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EXPERT WEIGHTING BASED DYNAMIC ECOEFFICIENCY ASSESSMENT OF WORLD CONSUMPTION

BY

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ABSTRACT

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Title: Expert Weighting Based Dynamic Eco-efficiency Assessment of World Consumption

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Optimizing the consumption of natural resources and ensuring the availability of resources for both current and future generations has been the target for sustainability research. This paper aims to assess the eco-efficiency of global resource consumption through the environmental footprint perspective. The study effectively utilized EXIOBASE 3.41, a multi-region input-output (MRIO) database, for collecting data and Multi-criteria decision making (MCDM) approach for eco-efficiency assessment. Besides, the present paper utilizes expert weighting strategies such as EPP, SAB, Harvard, and EQUAL for assigning relative significance to various environmental indicators. Primarily, the data sample represents the influence of environmental stressors like GHG emission, land use, energy use, material consumption, water consumption. The study expands through three major scenarios in terms of importance to the economic and environmental outcomes. As such, with three scenarios and four weighting strategies, twelve situations are considered for the purpose of the study. The study findings indicate that the eco-efficiency score for given weighting strategies concerning economic and environmental impact demonstrates a significant statistical difference. The countries like China, India, Russia, Mexico, and Turkey are worst performing while Switzerland, Japan, UK, Germany, and France are best performing in terms of eco-efficiency score. Finally, k-mean clustering algorithm has applied to rank the countries centered on eco-efficiency score and weighing strategies.

DEDICATION

I dedicate my thesis to my beloved parents, for their endless support and encouragement.

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Chapter 1: Introduction

The concept of eco-efficiency and sustainability gained more extensive attention in recent years. The breadth of sustainability is going beyond the scope of the current generation to future generations. The notion emphasizes the rational consumption of resources with a deep understanding that natural resources are not inexhaustible. Academics, industrialists, governments, and businesses around the globe are conducting advanced research on the concept, thus ensuring productive use of available resources. Extensive breadth of thinking is required to work towards attaining and maintaining a satisfactory level of quality life with balanced economic growth, and a safer environment. In general, the topic sustainability addressed as triple bottom lines which is about managing social, environmental, and economic factors. Whereas, eco-efficiency is considered as a part of the broader concept of sustainable development which emphasizes the industrial efficiency, ecological preservation, and economic development. The subsequent section of the literature review will provide a solid understanding of eco-efficiency and sustainable consumption and its global significance.

1.1 Background and Motivation

The universal economy is advancing through a comprehensive transformation with the adoption of a sustainable developmental approach as a result of global climate change and the environmental campaign. In this revolutionized economy, sustainability and eco-efficiency have shifted an integral part of policies and decision-making processes. Every industry has a critical role to play in the sustainability program, which puts pressure on countries and corporates across the globe. Sustainable development prospect raises voice for changes in all phases of an industrial process which does not limit to material, techniques, or personnel. Though there are theories and constraints addressed across research, the optimal tool and techniques to attain sustainability are lacking (Tsai & Chang, 2012). While assessing sustainability, there is also an urgent need to address the eco-efficiency and sustainability issues with regard to natural resource depletion and mismanagement. Furthermore, there identifies a considerable gap in the literature in assessing the eco-efficiency of global consumption through the eco-footprint perspective. With the insight of the sustainability emphasis in both national and international platform through United Nations development goals and the Qatar National Vision 2030, there is a growing demand for standardized tools and facilities for implementing sustainability (General Secretariat For Development Planning, 2008; United Nations, 2019). Most importantly, by ensuring sustainability, the global community can realize the global well-being of both current and future generations. The present study aims to assess the eco-efficiency of global consumption-based on expert weightage systems.

1.2 Research Objectives

The current research set out to investigate and measure the eco-efficiency of global resource consumption for the past twenty years. Drawing upon the consumption data from an environmental footprint for twenty revolutionary countries are applied for the research. The purpose of this investigation is to explore the global environmental impact as opposed to the economic development in the respective countries. The impact of global consumption in Greenhouse Gas (GHG) Emissions, energy consumption, water usage, land usage, and material depletion are considering in the eco-efficiency measurement of the research. This study seeks to obtain a better understanding of the economic and environmental impact of global consumption, thus will contribute to global environmental movements. Principal motivations of the present research can be encapsulated as:

- Understanding the environmental footprint of consumption over time.
- Develop a dynamic Eco efficiency modeling approach using different weights.
- Identify the best and worst performing countries

1.3 Thesis Outline

The current research paper begins with a short review of the literature, research objectives, and background understanding about sustainability and ecoefficiency in the global industry. The literature review in Chapter 2 explored the underlying factors of eco-efficiency and ecological impact in the global consumption of natural resources and associated resource degradation. That being said, the review also focusses on the economic and ecological impact of sustainable development and explores eco-efficiency indicators to measure those impacts. Further, the review explores existing assessment frameworks and tools to draw a baseline for the research. The review discusses the current state of eco-efficiency research and activities globally with a special emphasis on Middle East countries like Qatar. The last section of the review provides a brief overview of the Multi-region input-output (MRIO) table and the Multi-Criteria Decision making (MCDM) approach, which is the core research approach of the present paper. Chapter 3 introduces the methodologies of the research, which primarily is the assessment method of global consumption through a standardized weightages system formulated on MCDM, through EPP, SAB, Harvard, and Equal. Further, the chapter provide details on dataset, data source, and a flowchart to get a better understanding of the research approach and actions. The Chapter 4 presents the findings of the research, provides a deep insight into the eco-efficiency of global consumption which would further facilitate to get a better understanding of global sustainability and related activities. The evaluation follows a comprehensive discussion in chapter 5 through a summary of research and implication of the findings. The section then follows to discuss the challenges faced during the research to future research opportunities on the topic. Lastly, the paper list all used literatures in reference section along with additional charts and information in the Appendix for further clarification.

Chapter 2: Literature Review

2.1 Introduction

The global population and global gross domestic product have significantly grown over the past couple of years. The rapid urbanization and population growth instigated the worst climate change and other socio-economic transformation. United Nations Environmental Program's Global Resources Outlook (2019) reveals that the global natural resource extraction extended to 92 billion tons in 2017 as contrast to 27 billion tons in 1970 for meeting economic development and associated global material demand. Likewise, around the globe, a notable amount of industrial waste is generated through industrialization which is close to 85% of the total waste produced by various industries (International Solid Waste Association, 2015). Over the last decade, a rising number of environmental management initiatives has risen, encouraging efficient resource consumption and waste generation to minimize ecological disturbance. This environmental focus has been paving the way for adopting sustainability assessment and assessment frameworks.

Primarily, the sustainability assessment approaches not only address and integrate the environmental factors, but also the economic and social aspects of the project. A large number of existing studies in the broader literature have examined the concept of sustainability and eco-efficiency. Despite decades of research, eco-efficiency and sustainability continue to be debated among environmentalists, academics, and businesses. In short, there is an increasing demand for eco-efficiency assessment of global resource intake while proposing a standardized model for the effective implementation of environmentally friendly projects around the globe. Most recently, research has been using models such as Multi-Region Input-Output (MRIO), Hybrid Life Cycle Assessment (LCA), and Bilateral Trade-based Analysis and to measure the environmental emission and resource consumption in various industries (Lenzen and Crawford, 2009; Wiedmann and Barrett, 2013; Pairotti et al., 2013; Onat et al., 2014; Jang and Hong, 2015; Duchin and Levine, 2016; Ezici et al., 2020). Later part of the literature will provide a deep understanding of eco-efficiency and assessment models in the current sustainable economy.

2.2 Define Sustainability and Eco-efficiency

In a broader perspective, sustainable development or sustainability refers to the concept of enhancing the quality of life while preserving the natural resources and the existence of living things. During the late 1970s environmentalists and authorities identified the need for new development models to overcome environmental issues, to facilitate unbiassed distribution of resources, and to improve the quality of life, which eventually lead to the development of sustainability and sustainable models (Kaur and Garg, 2019). Although the underlying factors of eco-efficiency and sustainable development remain the same, the definitions vary due to the nature of its focus. The term sustainability was first coined by the Brundtland Report published by the United Nations of the World Commission on Environment and Development. Further, the Brundtland Report formulate sustainable development as a process “meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). Nevertheless, eco-efficiency is a critical aspect of sustainability. The term eco-efficiency primarily is a management concept that addresses the environmental impact and economic performance, disregarding the social aspects in comparison with sustainability. The term eco-efficiency was first described Schaltegger and Sturm in 1989 (Huppes and Ishikawa, 2005), which explains the ratio between environmental impact and the value of consumption. Glavic et al. (2012) describe eco-efficiency as a management strategy of creating additional goods and services while consuming fewer resources and producing less wastage and ecological impact. The eco-efficiency definition principally focusses on reducing the environmental effect while improving the economic benefits.

A growing number of literatures interpreted both sustainability and eco-efficiency in various industrial perspective yet pointing to the alarming rate of natural resource depletion. However, there was no specific definition that exist for eco-efficiency, and often it is observed as a business strategy for sustainable development. In contrast, some research identifies eco-efficiency as an indicator of eco-friendly performance. The broader definitions of eco-efficiency can be characterized into four major categories are (i) "statement of more from less", (ii) "ratio between environmental and economic output" with focus on producing more value with less ecological impacts, (iii) economic to environment impact ratio with emphasis on reducing the ecological intensity of the economic performance, (iv) "management strategy", and (v) as an "adjustment to the management strategy" with directions to improve eco-efficiency in organizations (Koskela and Vehmas, 2012). That is to say, the concept of eco-efficiency is explained in pieces of literature using various terminologies like environmental productivity, environmental cost-effectiveness, and environmental improvement cost. While a variety of definitions of the term eco-efficiency have been suggested, this paper will clarify the term as an approach to optimize resource utilization by identifying the ratio of environmental to the economic impact of resource consumption. The current paper adopted the eco-efficiency equation from The World Commission on Environmental and Development (1987) as:

$$\text{Ecoefficiency} = \frac{\text{Economic value}}{\text{Environmental impact}}$$

Stronger, yet collective action from government, private organization, and policymakers are focusing on transforming the way the natural resources are "extracted, processed, used, and disposed" (International Resource Panel, 2019, p.9).

Sustainable development enforces an equilibrium or balanced use by changing the resource usage habit while maintaining the quality of living (Yılmaz and Bakış, 2015). Likewise, Ortiz et al. (2009) claim that sustainable development is a balanced act among technology, innovation strategies and national-international policies. Along the similar lines, the World Business Council for Sustainable Development (WBCSD, 2006) argues "eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring a quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the Earth's estimated carrying capacity". More recently, the concept of sustainability and eco-efficiency drew increased attraction among authorities, and several recommendations have been made underscoring recycling and reuse as a means of adapting a sustainable approach.

2.3 Sustainable Consumption

The world is going through rapid urban expansion and infrastructure development as the effect of globalization, driven by advances in transportation and telecommunications. The world's urbanization rate is growing at an alarming rate and the report anticipated to have 61% of the world population will soon be residing in urban areas (Cohen, 2005). If not planned and executed appropriately, the urban expansion and industrial revolution will have an adverse impact on the living being and the surrounding environment. The waves expand from air-soil pollution to climate change and life span every living being on the planet. Even though it became progressively popularized and elaborated, recent trends in urban development consecutive to higher consumption of energy resources and associated waste production and pollution (Kaur and Garg, 2019). The advantage of incorporating sustainability into infrastructure development may lead to a reduction in energy consumption, ecological consequences, and pollution while ensuring integrated roadways. Sustainable development has always been considered as a multifaceted topic which complies with environmental responsibility, economic advantage and social awareness (Shelbourn et al. 2006).

Back in 1992, the body of the united nations for sustainable developed named as United Nations Commission for Sustainable Development (UNCSD) was first formed to facilitate the smooth path of environmental and sustainability goals (UN Department of Economic and Social Affairs, 2020). Subsequently, the Sustainable Development Goals (SDG) of the United Nations (2019) emphasizes on ensuring sustainable consumptions and production by aiming the responsible consumption of natural resources. SDG 12 encourage developed countries to take a lead role in this attempt and to cut down waste creation through "prevention, reduction, recycling, and reuse". Further, they target to "rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, following national circumstances, including by restructuring taxation and phasing out those harmful subsidies". The concept of sustainable consumption accelerates over the past three decades and has been coined differently by various academics and policymakers. The interpretations vary from consumption efficiently, energy preservation, product sharing, recycling, and use of the high-quality product. The Oslo Roundtable held in 1994, put forward a promising definition to sustainable consumption as "… 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 the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of further generations" (Dawkins et al. 2019). Sustainable consumption is a broad term addressing the responsible consumption of resources while ensuring environmental protection and quality life for all generations. Quite recently, the emphasis and focus of this consumption sustainability is yet another topic for debate. Consumer behavior, lifestyle, consumerism pattern, production process emphasis are some of the topics for interest among scholars; whereas the discussion on consuming less quantity through efficient and responsible manner are opening the door to broader research (Jackson, 2004; Jackson, 2014). A growing body of works of the literature suggests increased attention and the vital need for policies and further discussion.

The dimensions and the actors of sustainable consumption is another frequent source of debate under this topic. The main actors in the consumption process are the consumer and goods or services which are participated in the course, in some cases, intermediate consumers too. However, the subject of goods and services include an array of the topic which would fundamentally address both recreational and physical goods (Jackson, 2014). Sustainable consumption and production (SCP) were talked about in pieces of literature as a "top-down" approach by policymakers emphasizing economic intervention whereas the "bottom-up" approach by organizations focus on corporate commitments (Wang et al. 2019). The research also observed a more considerable gap in the activities of developing and developed countries. It is often recognized the lack of essential resources in developing and countries and is weighing more and more on meeting the economic and social needs over environmental performance (Clark, 2007; Fang et al. 2007; Manohar and Kumar, 2016). In essence, sustainable consumption is about decoupling the economic benefits from environmental exploitation through promoting sustainability and resource productivity. Sustainable consumption requires the coordination of stakeholders across different sectors around the world. The process involves not only the economic-environment decoupling but also the expanding opportunities through "leapfrogging", sense to promote a process of "…more resource-efficient, environmentally sound and competitive technologies, bypassing the inefficient, polluting, and ultimately costly phases of development" (United Nations Environmental Program, 2020). As a process of ensuring the quality of life for current and future generations, policymakers should take action for eliminating the unsustainable outline of both consumption and production. Last couple of years seen the emergence of "Conscientious Consumerism" as an effect of tackling sustainability at the consumer level. Although conscious consumer makes less impact on the production side, this still can contribute towards a sustainable economy.

2.4 Current State of Eco-efficiency

The global economy is alarmingly showing a negative trend in its global circularity. Every year, more than 100 billion tons of materials are harnessing in the global economy, the Circularity Gap Report 2020 found (Wit et al., 2020). It is worth noting that the decision-makers and environmentalists have already initiated a drive towards incorporating sustainable best practices in global resource consumption and development. Acai and Amadi-Echendu (2018) state that transport infrastructure development necessitates ensuring less impact on the environment while guaranteeing reduced life cycle cost and socio-cultural benefit. As the adoption of eco-efficiency measures requires addressing all levels of a business, the organization will get a better understanding of their activities and their positioning in the environmental and financial outcome. The pieces of literature observe the transformation of the business to be more competent and profitable when integrating eco-efficiency measures since it leads to less virgin resource consumption, less wastage, less pollution, and improved production approach, recycled material usage, and more innovative method (Srinivas, 2015). Sustainable development is recognized as a comprehensive process that involves learning and developing skills. Keeping such a learning approach as a baseline, sustainable development is not just about what can be achieved; instead, sustainability addresses organizational principles of raising awareness and learning process. Enquete-commission examined sustainability as a regulative idea that comprises strategies to enforce sensitivity, discipline, participation, conflict management, and creativity (Lütteken and Hagedorn, 1999). Sustainability is inevitable and is essential to improve and uphold the standard of living. In fact, eco-efficiency is a dynamic process helping organizations to develop and implement strategies to achieve sustainability.

The dependence and determining factors of sustainability have been largely underscored in the literature—Berardi (2013) emphasis on the time dependence of sustainability as observed in the Brundtland sustainability definition. On similar lines, Hjorth and Bagheri (2006) view sustainability as an ongoing process, not a project with a specific closing date. The spatial dependence of sustainability is observed further by Berardi (2013) as a moving target, initiated on a local scale and continuously expanding to a broader dimension. The domains and categorization factors of sustainability are the most discussed among the concept of dependency. While Bruthland's report undoubtedly points to the social, economic, and environmental dimension, studies underlined the cultural and political perspectives too. In essence, sustainability can be accosted as a "pluralistic approach" which should consider and integrate multiple factors, actors, and characteristics to ensure meeting current needs without compromising for the future (Acai and Amandi-Echenchu, 2018). Sustainability signals to improve economic and environmental factors of living along with the social characteristics and leading to improve the standard of living. It is imperative to maintain environmental equilibrium with effective policies and government regulations.

With the rapid growth of urban population and infrastructure developments, Middle East countries are facing enormous challenges with environmental responsibilities than ever before. To build an environmentally feasible industry, countries need to focus on alleviating the natural resource exhaustion and illicit use of the resource. In recent years, Gulf Cooperation Council (GCC) countries have been working more rigorously towards attaining sustainability in all sectors with a particular emphasis on construction and buildings. Recent research on growth and sustainability trends designating that GCC countries are among the top list of environmental emission and energy consumption (De Gruyter et al., 2016). Analogously, the consumption of liquid fuels and the associated pollution rate has snowballed in the last few years. By engaging with global environmental campaigns, Middle East countries have formulated comprehensive sustainability goals and policies for ensuring active and responsible resource consumption. The Global Sustainability Assessment System (GSAS), earlier known as Qatar Sustainability Assessment System (QSAS) is one of the early formulated green building and performance-based systems in the Middle East and North Africa (MENA) region (Issa and Abbar, 2015).

GSAS explicitly addresses the natural resource exploitation and reinforces sustainable built environment and associated environmental impact. It is also highlighted that climate change, resource depletion, pollution, and contamination are some of the highlighted challenges of the Middle East economy (Gulf Organization for Research Development, GORD, 2017). Needless to point out that, GORD is committed to contributing to sustainable development through best practices, standards, and schemes. Likewise, Qatar Green Building Council (QGBC) is aiming to support the design and development of environmentally sustainable infrastructure. Corporate behavioral change combined with community support is crucial to the success of sustainable urban development. Whilst progressing towards meeting the Qatar National Vision 2030, Qatar has committed to be upfront with the United Nations Sustainable Development Goals. Activities in coordination with QGBC has aimed to raise awareness while making the community recognize the benefit of ensuring sustainability (Youssef, 2017). Qatar's national dietary guidelines were one of the first initiatives to consolidate the concept of sustainability into a public platform like the Supreme Council of Health (SCH). The guideline was incorporating the underlying principles of food security, food wastage and Islamic perspective with a compelling authority of the SCH (Seed, 2015). Having said that, the guidelines will contribute to both environmental and economic sustainably in no small extent. Kucukvar et al. (2019a) explored the economic and environmental impact of global food production using open source environmental footprint databases to underline that governance and policymakers should focus more on the supply chain as a means to reduce carbon footprint. That said, countries around the globe are working rigorously toward sustainable performance through enforcement of standards and code to practice sustainability across different sectors.

Nonetheless, research findings pinpoint the challenging circumstances of implementing sustainability due to both human-made and natural constraints. The region only holds 1% of the total world freshwater, which points to the notable scarcity of water in addition to the intense heat and dry weather. The scarcity of water has a meaningful impact on food production and cropping, which eventually limits subsistence use and economic opportunities. While considering the global impact of water scarcity, research claimed that the possibility of reducing undernourishment is limited as the food production would require more water and put even more pressure on their limited water resources (Mathew, 2016). Another challenge of sustainability in Middle East countries was the lack of awareness. It is required to raise awareness, thus providing an understanding of the individual and community benefits. Nevertheless, another challenge of countries with a higher Human Development Index (HDI) is the non-correlative bond between human development and natural resources, particularly in the overconsumption pattern. The aforementioned case raises a considerable concern that awareness and availability of the natural resources rating system do not alleviate resource overconsumption (Issa and Abbar, 2015); rather law and policies by governance are important.

2.5 Sustainability Assessment Models

Ensuring ecological and economic efficiency is often hindered through various organizational and procedural barriers. New technologies and methods face resistance from organizations and stakeholders due to the process change requirements, which will lead to possible risk and cost entailments (Hakkinen and Belloni, 2011). Novel approaches, awareness and standardized assessment methods would overcome the hindering factors to an extent. Numerous works of literature addressed a relevant aspect of sustainable consumption and proposed frameworks and policies for assessing eco-efficiency. Sustainability tools and eco-efficiency assessment method has been gaining importance since the 1990s and has been expanding to various infrastructural sectors. Eco-efficiency rating tools are necessarily addressing the sub-processes, and life span thus identifies the policies and best practices to ensure its sustainability. Further, the assessment tools help to define measures that would facilitate sustainability and later enables to measure the impact of measures in the sustainable outcome (Bryce et al., 2017). The emphasis is on its global and universal applicability while enabling them to customize and adapt to countries predicated on their capabilities and requisites.

What is more, eco-efficiency assessment indicators have been widely used for comparative studies and decision-making tasks in sustainable development activities. Sala et al. (2015, p.314) recognize sustainability assessment as a complicated appraisal method - further complemented that sustainability assessment as a technique that supports "decision-making and policy in ubiquitous environmental, economic and social context, and transcends a purely technical/scientific evaluation". Likewise, Ness et al. (2006) identifies the purpose of sustainability assessment as a means to guide decision-makers facilitating to assess both local and global natural resource consumption systems. As such, decision-makers learns an outlook of policies and enforcement to be applied in both short term and long term. The identification of eco-indicators for eco-efficiency assessment is a rigorous systematic task due to its higher impact on the quality of assessment results and subsequent decision making. Thus, the eco indicators are indirectly playing a role in improving the quality of living while preserving the natural resource (Van Caneghem et al., 2010). However, performing eco-efficiency assessment is often challenged with identifying the subtle difference between scientific-based and policy-based activities, which would contribute to propose solutions and to educate stakeholders as appropriate

The World Business Council for Sustainable Development (WBCSD) raises the need for set indicators with a sound basis for efficient sustainability assessment. More specifically, for transport and mobility, these indicators will facilitate to evaluate the sustainable development in particular for a regular interval, thus contributing to the long-term sustainability goals (Fahy and Roizard, 2015). United Nations Commissions devised a framework to evaluate a set of sustainability indicators for assessing individual countries and their government level activities. The eco-efficiency indicators (EEI) is aiming to measure the ecological efficiency of an organization by recording their economic activity in both consumption and production (United Nations, 2009). In essence, the EEI is an eco-efficiency metrics helps to condense all required information and guide in the organizational decision-making process. Further, Singh et al. (2009) conducted a comprehensive review of the sustainability assessment framework and methodologies to draw an overview of sustainability indices and sustainable development activities across the domain. The review mentioned above mainly focused on the formulation of indices through normalization, weighting, and aggregation- thus emphasis on the complex, yet advantageous multi-dimensional characteristics of indices. Having said that, Mata-Lima et al. (2017) state that sustainability assessment indicators are often related to key organizational objectives. In a nutshell, every organization can contribute to sustainable development and environmental protection, and the assessment indices are dependent on its products and services.

European Environment Agency (EEA) argues that road transport is liable for 72% of the greenhouse gas emission of the sector urges the inevitability of monitoring and scrutinizing (EEA, 2018). There have been several approaches adopted for sustainability assessment in various sectors; however, Life Cycle Assessment (LCA) based approaches are outstanding and prominent in the research arena. Santos et al. (2016) developed a comprehensive multi-dimensional model which assess Life Cycle Costing (LCC) and LCA. This integrated LCC-LCA model is prepared for a long-term assessment of both the economic and environmental impact through a full life-cycle perspective. More recently, research recognized some drawbacks of LCA, which primarily affects its accuracy (Loiseau et al., 2012). The argument mentioned earlier addresses the primary objective LCA as environmental consequences and the associated bias. Beyond that, Tsai and Chang (2012) underline the rising demand for concrete tools and techniques to evaluate sustainability in all phases of the project life cycle. Aforesaid assessment approach would eventually benefit regulators and policymakers in the successful enforcement of sustainability regulations. Though there are approaches introduced to incorporate the social impact, it is not well-developed as the existing environmental and economic approaches. Evaluation partnership and the Centre for European policy studies (Bueno et al., 2015) identified the limitations for mainstreaming social impact assessment as the term “social impact” itself is broad and not clearly defined. Above and beyond, there is a lack of quantitative tools that measure social impact, which makes it inefficient to address in the evaluation process.

A broad range of literature discussed rating systems and certification tools to aid in applying sustainability principles into consumerism and resource consumption. Although most rating systems share some standard functionalities, each holds unique features according to the nature of resources and industry as intended. Mata-Lima et al. (2017) proposed a tool to set benchmarks based on the organization’s existing sustainable development activities and to identify suitable best practices. Apart from this, Montgomery et al. (2015) have proposed a rating system for transport facilities which mostly grouped the sustainability features into five categories such that living standards, natural resources management, emissions, and leadership are measured. A New Zealand based eco-efficiency study adopted a unique approach by applying Principal Component Analysis (PCA) to eco-efficiency indicators, thus producing some aggregate indicators for guiding in national environmental policies. The five significant dimensions of eco-efficiency as identified by the research were air discharges, water contaminants, and the consumption rate of material, land, and water (Jollands et al., 2004). However, it is worth pointing out that the rating system acts as a foundation for integrating sustainability into the overall life cycle of a product or service. However, another advantage of the rating scheme is its quantitative and holistic approach to assess sustainability. Harger and Meyer (1996) argue the essential characteristics of assessment indicators as simplicity, quantifiable, customizable, and reflecting the current market trends. Besides, the review by De Gruyter et al. (2016) on Transport systems in the Asian region indicated the higher pollution rate in Asia and Middle East region and further suggested to take appropriate action for improving environmental and social performance. Just recently, Al-Thawadi and Al-Ghamdi (2019) evaluated the sustainability of urban mobility in Qatar using a comparative LCA model reveals that the transportation system depletes water and energy resources considerably. With all these, there is a significant need for efficient tools and frameworks for assessing resource consumption. Regardless of the forms of models and frameworks, the interpretation of sustainability is more important in the selection of tools for industry and region. It has been observed that most existing tools are retrospective, stressing the non-optimality of assessing future sustainability patterns. The particular argument underscores the applicability of forecasting tools for better interpretation of impacts, advantages, opportunities, risks and vulnerabilities (Ness et al., 2006). The globally interconnected nature of the economy signifies critical instruments to measure global resource consumption and associated footprints. The need for such international standards and methodologies leads to development tools like multi-regional input-output (MRIO) analysis, consumption-based accounting (CBA), and production-based accounting (PBA). In models like MRIO, the economic systems are represented employing interdependent industries and interrelated regions, leading to a comprehensive view of global impact (Tukker and Dietzenbacher, 2013).

2.6 A Review of Multiregional Input-Output (MRIO) Analysis

The global economy comprises interconnected processes, activities, interactions, interdependencies, and industries around the globe. Input-output analysis

(IOA) is a framework formed for representing economic transactions in various sectors over a year by the Nobel Prize winner Russian American economist Wassily Leontief. The wider implications on climate policy and environmental challenges necessitate researchers to integrate the economic and environmental aspects into one analysis platform. The Environmentally extended input-output analysis (EE-IOA) was formed to integrate environmental impact and resource consumption from both economic and environmental perspectives. The EEIO and single-region IOA (SIOA) has gained popularity in the last decade, specifically in the emission assessment of GHG, Carbon-di-oxide (CO2), and other toxic air pollutants (Dietzenbacher and Mukhopadhyay, 2007; Andrew and Forgie, 2008; Cruz and Barata, 2008). However, the difference in production technology, production structure, and the consumption pattern across global countries raised challenges with modeling using Single Region Input-Output (SRIO) analysis. The mandate for a powerful, yet effective tool to represent a complex web of economic data leads to the emergence of MRIO, an effective tool to put together economic decisions from limited information (Steen-Olsen, 2015). Over the last two decades, MRIO have been adapted in various environmentally extended sustainability studies for assessing GHG emissions (Hertwich and Peters, 2009), land and water use (Wilting and Vringer, 2009; Feng et al.,2011), and air and water pollution (Kim et al., 2001; Levinson, 2010). The environmentally extended model of MRIO provides a methodological framework for estimating consumption footprints at both the national and international level across sectors. The fundamental concept of MRIO is in regional economics and the difference in production technologies and regional technology coefficients (Miller and Blair, 2009). It is worth pointing to the fact that not all MRIO methods have the same mathematical modeling and formulation.

A research on assessing the impact factors of Global warming Potential and

Potential acid Equivalent for consumption in Italy have effectively utilized the MRIO modeling. The research findings pointing to the fact that resource exploitation in the consumption phases is larger than in the material production phase (Bertini and Paniccia, 2008; Ali et al., 2018). Several studies in UK employed MRIO and its alternative version for measuring CO_2 and GHG emissions. A notable example in UK is the comprehensive study conducted by Minx et al. (2008) applying structural path analysis in MRIO covering 57 sectors and 81 regions for GHG emission. A broad range of literature from United States indicates the use of MRIO and Input-output analysis to explore consumption and ecological consequences in manufacturing, food, and transportation sectors by assessing carbon emission and resource exploitation (Wiedmann et al., 2011; Kucukvar et al., 2014a; Onat et al., 2014). A material footprint (MF) based analysis on electric vehicles argues that 63% of the MF associated with electric vehicles are in United and urged the need for deploying alternate fuel vehicles (Sen et al., 2019). In this regard, several kinds of literature discussed the integration footprint-based analysis into sustainability assessment across countries like UK, United States, and Turkey (Onat et al., 2015; Onat et al., 2016a; Onat et al., 2016b; Kucukvar et al., 2017). With the availability of a large amount of quality data, more sophisticated MRIO based research has been proposed in recent years.

The MRIO measures follow the measurement of natural resources as an area-based and international indicator. Several concepts have originated as side effects of these models. The concept of “carbon footprint” has emerged to be a climate change abatement action in recent times. Wiedmann and Minx (2008) define the concept as a measurement of the CO_2 emission from any product during its lifecycle, which essentially doesn’t take account of other carbon products due to the quantification challenges. Another notable concept is “water footprint” investigates the unsustainable use, quality, and consumption-based indicator of freshwater usage. The water footprint further indicates the interconnection of freshwater consumption among water resources, human and international trade (Ali et al., 2018). The "ecological footprint" is a wider concept to quantify human resource consumption and waste generation regarding the total carrying capacity of a particular geographic region (Wackernagel and Yount, 1998). An ideal MRIO database can be defined to be as detailed as possible on the various sectors and products while extensively covering economic and ecological impact in a wider geographical region over period in time-series fashion (Tukker et al., 2013). The disparities in quality of data, availability, consistency, and the advanced technologies have caused the emergence of MRIO databases such as AIIOT, Eora, EXIOBASE, GTAP, OECD and WIOD, each differing in terms of regions, time-series, sector, and its resource consumption extension.

As developing an MRIO database is complex, yet lengthy process, the researchers should pay critical attention to choose the database according to the research need (Inomata and Owen, 2014). Nevertheless, research across the globe employed an MRIO approach for measuring and investigating various environmental and economic impacts. MRIO tables extended with environmental satellite accounts facilitate to draw information on balancing act of energy consumption and carbon footprint in various economic regions (Wiedmann et al., 2007). Similarly, Nijdam et al. (2005) conducted a household environmental impact study based on production technologies and consumption emission in the Netherlands and other world regions. The respective study findings leading to the fact that most of the ecological impact is happening due to the unsustainable nature of the product while most consumption emissions are from industrialized countries around the world. The only forewarning of MRIO database is its requirement for harmonizing and reconciling regional data to accommodate the integrated structure. Having said that, there might be possible deviations from the statistical data of a country versus its global representation in the MRIO databases which subsequently rise challenges in the policies and decision making (Wood et al., 2014; Moran et al., 2018). Despite the uncertainties and challenges, the potential to represent multiple production technologies and supply chain makes the MRIO model relevant to sustainability studies.

2.7 A Review of Multi-Criteria Decision Making (MCDM)

The globalization and enormous technology proliferation lead to complex, disintegrated criteria and indicators in energy planning and resource consumption. The sophisticated scenario of multiple criteria and objectives challenges governance in framing policies and decision making. The MCDM has risen to deal with such complex problem-solving scenarios in energy planning and sustainable consumption and production. The MCDM can be broadly defined as a branch of operational research target to attain optimal results in sophisticated setups involving multiple indicators and different criteria. The MCDM tool has disseminated in sustainability research and decision making due to its flexibility to take consideration of multiple criteria and objectives simultaneously in the disintegrated level of electrification (Kumar et al., 2017). In recent years, MCDM has found an integral role in energy system design expanding through agriculture resource management, education, healthcare, and defense. Analytic Hierarchy Process (AHP), Fuzzy set theory, Principal Components Analysis (PCA), Simple Addictive Weighting (SAW), Weighted Arithmetic Average (WAA), Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS), and Multi-Attribute Utility Theory (MAUT) are some of the most common MCDM techniques applied in sustainability research (Velasquez and Hester, 2013; Kumar et al., 2017). The WAA approach, often used as Weighted Arithmetic Mean (WAM) is one of the simplest methods can imply the preferential independence among the criteria (Diaz-Balteiro et al., 2017). Fuzzy MCDM, an emerging technique that uses the principles of fuzzy theory facilitate to solve problems involving unquantifiable or qualitative data has been applying for the sustainability decision-making process (Yeh & Xu, 2013; Kucukvar et al., 2014b; Ghorabaee et al., 2018). Analogously, MCDM techniques like PCA, fuzzy DEA, TOPSIS are applied in assessing consumption pattern and environmental footprint-based analysis (Streimikiene et al., 2012; Onat et al., 2016; Gumus et al., 2016a; Gumus et al., 2016b). Essentially, the MCDM approach has been employing as an evaluation structure solving environmental, economic, social, and formal obstacles involved in energy planning.

The current literature review recognizes the lack of an optimal framework for the sustainability assessment in global consumption. The review further identified that industrialization and globalization have a critical role in ensuring sustainable nature of products and services. In particular, for countries like Qatar, who are undergoing rapid infrastructure expansion requires to focus more on protecting the natural resources while meeting the current and future needs. In the current context and with the preparation for the World cup 2022, the Supreme Committee of Delivery and Legacy (SC, 2020) stretch emphasis to sustainability and post-tournament legacy. The SC strengthen its sustainability move by claiming that " water conservation, waste management, carbon management, renewable energy, environmental protection, urban connectivity, biodiversity, and urban ecology are just a few of the means being used to achieve our goal of delivering the most sustainable major sporting event in history". Though sustainability has drawn much attention for the past three decades, the review recognized a considerable research gap in the sustainable consumption and assessment. The current research aims to fill the existing research gap and investigate the eco-efficiency score from a global perspective through expert weighting strategies. The research goes beyond finding the eco-efficiency score to correlate for over twenty countries for twenty years. The current study will act as a baseline for the sustainability enforcement and assessment which possibly can be re-assessed and replicated. The new research will also contribute to the underlying sustainability principle of UN development goals, Qatar National vision 2030, and align with the various global environmental protection campaign.

Chapter 3: Methodology

The current study has adopted and replicated the underlying principles of a multi-criteria based eco-efficiency analysis research conducted among the United States' (US) manufacturing industry. All elements in the calculations and equations are adapted from a meticulous study on eco-efficiency assessment (Gumus et al., 2016a). The research is fundamentally delivered through two-phased hierarchical methodologies. In the first phase, the study gathered data on both the environmental and economic impact using an environmentally extended Input-output database, EXIOBASE 3.41. Subsequently, in the second phase, the experiment enforced a multi-criteria decision making (MCDM) approach for measuring and analyzing the eco-efficiency scores for resource consumption in selected countries. The following sections of the chapter briefly describe the eco-efficiency assessment along with the data collection method and other methodological prospects.

3.1 Data Collection

Credible and accurate data is principal requirement of research success. Therefore, selecting reliable data source was of highest priority of current research, which leads to the choice of MRIO based databases. The MRIO databases are primarily operationalizing for consumption-based accounting around the world. Without MRIO databases, it would have been impossible for executing studies on environmental, social and economic impact associated with global consumption and trade in the last decades. EXIOBASE was first developed under the project EXIOPOL and later improved under project Compiling and Refining Economic and Environmental Accounts (CREEA) and Development of Indicators for a Resource Efficient Europe (DESIRE) to EXIOBASE v2 and EXIOBASE v3, respectively (Tukker et al., 2013; Stadler et al., 2018). The present study utilizes the data from MRIO database, EXIOBASE 3.41 for quantifying the economic and ecological impact-induced through resource consumption. The database was accessed through an open access data source named as Environmental Footprint Explorer. The EXIOBASE can be defined primarily as a “global, detailed Multi-regional Environmentally Extended Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT)” (EXIOBASE, 2015). This database provides comprehensive information on resource extraction and utilization by various countries in different product groups and industries. In essence, the robust nature of the database offers a balanced check-in resource consumption across the listed countries for the given period and is explained in below sections.

3.1.1 Environment Footprint Explorers. The present research employed Environmental Footprint explorer’s website as the data collection tool, which is available from the Industrial Ecology Programme of the Norwegian University of Science and Technology (NTNU, Stadler et al., 2015). The environmental footprint explorer accumulate data from various international databases and makes it available to users for extraction. Further, the tool estimates and visualize environmental impact for both production and consumption through time-series analysis for MRIO databases like WIODr2013, EXIOBASE 2.3, EXIOBASE 3.41, EORA, OECD, and GTAP9 (Wood et al. 2015; Kucukvar et al. 2019b). Likewise, the tool provides extensive visualization and detailed analysis for the impact of eco-indicators like GHG, water, land, material, and energy consumption. In the current project scenario, the tool is primarily used to aggregate environmental footprints of consumption for the selected 20 countries. Figure 1 depicts the Environmental Footprint explorer’s visualization for GHG emission impact for consumption parameters in the United States. Similarly, Figure 2 illustrates the GHG emission rate for United States in Kilogram Carbon dioxide (kg CO_2) equivalent unit for 20 years. The graphical representation helps not only to collect the measures but also to visualize the impact for better comparison. Additionally, the database provides the distribution of a consumption impact from various sectors as shown in Figure 3, which is essentially the distribution of consumption in United States for the year 2007. More importantly, the database provides the opportunity to collect, compare, and visualize the global consumption impact through the global, national perspective for a range of years. The notable advantage of this open-source database is its functionality to compare and visualize data using several parameters like base-years, stressors, countries, sectors, and other ecological perspectives (Stadler et al., 2015).

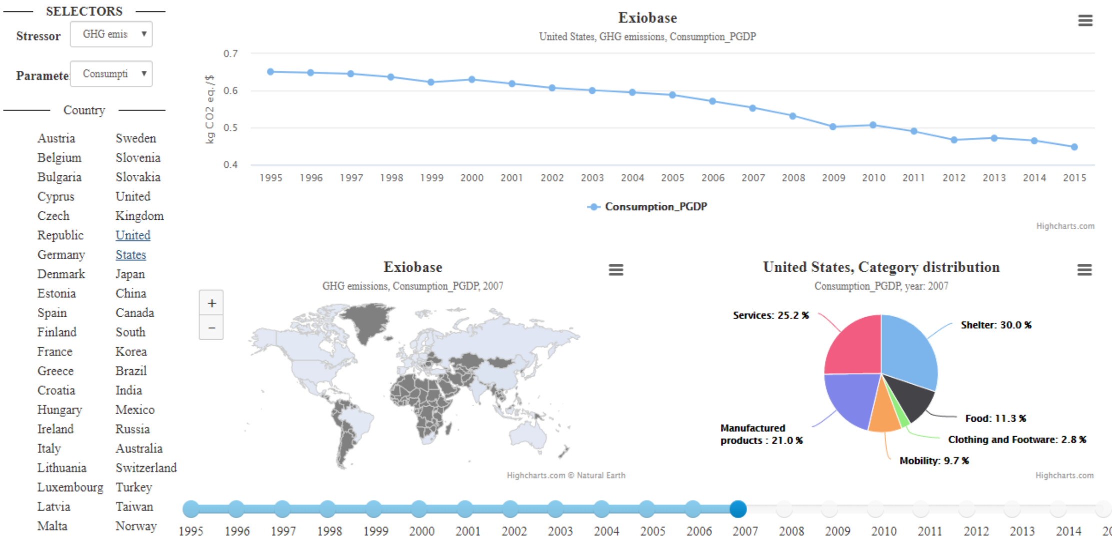

Figure 1. Environmental Explorer Footprint Webpage

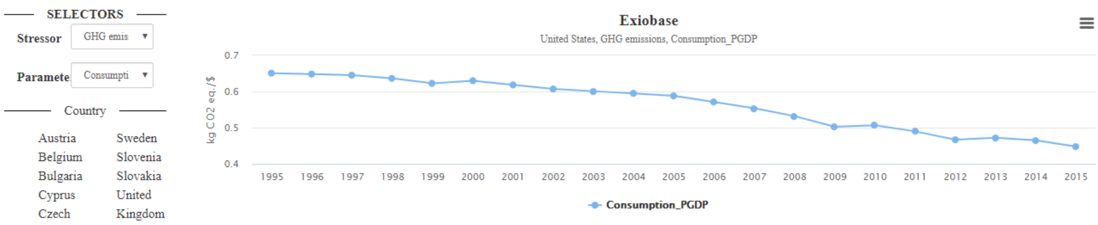

Figure 2. GHG emission data for United States for 1995-2015

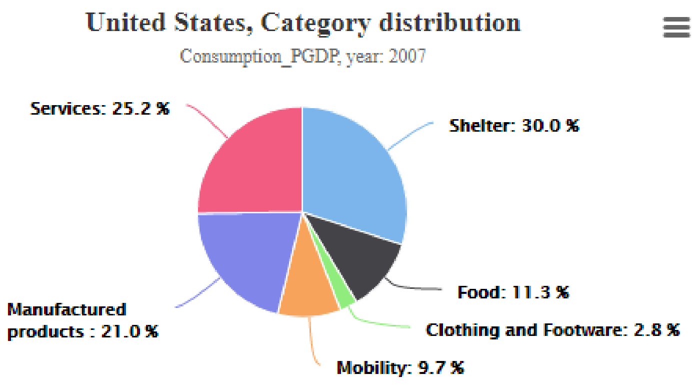

Figure 3. Categorial distribution of consumption in United States for the year 2011

In the present study, five eco-indicators are considered for measuring eco-efficiency scores. Table 1 will provide a thorough understanding of the eco-indicators and associated factors used in the current research. These eco-indicators are carefully chosen from the pieces of evidence of previous research outcomes on eco-efficiency and sustainability assessment and the accessibility to EXIOBASE database (Gloria et al., 2007; Gumus et al., 2016a; Egilmez et al., 2013; Gloria et al., 2017).

Table 1. Summary of Eco-indicators

Impact categories	Unit	Description
GHG Emission	Kg CO_2 eqv.	The total greenhouse gas emissions contributing to the air pollution
Energy Use	TJ	The total energy consumption in the form of fossil and electricity
Material Use	kt	The total material extracted and consumed including crops, fishery, metal, and other unused extractions
Bluewater Consumption	Mm3	Total water consumption in various sectors
Land Use	Km2	Total land are used

(Adapted from Stadler et al., 2018)

3.1.2 EXIOBASE 3.41. As a global MRIO database, the present research utilized the EXIOBASE 3.41 database to gather monetary transactions and environmental consequences for global consumption. The EXIOBASE tables principally provide information from 49 world regions, 200 products, 163 industries, 417 types of emissions, and 662 resources including materials in time series fashion. (EXIOBASE, 2015; Stadler et al., 2015). As another note, the tables effectively help to gather natural resources consumption and associated ecological impact for more than 20 years (EXIOBASE, 2015). Generally, MRIO databases have been recognized as a critical framework to obtain information on the global economy and its ecological impact in terms of emission, resource use and ecological pressure. Alternatively, the time-series features of data enable to identify the priority sectors and consumption rate, facilitating to decouple economic activity from ecological impacts (Stadler et al., 2018). Another notable feature of EXIOBASE is the waste module which highlights the importance of recycling the reuse of materials in the economy. The particular features yield to measure the waste flows and to run a comparison for finding any discrepancies or unregistered waste emission in the industrial process (Merciai and Schimdt, 2017). As such the tables covers a comprehensive detail of resource consumption and emission as 36 sources of minerals, metals, and energy, five types of land allocation, three types of water consumption, and veracity of emissions which constitute as 29 into the air, two to water, and three to soil (Moran and Wood, 2014; Beylot et al., 2019).

As for the research requirement, this study sought to document the data for Consumption parameters under five major stressors such as GHG emission, blue water consumption, land use, material use and energy use. Although the website put forward particulars of 49 countries, the research considers the highest ranked 20 countries in Gross Domestic Product per Capita (PGDP) according to World Bank data (The World Bank Group, 2019). The selection of PGDP ranking for the present research is based on the understanding that consumption act as a principle component in determining the

GDP values of a country. Further, PGDP has been observed in research as one determining factors for sustainability research in association with resource consumption rate (Bai & Yang, 2012). That being said, the consumption rate for selected countries are recorded from Environmental Footprint explores website. The data congregated represents the consumption impact of 20 countries for high consumption expenditure from 1995 to 2015.

The environmentally extended input-output tables grow beyond the conventional input-output tables to assimilate the environmental metrics with financial flows (Onat et al., 2014; Kucukvar et al., 2019a). The Environmentally-Extended MRIO (EE-MRIO) table in EXIOBASE 3.41 is built using the Supply and Use Tables where the products were assigned to basic prices and predicted sale transactions. The calculation of environmental multipliers for product follows the standard demand model of the Leontief inverse equation. The calculation considers the aggregate of the total environmental or economic output of a sector to the total demand from other sectors (Gumus et al., 2016a; Steinmann et al., 2017; Beylot et al., 2019). The equation for economic impact can be represented as:

$$Ec = S * (I - A)^{-1}$$

Where Ec is the total economic output of a sector, S is the final demand indicating the economic output for individual sector, I is a diagonal identity matrix, and $(I- A)^{-1}$ represents the total requirements. The total environmental impact can further calculate by multiplying the economic output of a sector with a multiplier matrix representing environmental impact per unit cost. The environmental impact can be calculated using:

$$Env = Edx * [S * (I - A)^{-1}]$$

Where Edx represents the multiplier matrix. To all intents and purposes, the EE-MRIO analysis is an impactful approach to evaluate the association of upstream environmental score to downstream economic consequences overcoming the limitation of existing process-based methods. Nevertheless, the inconsistencies in the economic activities and disparities in the recording of national data by different countries would raise challenges for the accuracy of assessment in EE-MRIO (Kitzes, 2013). Despite this, the approach is an efficient way to determine the flow of resources and consumption demands in the growing global economy.

3.2 Multi-Criteria Decision Making (MCDM)

Decision making in environmental activities is seemingly intractable and multifaceted due to the need for balance among ecological, economical, socio-political, and environmental factors. Often this involves multiple stakeholders and multidisciplinary knowledge bases lead to group thinking and entrenched positioning (Kiker et al., 2005). MCDM approach fundamentally implemented in situations when contradictory indicators and divergent criteria are involved in a decision-making process. Every MCDM has four keys such that alternatives for ranking, criteria for evaluation, weightages, and decision-makers for respective preferences (Hansen and Ombler, 2008). As a matter of principle, MCDM is aiming to rank the indicators while finding the preference of an indicator over another. As such, every indicator considered in decision making should be measurable and quantifiable (Gumus et al., 2016a). The most frequently used operators for multi-criteria value functions are weighted average and weighted geometrics. Although there have been several methods proposed such as SAW, Weighted Sum (WS), and AHP are proposed in this regard, the current paper adopted the use of weighted averaging aggregation (WAA) approach. Most significantly, its efficiency and flexibility to extension based on fuzzy logic and grey theory, are expanding the employability of this approach. This approach of MCDM techniques is applied for ranking 20 selected countries on five designated environmental indicators. The subsequent sections will offer a basic understanding of the weighted sum method and its applications.

3.2.1 Weighted Arithmetic Averaging (WAA). The Weighted Arithmetic Averaging techniques is one of the most known approaches for ranking in multiple criteria during the complex decision-making process. The formula used in the current research is acquired from the same principles applied by Gumus et al. (2016a) for ranking manufacturing firms in US.

Let WAA: $R^n \rightarrow R$, if

$$\text{WAA}(\alpha 1, \alpha 2, \alpha 3, \alpha 4, \ldots \alpha n) = \sum_{i=1}^{n} w_i \alpha_i$$

Where α_i represents the value and w_i signifies the weightage corresponding to the environmental indicator and weighting strategies.

3.2.2 Normalization. Criteria in MCDM may have different scales rendering to the nature of the data. This veracity of scale mandates the need for pre-processing to achieve a standard scale, thus enabling the aggregation and converting the data into a numerical and comparable format. As such, choosing the most appropriate normalization technique is the first phase of applying an MCDM approach (Vafaei et al., 2018). Several studies evaluated the normalization techniques and ranking alternatives in MCDM problems. As another note, Chatterjee and Chakraborty (2014) state that the MCDM approach may fail to provide the best solution if not adequately assigned and the values are not communicating the exact information. Besides, the aforementioned study highlights the benefit of normalization to represent the criteria values to be around a same magnitude and pointing to the fact that often normalization may results deviation from originals depending on the normalization technique applied. In summary, normalization converts the data into a single metric type and comparable.

Eftekhary et al. (2012) reviewed works of literature to come up with a list of most popular normalization techniques as non-monotonic, vector, and linear normalization. The Z-score normalization is observed as one of the globally accepted non- monotonic normalization approach applied in the major decision-making process. The z-score normalization is calculated using arithmetic mean and standard deviation of any given data. Although z-score normalization technique does not guarantee a specific value range, the values will occur within a distribution. The positive or negative signs of the data will determine whether the values place above or below the mean value (Jain et al., 2005). The environmental indicators applied in the current research are measured and represented using different metric units. The eco indicators GHG emission, energy, material, water, and land use are represented using kilogram Carbon dioxide (CO2) equivalent, Tera Jules (TJ), Kilo Tones (kt), cubic millimeter (Mm3), and square kilometer (km2) respectively. As such, for normalizing these values, current research employs the z-score normalization and the formula can be represented as

$$z = \frac{(x_{ij} - \mu_{j})}{\sigma_j}$$

Where μ is the arithmetic mean and σ is the standard deviation for some particular criteria at the position j.

In the current project scenario, the z-score normalization produced negative results for certain cases. To handle the negative and positive values together, the z-score results are fed into a standard normal distribution function in Microsoft Excel. The standard normal distribution facilitated to obtain a symmetrical distribution of the values.

3.2.3 Process Flow. Using the WAA operator, the 20 selected counties will be ranked in terms of each of the assumed eco-indicators and facilitate to apply the MCDM techniques and decision making. The adopted methods are explained in the following section along with a flow chart as shown in figure 4 to get a better understanding of the research approach. The process begins with identifying and determining the countries whose efficiency scores are going to be calculated and analyzed. The selection of countries is purely based on their current PGDP ranking available through World Bank data. Following the selection of countries, the environmental indicators of the research are identified from Environmental Footprint explorer website and EXIOBASE database. The consumption PGDP against each environmental indicator are recorded for the selected countries for the period 1995 to 2015. The recorded values will undergo normalization to guarantee its alliance with a same comparable scale. The current research has chosen the z-score normalization technique to achieve the normalization of all input values. Later, all the normalized values are documented for further calculation of eco-efficiency scores. The most critical step in the methodology of the present research is determining eco-efficiency score for given three scenarios. The calculation applies the values of weighting matrix and scenario objectives, thus forming the eco-efficiency score matrix.

Let $\varphi = \{e_1, e_2, e_3, \ldots e_m)$ are the economic indicators and $£= \{v_1, v_3, v_3, \ldots v_n)$ are environmental indicators. Using WAA operator, the eco-efficiency score for the i^{th} country in the j^{th} year can be calculated using the formula as described by Gumus et al. (2016a) as

$$\beta ij = \frac{\text{Sum of normalized weighted economic impact of ith country for jth year}}{\text{Sum of normalized weighted environmental impact of ith country for jth year}}$$

In the last step, all the selected countries have assigned their respective eco-efficiency score and further analyzed through visualization and cluster analysis.

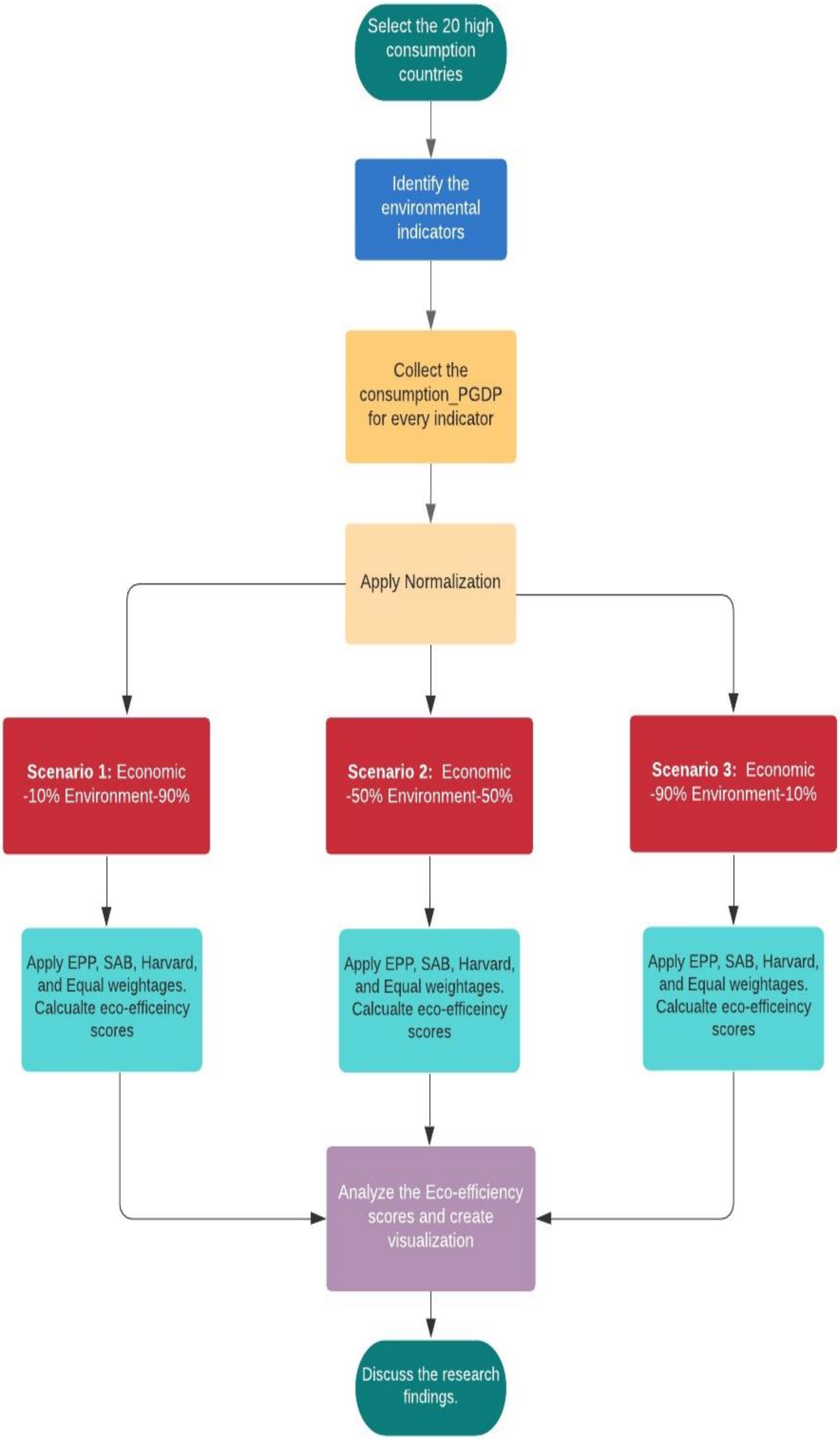

Figure 4. Research Flow Chart

3.3 Experimental Setup

The research process continues through two phases. In the first phase of the research, global resource consumption in terms of GHG emission, energy consumption, material consumption, blue water consumption, and land use were recorded. Following this, an MCDM based approach is applied for calculating and analyzing the eco-efficiency score. Given the fact that weighting components are an influential aspect of sustainability assessment. The weightage schemes can efficiently articulate the relative significance of different stressors against their contribution to the overall eco-efficiency score and sustainability performance (Gan et al., 2017). The current research approach is mainly using weighting strategies embraced from US Environmental protection agency's Environmentally Preferable Purchasing (EPP), US Science Advisory Board (SAB), Harvard University's Kennedy School of Government index, and equal weighting method (Gloria et al., 2007). The weighting strategies are summarized in Table 2. The weights are compromised according to the needs and nature of the research data. For assessing the eco-efficiency, the ratio of both ecological and economic factors are considered, and their trade-off is given at most importance. Having said that the weight sets vary in percentage derived from its relevance in a particular scenario and are given as follows

1. Environment (90%) and Economy (10%)
2. Environment (50%) and Economy (50%)
3. Environment (10%) and Economy (90%)

In this regard, the current research addresses 12 scenarios drawn from the three environment-economy relative significance categories and four weighting strategies. The experiments then proceed to the calculation of eco-efficiency scores and analysis for the purpose of expert decision making. Multiple data analysis techniques had been applied on the calculated eco-efficiency scores using bar charts, time-series chart, tree map and k-mean clustering. The concept of K-mean clustering will be briefly explained in below section.

Table 2. Summary of Weighting Strategies

Impact categories	EPP	SAB	Harvard	Equal
GHG	0.497	0.285	0.282	0.2
Energy Depletion	0.164	0.089	0.179	0.2
Material Consumption	0.103	0.286	0.154	0.2
Water Consumption	0.132	0.054	0.231	0.2
Land Use	0.103	0.286	0.154	0.2

3.3.1 K-mean clustering. Clustering is one the mostly accepted and principal technique for classifying and categorizing data for knowledge discovery. In simpler terms, the clustering focus on partitioning dataset as standardized groups where each data points in a cluster are like each other. In most cases, clustering is applied as an analytical approach to conduct analysis on high dimensional and comprehensive dataset. The current research applies k-mean clustering technique to classify the world countries with regards to their natural resource consumption and performance in global environmental and economic impact. The K-mean clustering algorithm categorizes the datasets into k-clusters where each cluster are both compacted and separated as possible (Ahmad & Dey, 2007). It has been observed that research in the field of sustainability has been successfully implementing K-mean clustering as a tool to categories and rank industries or countries with respect to sustainability index or performance (Kucukvar et al., 2019a; Abdella et al., 2020). So as to categorize and rank, the present study conducted cluster analysis in order to rank the countries. The analysis produced the cluster allocation table and the results were visualized and analyzed.

Chapter 4: Data Analysis and Results

The data analysis and eco-efficiency results are discussed in the following sections. For data analysis, the present research utilized IBM SPSS 26 and Microsoft Excel 2016 software considering its efficacy in the management and visualization of data. The data imports result in 240 eco-efficiency score column drawn from 4 weighting strategies and 3 scenarios of economy-environment allocation for 20 years. The eco-efficiency results drawn from 20 countries over 20 years illustrate the threatening impact of consumption on the environment and ecological balance. Various charts and graphs were produced with respect to the average eco-efficiency scores on accounts of years, scenarios and countries. Table 3 demonstrates a brief overview of average and standard deviation of eco-efficiency score for 12 scenarios formulated on different weighting strategies and economical-environmental indications.

Table 3. Average and Standard Deviation of the eco-efficiency score

Scenario	Economy (%)	Environment (%)	Weighing Strategies	Average	Standard Deviation
1	10	90	EPP	0.492	0.301
2	10	90	SAB	0.486	0.305
3	10	90	Harvard	0.494	0.303
4	10	90	Equal	0.492	0.303
5	50	50	EPP	0.492	0.301
6	50	50	SAB	0.486	0.305
7	50	50	Harvard	0.494	0.303
8	50	50	Equal	0.492	0.304
9	90	10	EPP	0.492	0.301
10	90	10	SAB	0.486	0.305
11	90	10	Harvard	0.494	0.303
12	90	10	Equal	0.492	0.303

The present study analyses the eco-efficiency scores based on the four expert weighting strategies and for various scenarios using bar charts as illustrated in Figure

5. The interpretation of diagrams pointing to the fact that eco-efficiency scores exhibit significant differences in some countries. For example, the eco-efficiency score for the United States is less than 0.5 when EPP weightage is applied, whereas the eco-efficiency score is between 0.5 and 0.6 in Harvard and EQUAL are applied and just about 0.6 in SAB weightage scheme. On the flip side, the worst eco-efficiency score continues unaffected as India regardless of the weightage strategies applied. Similarly, Switzerland retain as the best eco-efficiency score for all weightage strategies. It worth noting that countries like China, India, Russia, Turkey, and Mexico are performing poor in terms of eco-efficiency score in all cases. Likewise, Japan, Switzerland, Germany, and France are performing well for all weighting strategies. As such a significant difference can be noticed in all top ranked consumers like China and India as well.

In Scenario 2, as provided in Figure 6 where both ecological factors and economic factors are given equal importance which essentially influence the eco-efficiency score of countries. Nonetheless, the eco-efficiency score of best performing and worst performing countries are not so different for different weightage strategies. The bar chart for scenario 3, where the economic output has given more prominence than ecological impact and has also shown similar average eco-efficiency score differences when weighting strategies are applied and is provided in the Appendix.

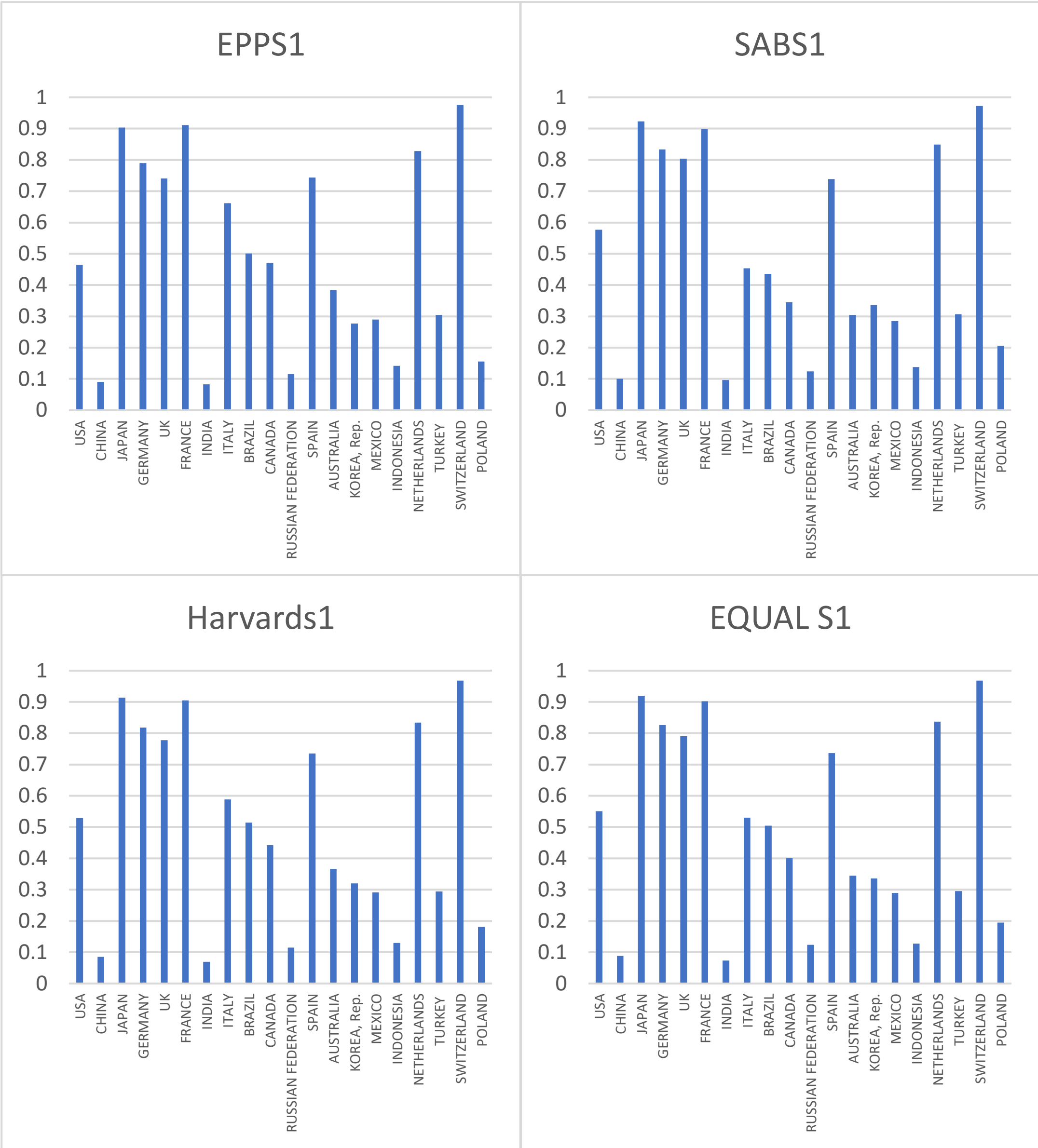

Figure 5. Average eco-efficiency score comparison for Scenario 1

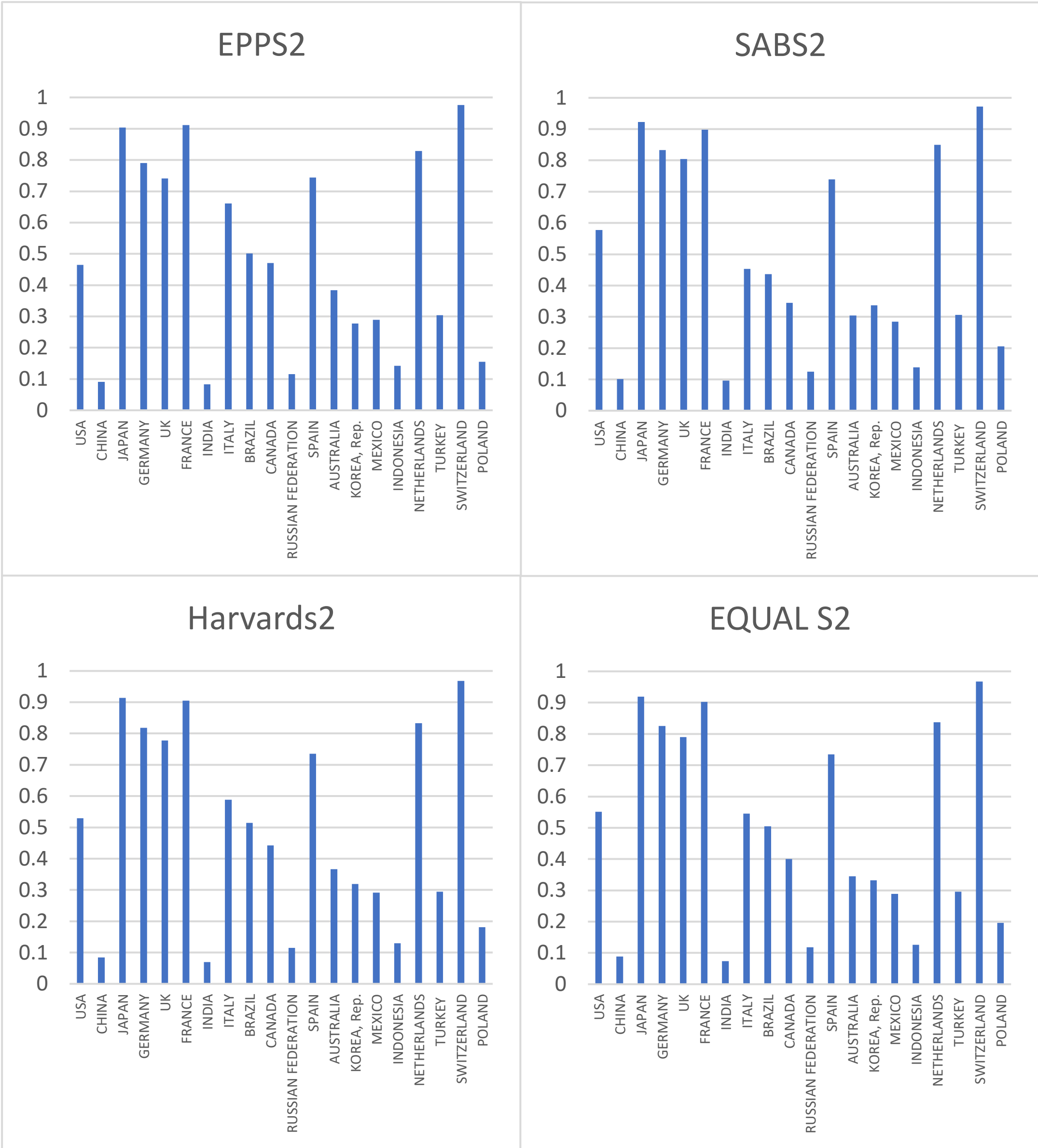

Figure 6. Average eco-efficiency score comparison for Scenario 2

For analyzing the patterns in the calculated eco-efficiency score, the present research also utilizes tree maps. Tree maps are essentially hierarchical chart where each rectangle represents tree branches and subbranches to represent the significance of values. In tree map, both the size of the rectangles and the position contribute to the magnitude of values. Figure 7 depicts a tree map representing the average eco-efficiency score with respect to the suggested weighting scenario for 20 years. Russia, India, China, Indonesia, Poland, Mexico, and Turkey represent the main contributors in the global consumption forming last cluster with low eco-efficiency rate. Following this, countries like Spain, Italy, USA, Australia form the second cluster reasonably better eco-efficiency score. As scenario 1 symbolizes economy 10% of significance to the economy and 90% to the environment, the tree map results pointing to an adverse impact on natural resources through consumption for more significant economic benefits. It is worth pointing out that the Switzerland, UK, Germany, France, and Japan are showing a significantly higher magnitude by forming the first cluster which indicates the sustainable consumption model of those countries.

Further, alike tree map results are attained for both scenarios 2 and 3, which are provided in figure 8 and figure 9, respectively. Interestingly, the treemap exhibit similar consumption pattern for all countries. However, minor differences recorded in some clusters due to the differences in calculated scores according to the relevance in ecological and economic impact. Principally, the analysis pointing to the fact that the overall impact remains the same, regardless of the weighting strategy applied for the eco-efficiency calculation.

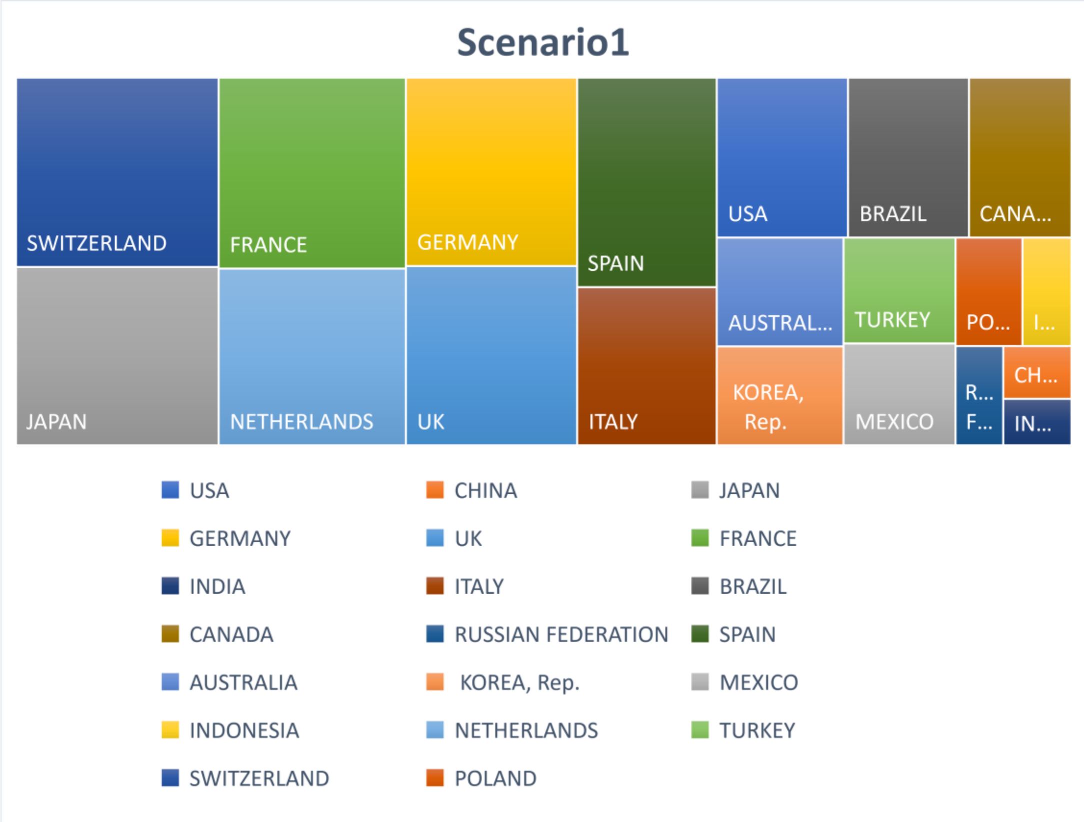

Figure 7. Treemap for Scenario 1

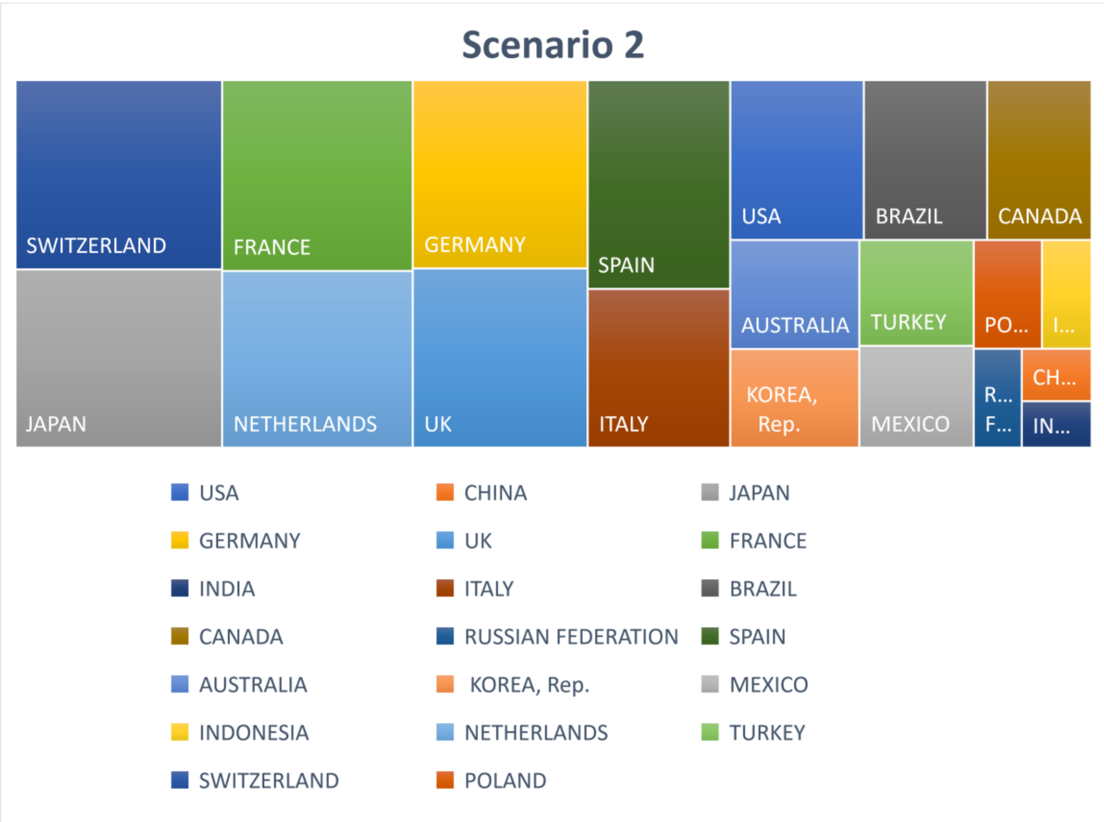

Figure 8. Tree map for Scenario 2

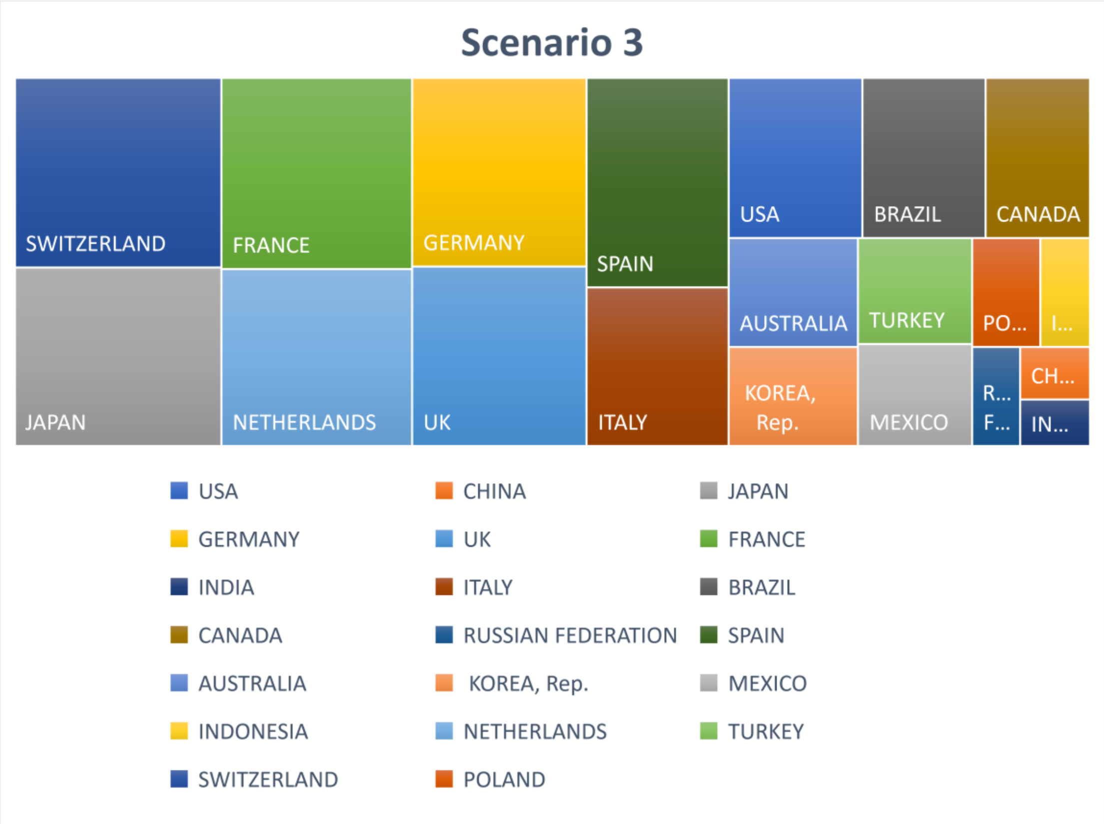

Figure 9. Tree map for Scenario 3

The consumption pattern of countries has been varying over the years due to the rapid expansion and urban developments. Figure 10 demonstrates the time series analysis of five countries with higher consumption expenditure, according to the World bank ranking. The calculated eco-efficiency score for 20 years with respect to the four weighting strategies are depicted for Japan, UK, USA, Germany, and China. The consumption rate and eco-efficiency have shown a significant fluctuation over the past couple of years, more specifically after the year 2000. This change possibly happening as a side effect of technological advances and the internet-based technology revolution. It can also be observed that the eco-efficiency score for china is exhibiting a fluctuating pattern yet remains relatively low for past two decades. In the similar fashion, USA shows a decrease in eco-efficiency score after the year 1999, however, the performance has gradually improved after the year 2007. Nevertheless, the timeline of USA is varying slightly in EPP and Harvard as oppose to SAB and EQUAL weighting strategies. Similar alterations can be observed for Germany, Japan, and UK with respect to weighting strategies. The graphs essentially highlighting the effect in eco-efficiency score for each of the subjected weighting scenarios. The time-series graphs for Scenarios 2 and 3 are provided in the Appendix for further detailed analysis.

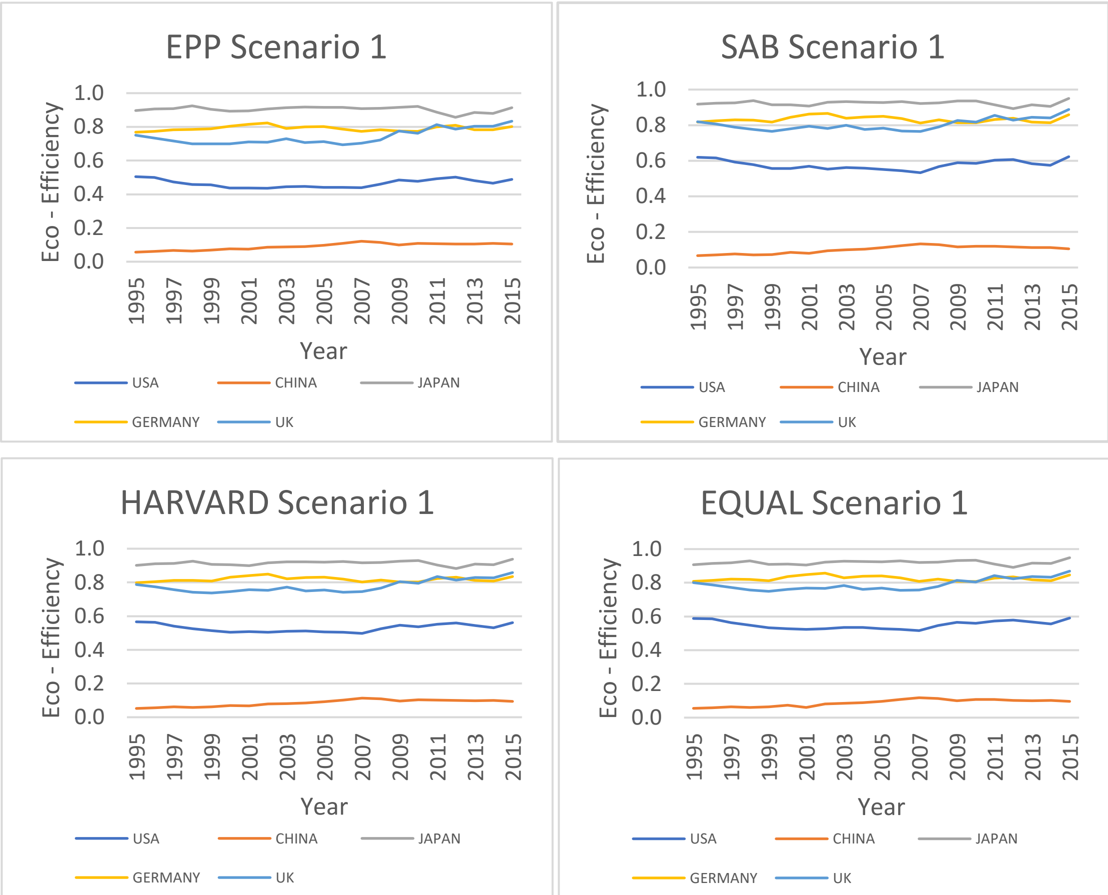

Figure 10. Time series chart for Scenario 1

Lastly, the K-mean clustering data analysis is the approach implemented to identify and classify similar values of the datasets. Primarily, the approach identifies the centroid of the dataset for selected k clusters. The present research applied the k-mean clustering for grouping the selected 20 countries drew on their eco-efficiency score and sustainability behavior. For the purpose, the study classified the data values for each of the weighting strategies applied through different scenarios. The value of k has been selected as three through repetitious iteration and trials. At k=3, most data values have been consistently distributed across the clusters, and significant differences were zero. Figure 11 illustrates the clustering membership for selected 20 countries with respect to their eco-efficiency score. The image depicts that India, China, Russia, Indonesia, Poland, Korea, Mexico, Turkey, and Australia are the worst performing countries, in terms of eco-efficiency score, and forming the third cluster. The USA, Canada, Brazil and Italy form the second cluster while UK, Spain, Germany, Netherland, Japan, and Switzerland shape the first cluster.

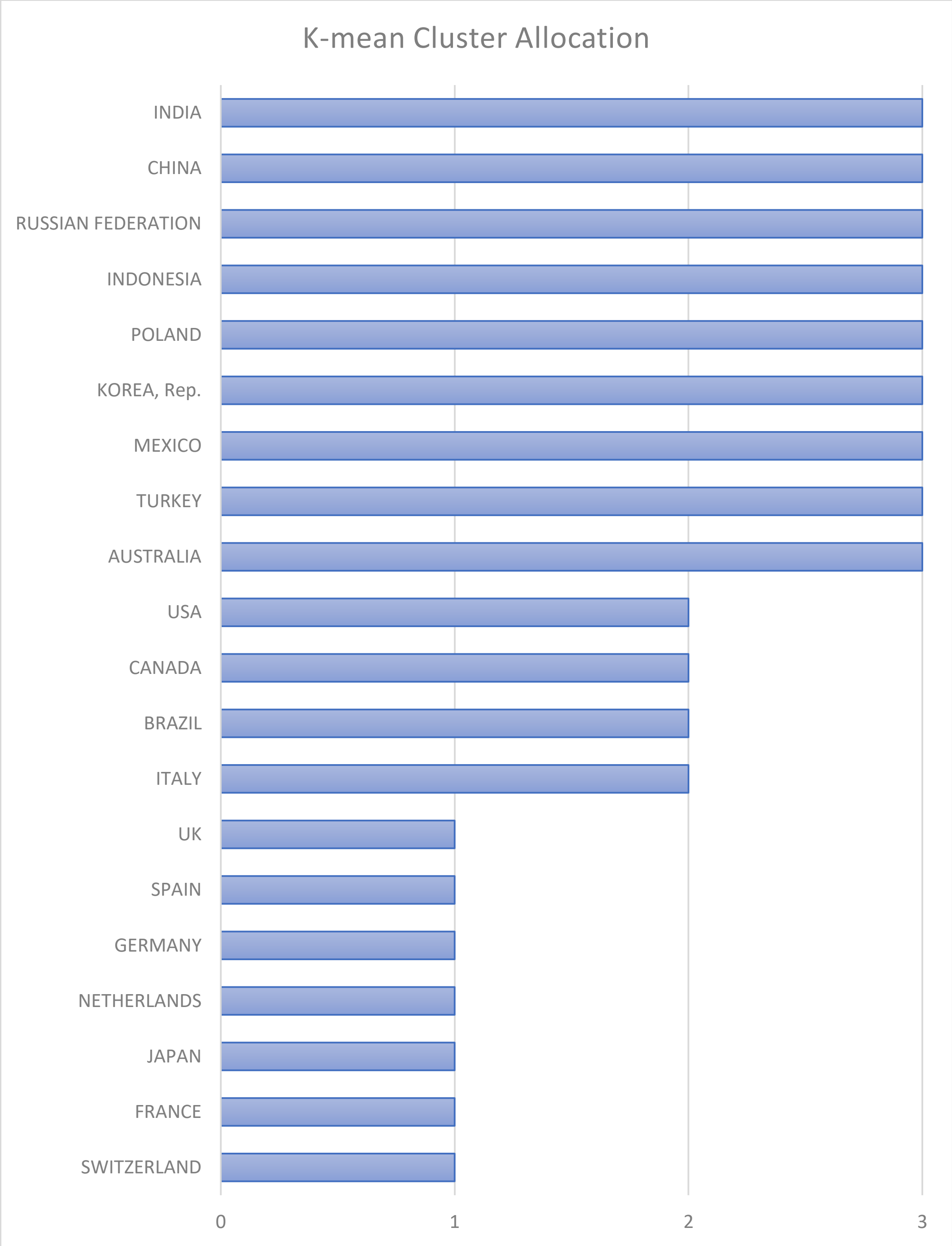

Figure 11. K- mean clustering membership

Chapter 5: Conclusion and Recommendations

The current paper analyzed the global resource consumption impact with the objective of being instrumental to the discussions of sustainability assessment tools. The proposed study uses eco-efficiency-based methods to assess and evaluate the consumption impact utilizing four environmental stressors such as GHG emission, land use, water use, material consumption, blue water consumption. The research adopted four weighting strategies for the eco-efficiency calculations, namely, EPP, SAB, HARVARD, and EQUAL, and have concluded a significant difference in the final eco-efficiency scores for each case. Data on economical environmental impact was collected from an open-source database provided through Environment Footprint explorer website from EXIOBASE 3.41, facilitated convenient and more accessible data analysis. The research not only addresses the knowledge gap in eco-efficiency based global resource consumption impact but also effectively applied an MCDM based sustainability assessment approach in decision making. The findings drawn from the study provide significant insight into the global environmental impact on policymakers and governance, enabling them to adopt eco-friendly decisions. With the view of results, the present study proposes governance to focus on law enforcement encouraging optimal use of environmental sources while emphasizing both environmental protection and economic benefits. The findings emphasize the need for a responsible global action to ensure better sustainable consumption.

The key findings of the present research are listed below

- Weighting strategies play a significant role in the eco-efficiency score
- Countries like India, China, Indonesia, Mexico, Turkey, and Russia have relatively worst eco-efficiency scores.
- Countries like Switzerland, Japan, UK, France, and Germany are best

performing in terms of eco-efficiency scores.

- Switzerland has constantly retained as the best performing country regardless of the weightage strategies applied.

The major advantage of using EXIOBASE is its ability to ignore any cut-off in economic flows and enabling to take account of economic activities both intermediate and final consumption. The tables do take account of statistical data along with process-based data in a slightly larger disintegrated level (Merciai and Schmidt, 2018; Beylot et al., 2019). Nonetheless, Beylot et al. (2019) pointed out the absence of numerous flows in environmental extensions such as ozone depletion, ionizing radiation, and oxidation state of chromium emissions. As such, the consumption impact assessment drawn from the values from EXIOBASE for the present study will have some unrecognized potential uncertainties that exist due to the absence of a whole or part of environmental flows. It is also worth noting that, depending on national interests and business policies, more scenarios required to be considered for calculating and assessing eco-efficiency. Likewise, appropriate weighting strategies also need to be applied to those values for efficient comparison. It is worth noting that most business decisions in recent years strongly depend on the national and international sustainability assessment policies, hence attention needs to be given to those sectors which need increased natural resource consumption.

The present recognizes the requisite for rigorous research under the topic of eco-efficiency and sustainability assessment using more advanced MCDM techniques such as DEA, PCA, Fuzzy set theory, and other Artificial Intelligence (AI) techniques. It would be interesting to have a comparative study using the results of the current study and results from a similar study conducted through an alternative MCDM technique. Furthermore, comparative studies can be conducted on similar studies by disaggregating the part of the world like EU and Middle East and North African (MENA) countries. The present study can be extended to have comprehensive research on consumption impact on specifics like air or water by various countries, possibly considering more than 20 countries. Thus, it would be enabled to understand the nature of emissions in each of those countries as opposed to their consumption, which would eventually facilitate for drawing an understanding of the nature of resource use and possible countermeasure regarding that. In addition, considering the social impact along with economic and environmental data will helps to bring the research into the broad sustainability assessment framework. In this regard, the research foresees applicability in using more advance data mining approaches such as regression analysis, predictive analysis, clustering, and advanced data analytics; see Abdella et al. (2019), Kim et al., (2019). There is a greater possibility of further research and studies on this topic due to the necessity to bring the environment to its equilibrium.

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Appendix A: Charts and Graphs

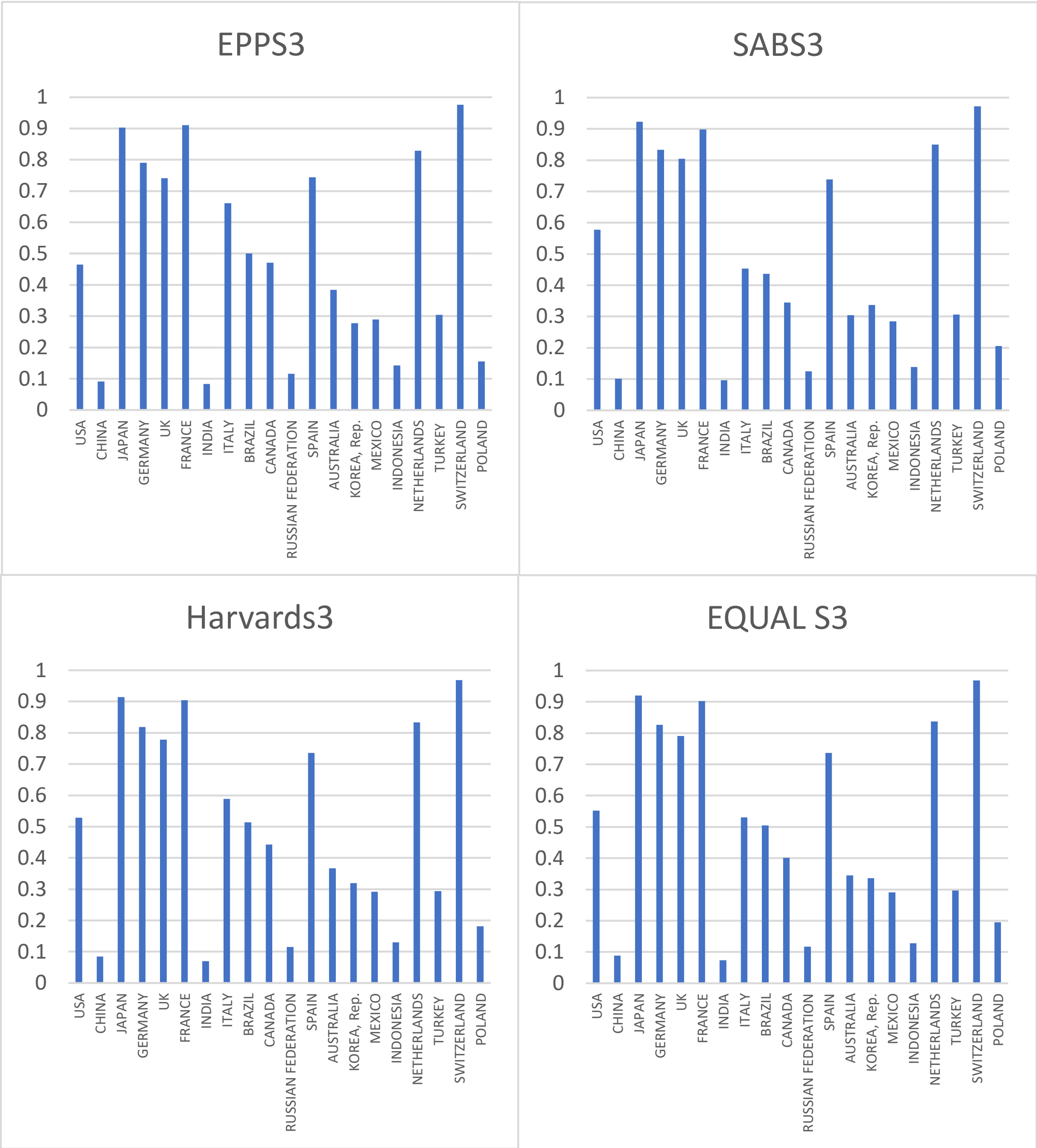

Figure 12. Eco-efficiency Comparison of Countries for Scenario 3 using bar charts

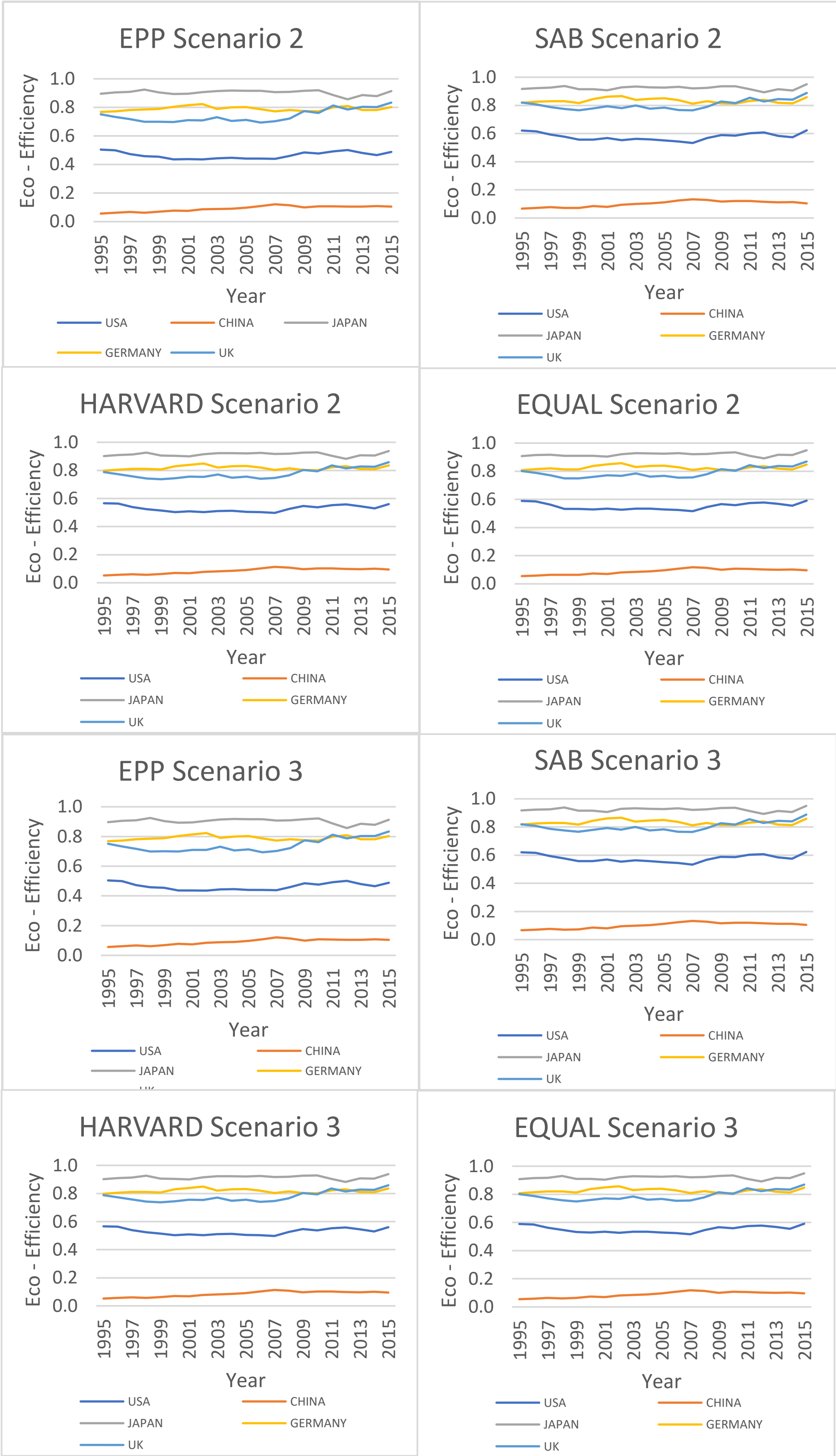

Figure 13. Time Series Charts for Scenario 2 and Scenario 3