The rescaling country score average/rank, DEA score average/rank between 1990-2012.

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Two-sample T for Rescaling Average_1 vs DEA Average_1

                     N   Mean  StDev  SE Mean
Rescaling Average_1  20  0.763  0.146    0.033
DEA Average_1        20  0.599  0.224    0.050


Difference = μ (Rescaling Average_1) - μ (DEA Average_1)
Estimate for difference:  0.1643
95% CI for difference:  (0.0425, 0.2861)
T-Test of difference = 0 (vs ≠): T-Value = 2.75  P-Value = 0.010  DF = 32
```

Figure 8.8: The relationship between the average countries SPI scoring obtained using PCA-DEA (1111) and Rescaling between 1990-2012.

8.5 Comparison between SPI and Major Sustainability Measures GDP, HDI and EPI

Figures 8.9 and 8.10 illustrate the time course of GDP and SPI scores using PCA-DEA (1111) for the USA and India, respectively. Interestingly, there is no link between GDP and SPI scores for the two countries. India and USA were selected and used as a bench mark since; the first has the worst rank while the later has the best rank based on SPI scoring using PCA-DEA (1111) methodology. This is another important trait of PCA-DEA (1111) methodology, which is the fact that it is not fully reliant on GDP. While, GDP was increasing for the two countries their progress toward sustainable prosperity was not as solid. Indeed, SPI score decreased for USA after 2008. This is not unexpected especially when we consider that economic prosperity is not the solo answer for attaining sustainable prosperity. This is a key limitation and drawback for GDP methodology. Unlike our proposed index, GDP has been widely criticized for its failure to truly assess a nation's social and ecological well being since it does not delineate negative activities and considers them as a profit for a country (Kuznets 1934; Kuznets 1941; Lawn 2003; Van den Bergh 2009). Furthermore, it does not consider activities that are beyond the boundary of monetarized exchange and contribute to the quality of life and well-being (Bleys 2005). So it was realized that GDP is an indicator of wealth, yet not welfare (Kuznets 1934). Our methodology ensured to capture parameters that assess progress toward social welfare as well as ecosystem wellbeing. For example, GDP Methodology does not take into consideration neither natural resource depletion nor environmental damage. It should be emphasized that this dimension has been considered in the methodology of our SPI. GDP Methodology promotes consumption, which is the primary driver for natural resources depletion. Under GDP measure, Mother Nature is assumed to have an infinite supply of natural resources. In which, higher commodity producing countries rate of natural resource depletion is associated with higher GDP (Anielski 2001). Overall, this clearly testifies that under this measure natural resource depletion and associated degradation of the ecosystem is considered a profit rather than a cost. Also, GDP focuses on activities that would ultimately add to the economic growth without differentiating between “goods” or benefits and “bads” or the societal cost of pollution to the personal development and well-being.

Figures 8.11 and 8.12 depict the time course of EPI and SPI scores using PCA-DEA (1111) for USA and India between 2002-2012, respectively. For USA, it was efficient country with an SPI score of 1 from 2002 till 2007, and then the SPI was reduced to around 0.6 by 2012; EPI did not change substantially between 2002-2012. For India, SPI and EPI did not change substantially between 2002-2012. While EPI enjoys significant recognition among policy makers and considered as one of the mostly used indices in the assessment of the environmental sustainability of countries, it does not consider economic sustainability, social sustainability or overall wealth as part of its assessment, which is captured in our SPI methodology. Furthermore, EPI valuation methodology has been criticized for its complexity, aggregation of its variables that have different units, normalized and converted to a common unit. Furthermore, the weighting of its indicators are the subjective and arbitrary. This along with the significant use of imputation compromises the overall quality of the assessment. The implemented SPI methodology based on the use of DEA is easily comprehendible and favored by policy makers, moreover, it handles variables that have different units without the need for normalization. This is another trait that this index has and consistent with the attributes of good sustainability index outlined in Chapter 4.

Figures 8.13 and 8.14 depict the time course of HDI and SPI scores using PCA-DEA (1111) for USA and India between 1990-2012, respectively. For USA, its SPI score improved from 1990 till 2007, then it decreased to around 0.6 in 2012. The HDI score of USA between 1990-2012 was consistent with it being a developed country where it was higher than 0.8. On the other hand, SPI score was not efficient over the period investigated. Furthermore, India realized an increase in its HDI. Still the increase was not substantial and lower than 0.8, which is consistent with it being developing country. It should be emphasized that HDI is a socio-economic index that fails to include both the political/civil dimensions of human development Dasgupta as well as ecological considerations. Furthermore, it does not consider gender inequality in its valuation methodology. SPI methodology is comprehensive and considered all these aspects in its valuation methodology.

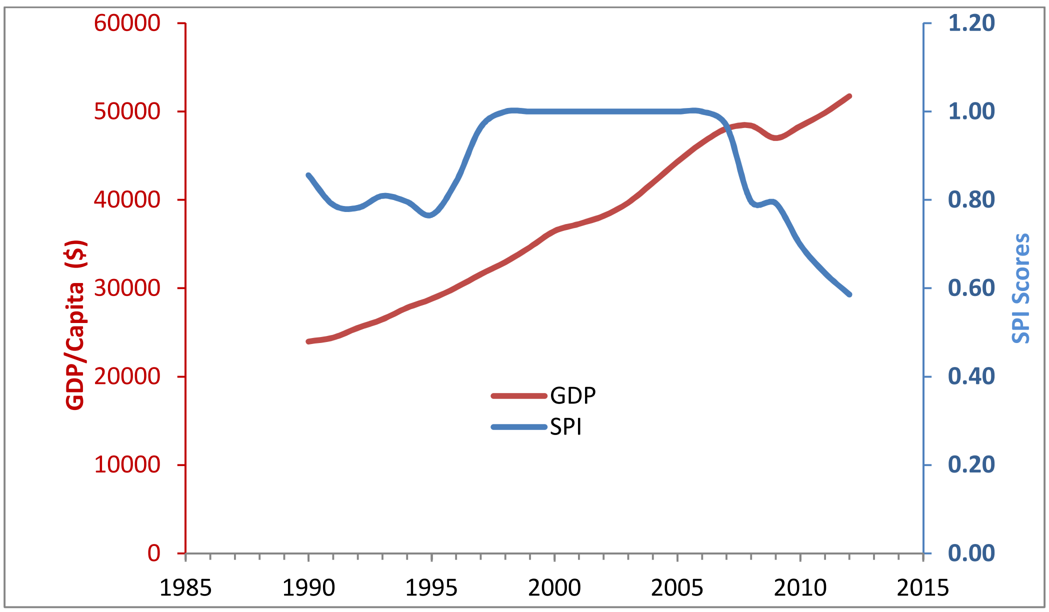

Figure 8.9: The time course of GDP and SPI scores using PCA-DEA (1111) for USA between 1990-2012.

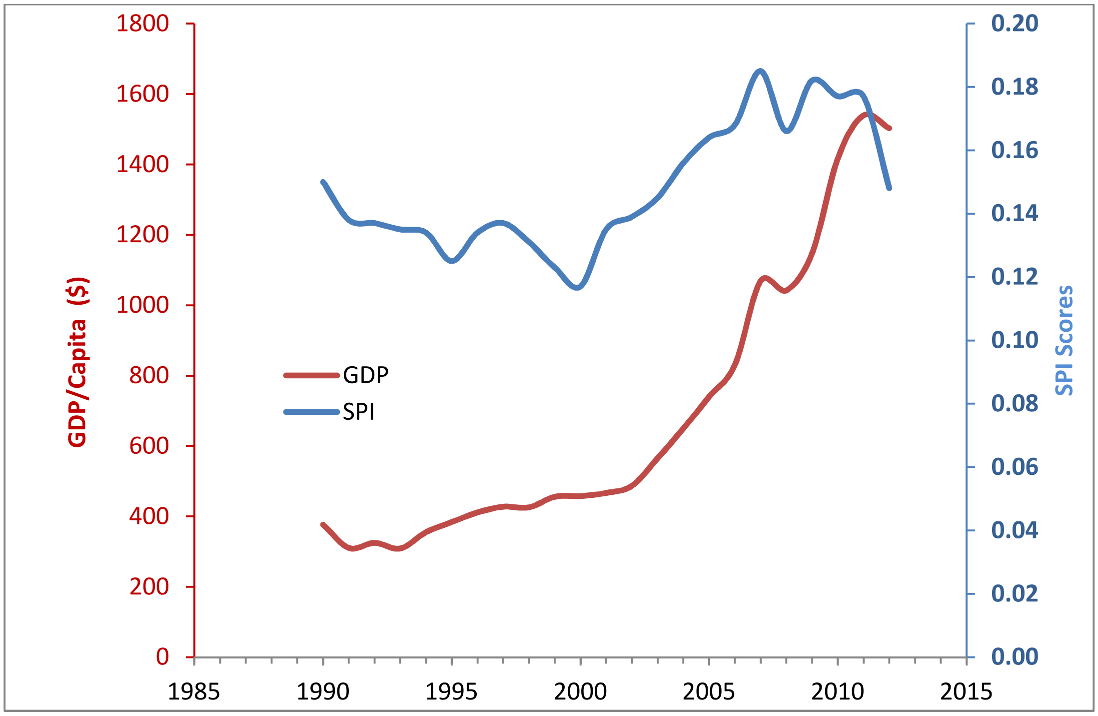

Figure 8.10: The time course of GDP and SPI scores using PCA-DEA (1111) for India between 1990-2012.

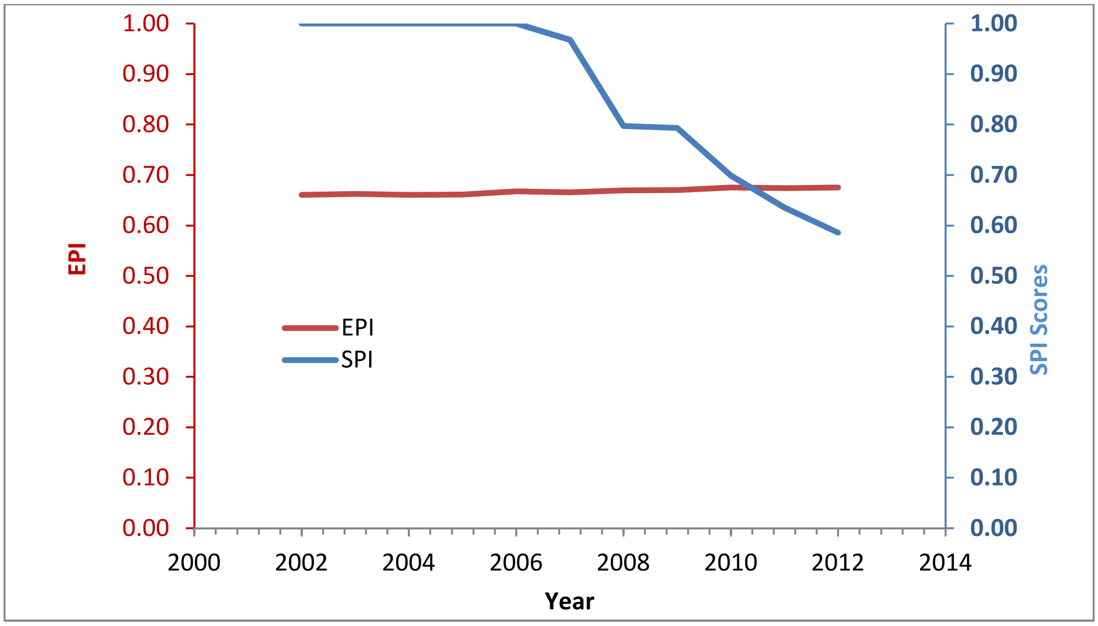

Figure 8.11: The time course of EPI and SPI scores using PCA-DEA (1111) for USA between 2002-2012.

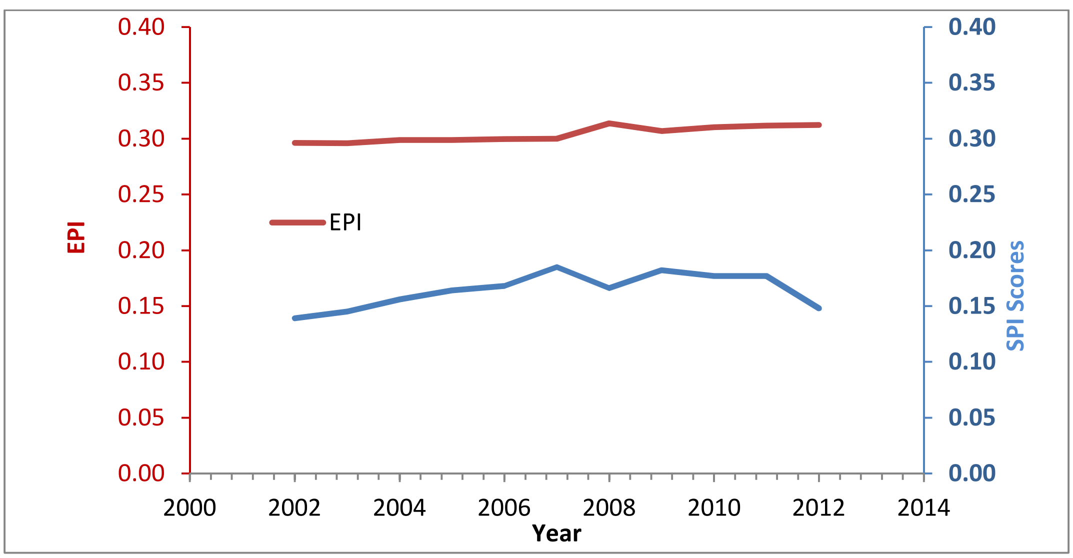

Figure 8.12: The time course of EPI and SPI scores using PCA-DEA (1111) for India between 2002-2012.

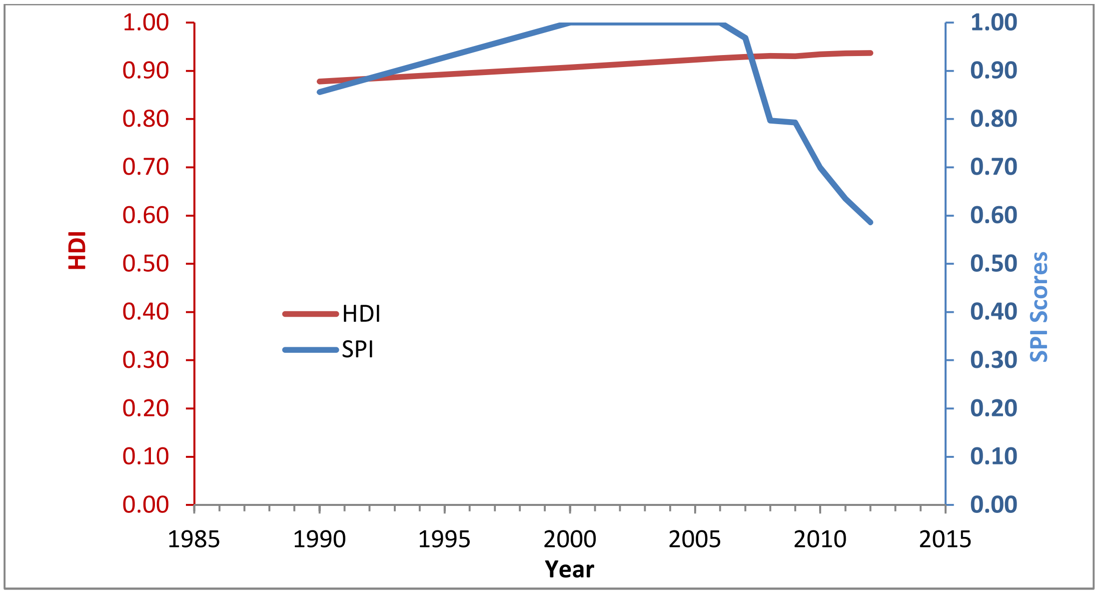

Figure 8.13: The time course of HDI and SPI scores using PCA-DEA (1111) for USA between 1990-2012.

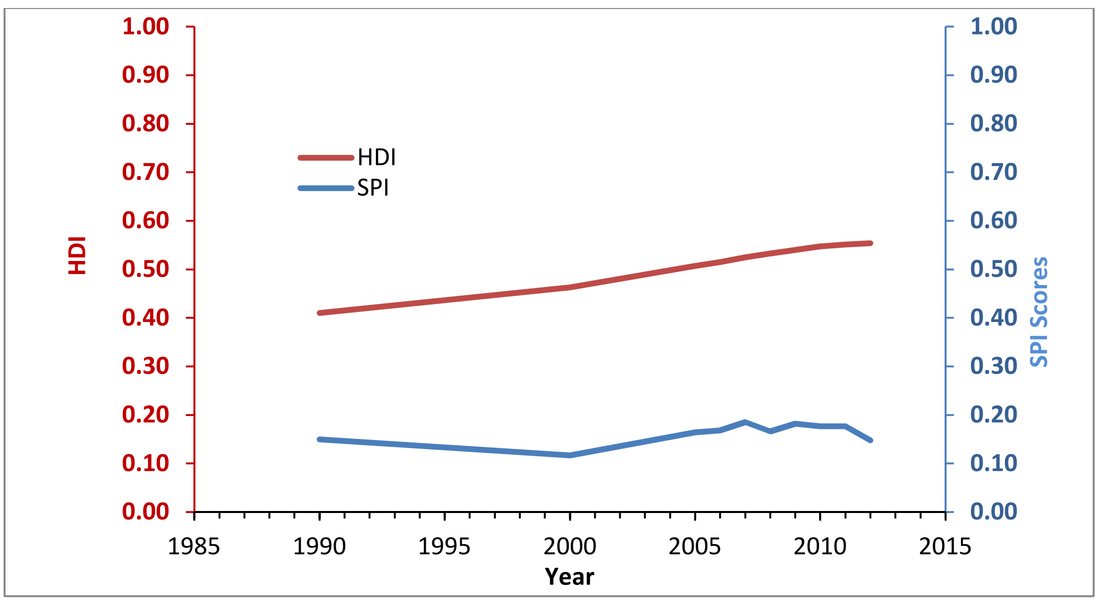

Figure 8.14: The time course of HDI and SPI scores using PCA-DEA (1111) for India between 1990-2012.

8.6 Sensitivity Analysis (SA)

The sensitivity of the constructed Sustainable Prosperity Index was applied with regard to changes in specific variables. The sensitivity rates applied in this 0.10, 1.0 and 10. This range was chosen to study variables variation over the years. The results for the year of 2012 are discussed below.

The sensitivity analysis was applied based on two aspects as follows:

(i) Economic impact using GDP as a changing variable.

(ii) Social aspect based variables.

SA examined the impact of changes outlined above on the countries scores and ranking.

(i) Economic Impact Using GDP

The results of the SA for the economic impact using GDP are illustrated in table 8.10. GDP variable per *se* was not used in the analysis; instead the Gross fixed capital formation /capita variable that is in the Wealth output aspect was used. This is the only variable among inputs and outputs used in the model, since it is associated with GDP.

The results were examined based on the scores that are determined using PCA-DEA 1111 for each country based on its efficiency score, and ranking. Spearman Correlation Test (SCT) was used to assess whether the changes in the ranking are statistically significant.

SCT is a statistical measure that is used to evaluate the strength of the relationships involving ordinal variables. The strength of the correlation can be assessed using the following criteria for the absolute value of rs:

- 0 .00-0.19 “very weak”
- 0 .20-0.39 “weak”
- 0 .40-0.59 “moderate”
- 0 .60-0.79 “strong”
- 0 .80-1.00 “very strong”

Country	GDP 0.1	GDP 1	GDP 10
South Africa	0.382	0.295	0.267
United States	0.809	0.586	0.513
Canada	0.974	0.745	0.671
Mexico	0.402	0.410	0.411
Brazil	0.561	0.398	0.345
Argentina	0.583	0.410	0.354
China	0.640	0.455	0.395
Japan	0.867	0.537	0.431
South Korea	0.718	0.454	0.369
India	0.251	0.148	0.115
Indonesia	0.753	0.642	0.603
Russia	1.000	0.462	0.284
Turkey	0.486	0.391	0.359
European Union	0.818	0.498	0.395
Germany	0.850	0.514	0.405
France	0.847	0.588	0.504
United Kingdom	0.823	0.439	0.315
Italy	0.693	0.555	0.510
Saudi Arabia	0.483	0.876	1.000
Australia	1.000	1.000	1.000

Table 8.10: The Sustainable Prosperity Score of G-20 countries for SA on GDP related variables.

As depicted in Figure 8.12, the results indicate that countries rankings are very strongly correlated (>0.8) when the sensitivity rates were increased from 1 to 10. The countries rankings are also strongly correlated (0.6-0.79) when the sensitivity rates were increased from 0.1 to 1. Alternatively, countries rankings have a weak correlation (0.20-0.39) when the sensitivity rates were increased from 0.l to 10. This indicates increasing Gross fixed

Spearman Rho: Rank GDP 0.1, Rank GDP1, Rank GDP 10

	Rank GDP 0.1	Rank GDP1
Rank GDP1	0.624	
	0.003	
Rank GDP 10	0.334	0.896
	0.150	0.000

Cell Contents: Spearman rho
P-Value

Figure 8.12: Spearman Correlation Test conducted on different PCA-DEA combinations using MINITAB.

capital formation can only change the SPI score for the country when a major change is realized i.e. 100 folds of original GDP. Typically, this cannot be achieved over a short period of time, rendering countries ranking to be not sensitive for this parameter. Consequently, this variable is not responsive to any policy action that is associated with investments in the capital formation and it will not significantly impact the countries SPI score and ranking. It should be emphasized that when the sensitivity rate was increased from 0.1 to 10 not all the countries ranking was significantly improved. For example, Japan and South Korea rank was decreased from 4 to 8 and 11 to 13, respectively. However, Saudi Arabia rank increased from 17 to 1. These observations are expected since DEA methodology is country specific i.e. favors country policies as discussed in Chapter 7. Thus, changes in one parameter should lead to similar outcome for all countries.

(ii) Social aspect based variables

As discussed earlier, it was observed that significant weight was assigned to the social dimension in most of the G-20 countries using PCA-DEA. To further investigate the significance of this finding, sensitivity analysis was applied on variables in this dimension. Life expectancy at birth and tertiary school enrollment were chosen for this analysis, where only Saudi Arabia's values were changed based on the previous discussed sensitivity rates (0.1, 1, and 10). These changes did not lead to neither major alteration in the SPI score nor Saudi Arabia ranking. This is not unexpected when we take into consideration the large number of social variables. As a result, the two variables tested only contributed to a minor part of the social one principal component integrated in the DEA model. When assessed separately, their contribution would not lead to significant alteration in neither the ranking nor the SPI value per se.

8.6.1 Sensitivity Analysis in the DEA Model

In 1984, Charnes et al. proposed performing Sensitivity Analysis in the DEA Model by reducing the number of variables (inputs and outputs) integrated in the analysis and recalculating the efficiency score for each DMU. It is worth noting that this is the approach that is recommended in literature and this research conducted in section 8.4 Scenario 3, to increase the discrimination among DMUs investigated. To study the robustness of this approach, a Spearman Correlation Test (SCT) was performed to evaluate the relationships involved in the ranking of the G-20 countries using different PCA-DEA combinations and reducing the number of variables (inputs and outputs) integrated in the analysis.

Conducting SCT on different PCA-DEA combinations and rankings, and considering the previously discussed SCT correlations criteria, Figure 8.13 shows very strong correlation between the countries' ranking among different PCA-DEA combination models (>0.80). The results indicate that despite the fact that the variability of the information has been reduced by integrating smaller number of PCA in the analysis; the rankings of the countries have not been much affected. Yet, we still have effectively increased the discrimination among countries investigated. Collectively, the use of SCT was effective in demonstrating the validity of this methodology, consistent with literature reports.

Spearman Rho: All Inputs And Outputs, PCADEA2433, PCADEA1222, PCADEA1111

	All Inputs And O	PCADEA2433	PCADEA1222
PCADEA2433	0.977		
	0.000		
PCADEA1222	0.842	0.846	
	0.000	0.000	
PCADEA1111	0.828	0.826	0.979
	0.000	0.000	0.000

Figure 8.13: Spearman Correlation Test conducted on different PCA-DEA combinations using MINITAB.

8.7 Conclusions

This Chapter is the culmination of the research that we have conducted. We presented the results of the various analyses of the proposed Index methodologies. It is apparent that the PCA-DEA (1111) methodology is superior to the traditional DEA and HDI rescaling methodology. The proposed PCA-DEA (1111) captured the essence of a good index that is outlined in Table 4.7. When compared to GDP, this methodology was not GDP reliant, which is consistent with its comprehensive methodology that addresses sustainable prosperity from its four dimensions, which are economic, social, environmental, and wealth.

CHAPTER 9: Conclusions, Recommendations, and Future Work

9.1 Introduction

In this chapter, a summary of the dissertation research is presented in conjunction with its conclusions, and relevant implications. Furthermore, the chapter ends with the contributions of this work to the field of sustainable design and development, as well as suggestions for future research. It will also briefly review the major problems encountered during the research.

9.2 Summary of the Methodology of the Study

Interest in sustainability came as an outcome of public awareness of the negative impact of our unsustainable practices that are consumption oriented and driven by the culture of disposability. In the last century, there was a quest to come up with a sustainable development index that enables policy makers to assess progress toward achieving economic sustainable development. Despite, the scientific research that was conducted, there is no general consensus on a sustainability index that would replace or subsume GDP as an assessor of progress in economic and sustainability terms. This is partially attributed to the fact that sustainability is a complex system that incorporates many dimensions. This led researchers to develop over-simplistic single value measures to evaluate and describe such complexity and allow for easy comparison among countries and institutions. However, this leads to a de-valuation of sustainability impacts and buries hidden costs. Furthermore, there are also fewer consensuses on how to assess the ecological and human well being from a conceptual as well as a quantitative stand point. The objectives of this research are as follow:

1. To review how disposability and disposable products are commonly defined, and discuss the correlation between GDP with the culture of disposability and its impact on the environment.
2. To review and discuss the most widely used sustainability indicators where emphasis is placed on the evaluation of their methodology, advantages and limitations.
3. To define and model a novel multi-attribute sustainability measure that would assess the impact of economic strategies that foster green practices and minimize the extent of disposability. This would enable general public to be more cognizant of current practices, their impact on the environment, and more importantly encourage green manufacturing and technology without compromising economic progress. This proposed indicator will be universal and applicable to different systems that include hospitals, manufacturing facilities and processes, universities, and countries.

The first objective was achieved in Chapter 2. The second objective was conducted with a critical review of sustainability principles, global sustainability measures, and their utility in assessing the progress toward sustainable development of the G-20 countries as a system case study. This objective was achieved in Chapters 3, 4, and 5. The final objective was accomplished via Chapter 6, where we introduced a novel concept, which is sustainable prosperity and overall methodology that is adapted to build this measure. In Chapter 7, we mapped the domains, sub-domains, and indices that were selected. Chapter 8, discussed methodologies and obtained results. The G-20 group was used as the system case study.

9.3 Significance of the Thesis Work

This section will provide a summary of the significance of this dissertation under these objectives.

9.3.1 Objective 1

The critical review of the GDP methodology revealed its role in driving the culture of disposability. Indeed non-durable goods i.e. disposable products, overall contribution to GDP has expanded in the last century relative to other components. This research identified the major factors throughout the linear manufacturing model that contributed to the spread of culture of disposability and the expanded use of disposable goods. These are: planned or built-in obsolescence, the design for limited repair, mass production, combined with injection molding and other relevant technological improvements that resulted in higher rate of production and decrease in overall products cost. Collectively, these practices led to the spread of use of non-durable disposable goods. Furthermore, we identified a major flaw in the definition of durable and non-durable goods. For example, the electronics industry is considered durable goods, although there are many electronic products such as cell phones, tablets, and personal computers that don't last more than few months to couple of years. This is inconsistent with the general definition of durable goods as the products that have a lifespan of more than 3 years. Evidently, having these goods such as electronic products, under durable goods component would underestimate the overall contribution of non-durable goods to the GDP.

9.3.2 Objective 2

A literature review was conducted to assess principles of sustainability and major indices as well as identify their pros and cons in comparison with GDP. Based on this work, the main attributes that should be in an ideal sustainable development measure were identified. None of the indices investigated fully met these criteria. These attributes were used as a framework to design the novel sustainable prosperity measure we built.

Due to the major limitations of GDP, we proposed a new approach that would better assess the impact of economic activities of a country on ecological boundaries and relevant progress toward human well-being development. This is based on the use of established measures such as Ecological Footprint (EF), Human Development Index (HDI), and Happiness Index (HPI) of the G-20 group to comprehensively assess the countries progress toward the recently proposed sustainability goals by UN. Interestingly, no single G-20 country satisfied the minimum criteria for countries to be considered developed, happy as well as ecologically sustainable. This clearly calls for global institutions to revisit economic drivers, consumption behavior, and identify policies that lead to both human development and economic growth, while living within Earth's ecological boundaries.

9.3.3 Objective 3

It is evident that many policy makers have the perception that pursuing strategies that embrace sustainability would be on the expense of economic prosperity. Therefore, we introduced a novel concept, which is sustainable prosperity. It advocates that systems can adapt strategies that not only embrace sustainability, but also ensure that the wealth of the system is not compromised rather maintained. To measure progress toward this proposed principle, we designed a new measure that is the Sustainable Prosperity Index (SPI). Its principles are based on the main attributes outlined in Chapter 4 to build a comprehensive index to assess progress toward sustainable development. Unlike other indices, our proposed index has a key advantage, which is its ability not only to measure sustainable development comprehensively, but also to ensure that adapted policy will contribute to maintaining and increasing the wealth of the system and called it Sustainable Prosperity Index. Up to our knowledge, there is no report in the literature that approached sustainability from this perspective. This is particularly important when considering some policy makers are reluctant to embrace the principles of sustainability due to their concern that this would be on the expense of maintaining wealth. While our emphasis was on the country case represented by the assessment of the progress toward sustainable prosperity by the G-20 group, this novel index can also be used to assess and compare other systems such as hospitals, bank, manufacturing facilities ..etc. Indeed, the analytical methodology developed to assess the systems is capable of comparing and differentiating them so as to identify the ones that are sustainable. This is consistent with the adapted comprehensive conceptual framework that ensured the selected domains and sub-domains to be flexible and easily mapped to other systems. Moreover, this dissertation integrated the concept of happiness to additional major sustainability measures to assess the progress and effectiveness of adopted strategies of countries toward sustainable development based on a set of minimum requirements needed to attain sustainable development and are consistent with the United Nation new sustainability goals proposed in 2012. This was done because of the growing body of evidence in the literature that relates people's happiness to economic progress and prosperity as discussed in Chapter 5.

9.4 Implications of Thesis Work

This dissertation used the G-20 group as a case study for the application of the SPI index developed. These countries are considered the driving force for the global economic growth for now and over the next 40 years. This is particularly relevant when considering the proposed Sustainable Development Goals by the United Nations targeting around the same time interval. Therefore, assessing their current policies toward economic sustainable development and prosperity has a critical impact on the global sustainable prosperity.

The results of the model constructed showed that developed countries among the G-20 group had higher average SPI scores compared to developing countries over the period investigated. However, between 2008 to 2012, developed countries realized a reduction in the overall average SPI scores from ≈0.8 to 0.6. This trend was not observed with the developing countries. These results are consistent with the 2013 human development report titled "The Rise of the South", that discusses that the developing countries had major investments in human development, which were substantial compared to developed countries (Malik 2013).

Furthermore, the present developed index allows policy makers to measure their progress based on their priorities and policy initiatives via the weights assigned based on endogenous country specific priorities using PCA-DEA. This was confirmed by examining the weights of input principle components of the final model. It was observed that significant weight was assigned to the social dimension in most of the G-20 countries. Thus, the scores attained via this framework are a reflection of the countries priorities and their position among other G-20 countries. As discussed earlier, this methodology is not Western biased, which makes it favored by policy makers. The results of the countries that are ranked high should promote a sense of empowerment and a greater feeling of wellbeing of their people. On the other hand, the countries that had lower SPI scores should adapt policy initiatives that would better improve the return on their investments and help them attain progress.

Unlike other indicators, SPI is not GDP dependant which is ascribed to its comprehensive methodology that doesn't only consider the economic aspect of sustainable prosperity, but also the social, environment and the wealth of the system investigated.

9.5 Conceptual and Methodological Innovation

The methodology developed used PCA-DEA to compare and differentiate systems investigated to identify the ones that are sustainable. This has complemented the adapted comprehensive conceptual framework that ensured that selected domains and sub-domains to be flexible and easily mapped to other systems.

Unlike other measures methodologies, the use of PCA-DEA approach avoided the need to transform all indicators selected into the same unit or into monetary terms. This would undermine the accuracy of their values they contend to measure and devalue and/or hide information that would mislead policy recommendations.

While DEA is an effective scientific valuation methodology that is comprehendible by the general public, it has a critical limitation that would reduce its utility. This is represented by its inability to discriminate between DMUs. Since, it is based on identifying weights that will work for the countries rendering it a tool of choice by policy makers. To overcome DEA's limitations, this research implemented the use PCA accompanied with consideration for various combinations of different principle components that would significantly reduce the number of variables. This enabled meaningful discrimination among countries evaluated. Collectively, this combination allowed PCA/DEA to become a more powerful methodology when compared to traditional DEA. Up to our knowledge, this is the first report that illustrates the utility of PCA-DEA principle in building an index that scientifically assesses progress toward sustainable prosperity.

In summary, the use of the comprehensive approach that is not only attributed to the domains/sub-domains selected to capture the three dimensions of sustainability, but also to its inclusion of the wealth dimension and integration of the people happiness, and the PCA-DEA and its combinations are ones of the main contributions to this research.

9.6 Reflections and Future Work

Despite the scientific research that was conducted to establish sustainability measures, and given the fact that sustainability is a complex system that incorporates many dimensions, it is challenging to assess systems progress toward sustainable development. Although this research established a comprehensive framework that includes domains and sub-domains based on an extensive literature review, it is evident that not all domains / sub-domains selected came with high quality data. For example, it was challenging to find recycling and reusing rates over the years for all the G-20 countries. This was particularly observed with developing countries, which led us to use imputation to address this issue. It should be emphasized that this issue is not applicable on all data collected, since such data were acquired from reliable sources such as the World Bank and United Nations. However, the assessment can be further refined if a newer sustainability indicators are introduced and there will be a reliable sustainability database that is similar to the World Bank, which will encourage more research to be done in this area and address relevant gaps.

One of the limitations of such measures such as the index developed in this dissertation is the choice of variables that were mapped to the domains and sub-domains. It is assumed that they will give only a partial representation of the picture they individually reflects. However, once aggregated with other dimensions in the sub-domains using PCA-DEA methodology, this would provide a holistic understanding of the progress made by countries toward sustainable prosperity.

It should be stressed that measuring sustainable prosperity index for other countries especially under-developed with poor economic foundation can be challenging. This is primarily ascribed to the lack of reliable sources and databases. This may force the researcher to impute considerable amount of data, which may compromise the quality of the overall assessment. It also calls for more efforts by national and international institutions to secure the quality as well as the consistency in the data collection for various counties regardless of their status.

The construction of this index was based on the application of PCA-DEA methodology that has not been used in this area up to our knowledge. While there is a controversy to the weighting and aggregation methods used in building such index, we advocate that this method has the ability to objectively compare among countries. Furthermore, it is easily comprehendible and embraced by policy makers for its ability in allocating country specific weights that are endogenously determined by the observed performances, which is the result of policy priorities. It is highly recommended that further research is done on this methodology to better improve it. For example, future research can be done by comparing the results obtained from this method with other methods. In addition, this research used a rather trial and error and based on the research by (Põldaru and Roots 2014) and others to identify the optimum combination of Principle Components that would give the best outcome and discrimination among countries assessed. In the future, advanced optimization tools that would run PCA-DEA over all combinations possible would increase likelihood for better outcome.

Finally, although the framework was constructed to be applied on different systems, the G-20 group was used a case study. Future work would include case studies that will allow the demonstration of the utility of this approach in measuring progress for other systems, such as hospitals, manufacturing facilities, farms, ….etc.

In summary, although building such progress measures continue to be associated with major controversy since there is no agreement on a methodology of choice, still this does not invalidate its application and usefulness. Furthermore, this work is a call for other research groups to evaluate the concept and compare it with other methodologies and applications.

Appendix A: Indices/Indicators Selected for the Countries' Case

Environmental Sustainability

System Consumption-Ecological Footprint Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
Ecological Footprint	"Ecological Footprint analysis is an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area"	Global Hectares per capita	World Wildlife Fund (WWF) , Living Planet Reports.
Biocapacity	The capacity of an area to provide resources and absorb wastes. When the area's ecological footprint exceeds its biocapacity, an ecological deficit occurs	Global Hectares per capita	World Wildlife Fund (WWF) , Living Planet Reports.

Waste - Solid Waste Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
Municipal Waste Collected	This is the waste that is collected by or on behalf of municipalities, by public or private enterprises, includes waste originating from: households, commerce and trade, small businesses, office buildings and institutions (schools, hospitals, government buildings). It includes bulky waste (e.g., white goods, old furniture, mattresses) and waste from selected municipal services, e.g., waste from park and garden maintenance, waste from street cleaning services (street sweepings, the content of litter containers, market cleansing waste), if managed as waste.	TONNES per Capita	**United Nations Statistics Division**

Environmental Issues - Ozone Depletion Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
Nitrous Oxide Emissions	Nitrous oxide emissions are emissions from agricultural biomass burning, industrial activities, and livestock management.	Thousand metric tons of CO_2 equivalent	WDI The WB

Environmental Issues - Greenhouse Gas Emissions Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
CO_2 Emissions	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.	Metric Tons Per Capita	WDI The WB

Water - Water Availability and Usage Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
Annual Freshwater Withdrawals, Total	Annual freshwater withdrawals refer to total water withdrawals, not counting evaporation losses from storage basins. Withdrawals also include water from desalination plants in countries where they are a significant source. Withdrawals can exceed 100 percent of total renewable resources where extraction from nonrenewable aquifers or desalination plants is considerable or where there is significant water reuse. Withdrawals for agriculture and industry are total withdrawals for irrigation and livestock production and for direct industrial use (including withdrawals for cooling thermoelectric plants). Withdrawals for domestic uses include drinking water, municipal use or supply, and use for public services, commercial establishments, and homes. Data are for the most recent year available for 1987-2002.	% of Internal Resources	WDI The WB

Air quality - Air Pollutants Sub-domain – 5 variables

Variable	Definition	Units	Source
PM10, Country Level	Particulate matter concentrations refer to fine suspended particulates less than 10 microns in diameter (PM10) that are capable of penetrating deep into the respiratory tract and causing significant health damage. Data for countries and aggregates for regions and income groups are urban-population weighted PM10 levels in residential areas of cities with more than 100,000 residents. The estimates represent the average annual exposure level of the average urban resident to outdoor particulate matter. The state of a country's technology and pollution controls is an important determinant of particulate matter concentrations.	Micrograms per Cubic Meter	WDI The WB
Non-Methane Volatile Organic Compounds	NMVOCs are organic compounds with low boiling point and high vapor pressure. They are either naturally occurring or man-made where they are emitted into the environment from sources such as combustion activities, and various production processes. Constant indoor exposure to certain NMVOC types has harmful health effects.	Metric Tons Per Capita	Emission Database for Global Atmospheric Research (EDGAR)
Sulphur Oxides Emissions	It is one of the common air pollutants that negatively affect the air quality. For the quality of data availability, SO_2 variable has been considered for this study. It is used in many industrial processes such as chemical preparation and in the preparation and preservation of food. It can harm crops and trees and can damage a person's respiratory system. Also, it is a major contributor to acid deposition.	Metric Tons Per Capita	Emission Database for Global Atmospheric Research (EDGAR)
Nitrogen Oxides	Nitrogen oxides emission is mainly realized from electric power plants that are generated by the combustion of fossil fuels, waste incineration, agricultural burning. It is associated with significant negative impact on human health. It is also the basis of acid rain that has harmful impact on ecosystems by undermining plants growth. It also destroys buildings and other infrastructures.	Metric Tons Per Capita	Emission Database for Global Atmospheric Research (EDGAR)
Carbon Monoxide	CO is a poisonous gas that results from incomplete combustion of fuels. When enters the body, it inhibits the blood from absorbing oxygen and thus harmfully affect human health.	Gg	Emission Database for Global Atmospheric Research (EDGAR)

Economic Sustainability

Human Capital- Education Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
Education expenditure	Education expenditure refers to the current operating expenditures in education, including wages and salaries and excluding capital investments in buildings and equipment.	% of GNI	WDI The WB

Human Capital- Health Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
Health expenditure, public	Public health expenditure consists of recurrent and capital spending from government (central and local) budgets, external borrowings and grants (including donations from international agencies and nongovernmental organizations), and social (or compulsory) health insurance funds.	% of GDP	WDI The WB

Human Capital- Innovation Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
Research and development expenditure	Expenditures for research and development are current and capital expenditures (both public and private) on creative work undertaken systematically to increase knowledge, including knowledge of humanity, culture, and society, and the use of knowledge for new applications. R&D covers basic research, applied research, and experimental development.	% of GDP	WDI The WB
Resource Depletion- Natural Resources Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
Adjusted Savings: Natural Resources Depletion (% of GNI)	Natural resource depletion is the sum of net forest depletion, energy depletion, and mineral depletion. Net forest depletion is unit resource rents times the excess of roundwood harvest over natural growth. Energy depletion is the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years). It covers coal, crude oil, and natural gas. Mineral depletion is the ratio of the value of the stock of mineral	% of GNI	WDI The WB

	resources to the remaining reserve lifetime (capped at 25 years). It covers tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite, and phosphate.		

Resource Depletion- Energy Sub-domain –1 variable			
Variable	**Definition**	**Units**	**Source**
Adjusted Savings: Energy Depletion (% of GNI)	Energy depletion is the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years). It covers coal, crude oil, and natural gas.	% of GNI	WDI The WB

Economy- Status Sub-domain –3 variables			
Variable	**Definition**	**Units**	**Source**
Inflation, consumer prices (annual %)	Inflation as measured by the consumer price index reflects the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. The Laspeyres formula is generally used.	annual %	WDI The WB International Monetary Fund
Gross domestic savings	Gross domestic savings are calculated as GDP less final consumption expenditure (total consumption).	% of GDP	WDI The WB World Bank and OECD national accounts data
GDP per capita growth (annual %)	Annual percentage growth rate of GDP per capita based on constant local currency. GDP per capita is gross domestic product divided by midyear population. GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources.	annual %	WDI The WB World Bank and OECD national accounts data

Sustainability Innovation- Resources Sub-domain –2 variables			
Variable	**Definition**	**Units**	**Source**
Recycling and Reusing Rates	Recycling is a material recovery process because of its transformation of returned products into valuable resources. It manages solid waste, reduces the consumption of fresh raw materials, reduces air and water pollution by decreasing the need for "conventional" waste disposal, and conserves energy.	**%**	**ESI**
Investment in Sustainable Resources	the amount of investments each country invest as a percentage of its GDP in adopting cleaner production and implementation of new technologies that involve those focused on the utilization of renewable natural resources	**US $**	**Not Available**
Sustainability Innovation- Energy Sub-domain –2 variables			
Variable	**Definition**	**Units**	**Source**
% Electricity Production from Renewable Sources	This index is the ratio of the amount of electricity production from renewable sources (kWh) divided by the total of electricity production (kWh) in the country.	%	WDI The WB International Energy Agency
Investment in Sustainable Energy	the amount of investments each country makes as a percentage of its GDP in adopting renewable energy	US $	Not Available

Social Sustainability

Health and Population - Health Sub-domain – 3 variables			
Variable	**Definition**	**Units**	**Source**
life expectancy at birth	"Life expectancy at birth indicates the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life."	years	WDI The WB
Mortality rate, under-5	"Under-five mortality rate is the probability per 1,000 that a newborn baby will die before reaching age five, if subject to current age-specific mortality rates."	per 1,000 live births	WDI The WB

Physicians	Physicians include generalist and specialist medical practitioners.	per 1,000 people	WDI The WB and World Health Organization, Global Atlas of the Health Workforce.

Health and Population - Population Sub-domain – 1 variable

Variable	Definition	Units	Source
Fertility rate, total	Total fertility rate represents the number of children that would be born to a woman if she were to live to the end of her childbearing years and bear children in accordance with current age-specific fertility rates.	births per woman	WDI The WB United Nations Population Division

Gender Equity

Gender Equity- Economic, Education, Political and Innovation Sub-domains – 1 variable

Variable	Definition	Units	Source
Global Gender Gap Index	This index is used to rank countries according to their gender gaps and their scores can be interpreted as the percentage of the inequality between women and men that has been closed.	Dimensionless	World Economic Forum

Education and Communication - Communication Sub-domain – 3 variables

Variable	Definition	Units	Source
Mobile Cellular Subscriptions	The number of subscriptions to a public mobile telephone service using cellular technology, which provide access to the public switched telephone network. Post-paid and pre-paid subscriptions are included.	Per 100 People	WDI The WB International Telecommunication Union

Telephone Lines	The number of fixed telephone lines that connect a subscriber's terminal equipment to the public switched telephone network and that have a port on a telephone exchange. Integrated services digital network channels and fixed wireless subscribers are included.	Per 100 People	WDI The WB International Telecommunication Union
Internet Users	The number of people with access to the worldwide network	Per 100 People	WDI The WB International Telecommunication Union
Education and Communication - Innovation Sub-domain – 4 variables			
Variable	**Definition**	**Units**	**Source**
Patent Applications, Nonresidents	The number of patent applications that are filed through the Patent Cooperation Treaty procedure or with a national patent office for nonresidents in a country, for exclusive rights for an invention, a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years".	Crude Number	WDI The WB World Intellectual Property Organization (WIPO)
Patent Applications, Residents	the number of patent applications that is filed through the Patent Cooperation Treaty procedure or with a national patent office for residents in a country, for exclusive rights for an invention, a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years	Crude Number	WDI The WB World Intellectual Property Organization (WIPO)
Researchers In R&D	professionals engaged in the conception or creation of new knowledge, products, processes, methods, or systems and in the	Per Million People	WDI The WB UNESCO

	management of the projects concerned		
Scientific and Technical Journal Articles	the number of scientific and engineering articles published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences	Crude Number	WDI The WB NSF Science and Engineering Indicators
Education and Communication - Education Status Sub-domain – 4 variables			
Variable	**Definition**	**Units**	**Source**
School Enrollment, Primary	Primary education is the education that provides children with basic reading, writing, and mathematics skills along with an elementary understanding of such subjects as history, geography, natural science, social science, art, and music.	% Net	WDI The WB UNESCO
School Enrollment, Secondary	Secondary education is the education that “completes the provision of basic education that began at the primary level, and aims at laying the foundations for lifelong learning and human development, by offering more subject- or skill-oriented instruction using more specialized teachers.	% Net	WDI The WB UNESCO
School Enrollment, Tertiary	Tertiary education is the education that, “whether or not to an advanced research qualification, normally requires, as a minimum condition of admission, the successful completion of education at the secondary level.”	% Gross	WDI The WB UNESCO
Literacy Rate, Adult Total	Percentages of people ages 15 and above who can, with understanding, read and write a short, simple statement on their everyday life	% of People Ages 15 And Above	WDI The WB UNESCO

Education and Communication - Education Access Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
Pupil-teacher Ratio, Primary	The number of pupils enrolled in primary school divided by the number of primary school teachers (regardless of their teaching assignment)	Ratio	WDI The WB UNESCO

Community- Safety Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
Global Peace Index	This index provides a ranking in term of countries progress according to their peacefulness. It assesses the extent of the country's involvement in both domestic and international conflict.	Score	Economist Intelligence Unit, published annually as reports by Institute for Economics and Peace

Community- Family Security Sub-domain – 1 variable			
Variable	**Definition**	**Units**	**Source**
Divorce Rate	Divorce is the final termination of a marital union and cancellation of all relevant legal responsibilities of marriage between involved parties	number of divorces per 1,000 population	UN Statistics Division-Demographic Yearbook

Community- Infrastructure Sub-domain – 6 variables			
Variable	**Definition**	**Units**	**Source**
Passenger cars	It is the road motor vehicles, other than two-wheelers, intended for the carriage of passengers and designed to seat no more than nine people (including the driver	per 1,000 people	WDI The WB International Road Federation

Road density	It is the ratio of the length of the country's total road network to the country's land area. The road network includes all roads in the country: motorways, highways, main or national roads, secondary or regional roads, and other urban and rural roads"	km of road per 100 sq. km of land area	WDI The WB International Road Federation
Roads, paved	They are those surfaced with crushed stone (macadam) and hydrocarbon binder or bituminized agents, with concrete, or with cobblestones, as a percentage of all the country's roads, measured in length	% of total roads	WDI The WB International Road Federation
Vehicles	Vehicles per kilometer of road include cars, buses, and freight vehicles, but do not include two-wheelers. Roads refer to motorways, highways, main or national roads, secondary or regional roads, and other roads. A motorway is a road specially designed and built for motor traffic that separates the traffic flowing in opposite directions	per km of road	WDI The WB International Road Federation
Improved sanitation facilities	Access to improved sanitation facilities refers to the percentage of the population with at least adequate access to excreta disposal facilities that can effectively prevent human, animal, and insect contact with excreta. Improved facilities range from simple but protected pit latrines to flush toilets with a sewerage connection. To be effective, facilities must be correctly constructed and properly maintained.	% of population with access	WDI The WB WHO
Improved water source	Access to an improved water source refers to the percentage of the population with reasonable access to an adequate amount of water from an improved source, such as a household connection, public standpipe, borehole, protected well or spring, and rainwater collection. Unimproved sources include vendors, tanker trucks, and unprotected wells and springs. Reasonable access is defined as the availability of at least 20 liters a person a day from a source within one kilometer of the dwelling.	% of population with access	WDI The WB WHO

Community- Political Sub-domain – 2 variables			
Variable	**Definition**	**Units**	**Source**
Political stability and security	Included in GPI see above	Score	Economist Intelligence Unit, published annually as reports by Institute for Economics and Peace
Political freedom Average of indexes of political and civil liberties	It is an index that is used by politicians, global agencies, and human rights defenders to evaluate trends and progress toward attaining and maintaining freedom and democracy worldwide.	Score	Freedom House The *Freedom in the World* data and reports

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