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The relationship between the three dimensions of sustainable development

The correlation between human development, economic complexity and ecological footprint.

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Abstract

Sustainable development is a widely discussed concept, and it is needed because the world is facing a massive global challenge of climate change. Sustainable development is envisioned as an all-inclusive concept of three dimensions; environment, economy, and society. However, there are trade-offs between these three dimensions. Thereby, there is a need for an enhanced understanding of the relationship of the three dimensions for better policy implications. This paper aims to analyze the correlation between these dimensions using the human development index (HDI), economic complexity index (ECI), and ecological footprint per capita as a proxy for society, economy, and environment. The research uses pairwise linear regression analysis to measure the correlation between HDI, ECI, and EF per capita for 114 countries between 1995 to 2017. The results show that all of them are positively correlated, meaning that economic complexity (economy) supports human development (society). However, both increase the ecological footprint, which is deteriorating the environment. This paper also revises the environmental Kuznets (inverted-U) curve hypothesis to make it more capability-oriented and test it for ecological footprint as HDI changes as well as for ecological footprint as ECI changes through nonlinear regression analysis. The evidence does not support the existence of environmental Kuznets (inverted-U) curves for EF per capita and HDI; however, it does support its existence for EF per capita and ECI, but only for certain periods. The findings enrich the understanding of the relationship between economy, society, and environment, which is useful for better policy implementation and identifies potential future research areas.

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1. Introduction

Sustainable development (SD), the hot topic of the 21st century, has encouraged nations, policymakers, and economists to expand the discipline of economics to integrate environmental and social aspects into economic development. Soubbotina T. P. (2004) emphasizes that the most significant paradigm shift in the concept of economic development is the introduction of sustainable development. However, Robert Solow (1991) wrote that SD is a vaguely defined concept, and it is a matter of perspective whether it shall be defined from a moral, policy, political or economic viewpoint. Nevertheless, by far, the most comprehensive definition was developed in 1987 by the United Nations (UN), which addressed and defined SD as "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, G., 1987).

Sustainable development consists of three dimensions of development; social (human) development, economic development, and environment (Soubbotina T. P., 2004). In 1987, the same year as the UN Brundtland Report was published, Barbier E.B. illustrates a model composed of three pillars (dimensions) of SD, shown in figure 1.1. Currently, the environment is the dimension that is deteriorating the most due to the increase in human activities that depletes resources and the planet (Mann, M.E., 2009). As a result, the ecological footprint – a measure of human pressure on the environment – is increasing beyond biocapacity (Footprintnetwork.org. 2022). Nevertheless, efforts are in place to preserve the environment and achieve sustainable development; an example is United Nations (UN) sustainable development goals (SDGs).

UN SDGs are focused on all the dimensions of sustainable development, along with other efforts of the UN to improve the quality of life, one of which is the UN development programme (UNDP). At the core of UNDP lies human development, which is crucial for enhancing basic socio-economic capabilities. Efforts of UNDP have led to many countries experiencing improved human development rates (UNDP., 2020). Additionally, the economic dimension of sustainable development is improving as the scope of economic development has been expanded beyond the growth of gross domestic product (GDP). As a result, more sustainable growth measures are observed, such as the concept of economic complexity – the diversity of a country's products and exports. It has also become an integrated part of measuring the socio-economic capabilities because economically complex economies rely on advanced technology and high skilled labor (Can, M. and Gozgor, G., 2017). This encourages countries to engage in a competition for economic growth that is more sustainable than economies competing based on GDP.

Achieving sustainable development is a complex process intertwined within three broad dimensions. Hence, maximizing the development in all three dimensions is highly challenging (Barbier, E.B., 1987). UN sustainable development goals (SDGs) are good examples of this. Kroll, C., Warchold, A., and Pradhan, P. (2019) state that SDG 13 (Climate Action) faces substantial trade-offs with goals, such as SDG 7 (Affordable and Clean Energy), that are built to enhance the basic standard of living. Reality is composed of trade-offs and synergies between all three dimensions of SD, which are the foundation of this research. There is a growing need to explore the interaction between all three dimensions of SD (illustrated by the model in figure 1.2). Especially between the sustaining dimensions, i.e., environment, and the development dimensions, economic and social, as illustrated by figure 1.2

Some previous research already exists that attempts to explore the interaction mentioned above. The most commonly known environmental Kuznets curve (EKC) models the relationship between environmental degradation and economic development (Yandle, B., Vijayaraghavan, M. and Bhattarai, M., 2002). EKC models this relationship by hypothesizing an inverted-U-shaped correlation between pollutants and income growth (Yandle et al., 2002). EKC has been tested for various environmental degrading factors but mainly pollutants. However, the environmental dimension of sustainable development consists of more factors than mere pollution. Even the economic dimension of SD is also concerned with factors other than income growth. Thus, the EKC's scope is narrow for explaining the correlations between the environmental dimension (sustaining) and the development (social and economic) dimension of sustainability in a comprehensive manner.

Henceforth, there is a need to broaden the EKC by testing it on more comprehensive variables of environmental degradation than pollutants and comprehensive variables of economic development than income growth. Secondly, EKC should also be tested for the impact of social or human development on environmental degradation. Overall, as mentioned previously, there is a need to enrich the understanding of the correlations between all three dimensions (environment, social and economic) of sustainable development. This would enhance the information on various trade-offs, and the institutions can find optimal potential solutions to achieve sustainable development more effectively.

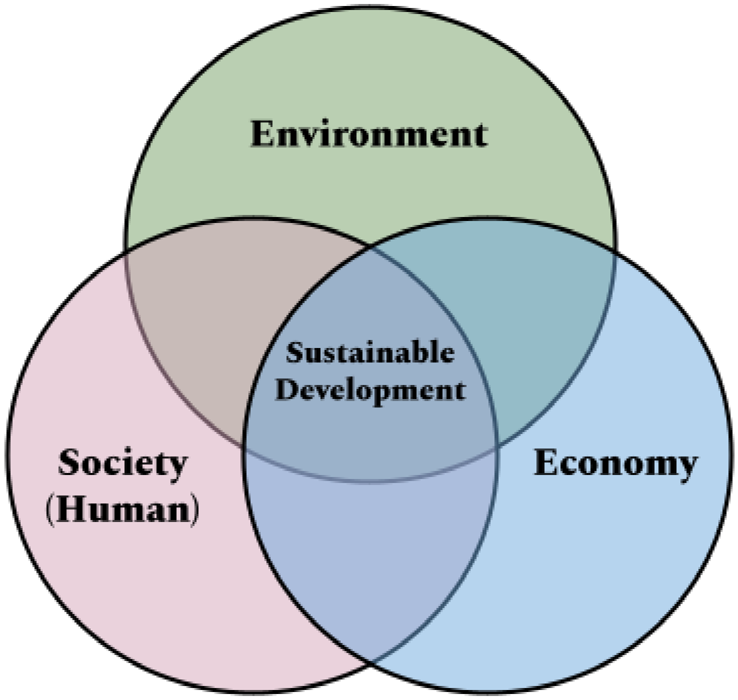

Figure 1.1 - Sustainable development model (Barbier, E.B., 1987)

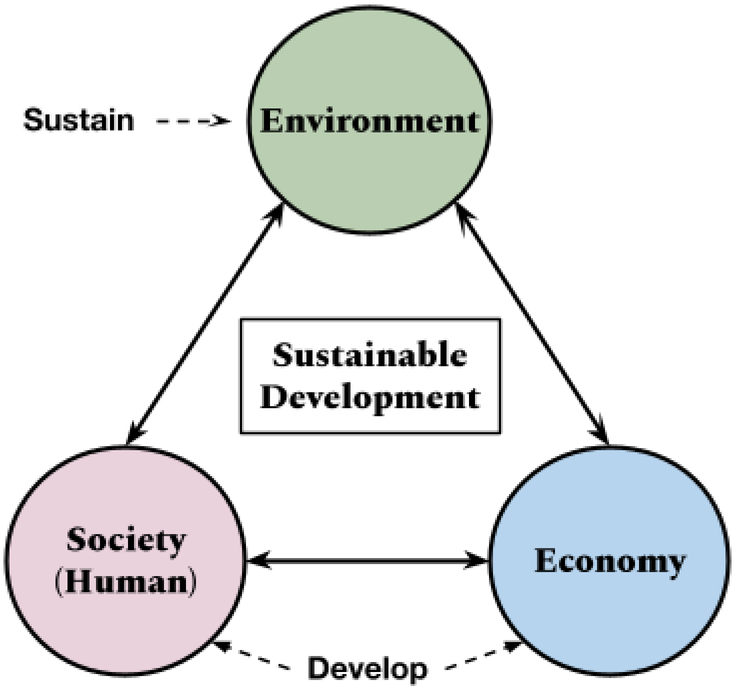

Figure 1.2 - Relational sustainable development model

1.1 Aim of the study

Simply put, the three dimensions of sustainable development are intertwined in a complex manner. The world faces the global challenge of climate change and overconsumption of the planet Earth. Thereby, the knowledge toolbox regarding these challenges needs to be enriched to achieve potential solutions to global problems. This thesis aims to enhance the understanding of development economics within the framework of sustainable development and contribute to uncovering the challenges embedded within the SD path. This objective ought to be achieved by addressing the relational interaction and understanding the correlation between the three dimensions of SD, namely, **economy, society, and environment**.

The optimal way for modeling correlation objectively is through quantitative exploration. The three dimensions of SD are composed of complex and diverse factors; therefore, many measures can be used to track progress. However, the pre-existing and widely accepted key performance indicators (KPIs) can be well utilized as proxies to explore the quantitative correlation between dimensions of SD. As this research focuses on providing a comprehensive account of the correlation between the dimensions of SD, the chosen KPIs also need to be comprehensive. The following qualify as comprehensive indicators for each dimension as the reasons why they are comprehensive and why they are chosen are mentioned in chapter 2 (Background).

- The ecological footprint (EF) measures the population's pressure on the environment, used as a proxy for the environment dimension.
- The human development index (HDI) measures the education, health, and income situation of a population to measure social and human development. Used as a proxy for the social (human) dimension.
- The economic complexity index (ECI) measures the trade diversity and complexity of the economy to capture the economic development more rigorously than GDP. Used as a proxy for the economic dimension.

These KPIs will be used as subsets to represent SD's environmental, social, and economic dimensions, respectively. Through investigating the correlation between these factors, the thesis will generate material used to discuss and study the relationship between the three dimensions of SD. Hence, this paper aims to utilize the EF, HDI, and ECI to explore the relationship between the three dimensions of SD to uncover synergies and trade-offs. To fulfill this aim research question is posed:

What is the correlation between ecological footprint, human development index, and economic complexity index?

The research question will be explored through the quantitative technique of regression analysis for data that contains 114 countries and 23 years from 1995 to 2017. This would be a global cross-sectional study based on a period of 23 years. The 114 countries are taken to increase the sample size for accuracy and provide general global trends rather than case-specific. Furthermore, 23 years are chosen because there may exist high fluctuations in the correlations of the same variables over the years, and also it provides an adequate overview of average how the correlation evolves over the years.

1.1.1 Hypothesis

The correlation analysis would be conducted using statistical methods by analyzing two dimensions at a time in a pairwise manner, contributing to understanding relationships presented in figure 1.2. Firstly, the correlation between the HDI and ECI. Secondly, the correlation between HDI and EF. Thirdly, the correlation between ECI and EF. For all of the three pairwise analyses, the following hypotheses will be tested:

- Null hypothesis: There is no statistically significant correlation between the variables.
- Alternative hypothesis 1: There is a positive correlation between the variables.
- Alternative hypothesis 2: There is a negative correlation between the variables.

In order to further enrich the answer to the research question, this thesis aims to test the validity of the environmental Kuznets curve (EKC) hypothesis, as EKC is also about measuring the correlation between the environment and economic growth (which are two dimensions of sustainable development). In the context of this thesis, the EKC hypothesis would be tested for sustaining dimension (environment) and development dimensions (social and economic) of sustainable development, contributing to an understanding of the relationships present in figure 1.2. For this following hypotheses are formulated:

- EKC hypothesis: There is an inverted-U shaped relationship between ecological footprint (a proxy for environmental dimension) and HDI (a proxy for social dimension)
- EKC hypothesis 2: There is an inverted-U shaped relationship between ecological footprint (peroxy for environmental dimension) and ECI (a proxy for economic dimension)

1.2 Relevance

The research is focused on enhancing the understanding of the interaction between the three dimensions of sustainable development. It would contribute to conforming or producing new information to the pre-existing research. The thesis will provide a global view of the interaction of sustainable development's dimensions rather than a case study of a specific country, focusing on 114 countries. Plus, it offers statistical robustness as the regression models are tested for 23 years, which illustrates the development of relationships between the three dimensions of sustainable development over the years. Furthermore, deepening the knowledge regarding sustainable development is highly useful for combating the planet threatening challenges of the 21st century that are rising to unsustainable practices (Mann, M.E., 2009). Thereby making this research enriching information that can be used in practice for policy implementation from the municipal level to the global level.

It also would enhance the academic understanding of development economics. This research would potentially aid in modeling the interactional model of sustainable development, thus, adding to the theoretical findings of development. Additionally, through the evaluation presented in this research, potential future research areas would also be identified, enabling future research projects' progress.

The research would broaden the scope of EKC. Various studies have been undertaken regarding EKC based on pollution and income growth, but the evidence shows that analysis that found EKC is not robust (Stern, D.I., 2004). Stern (2004) also notes that while particular pollution and income can validate the EKC, further robust analysis is required to validate EKC conclusively. Therefore, this thesis will use EF instead of using pollutants to represent environmental degradation. Some research has already been done in testing EKC with EF as the environmental degradation factor instead of pollution; however, the income growth variable remains the same. Therefore, this thesis further broadens the scope of EKC by also replacing the income growth with HDI and ECI towards more capability-oriented economic development. This would result in an EKC concerned with socio-economic development and not just economic growth. Hence, the EKC hypothesis will be tested while answering the research question by exploring the correlation curve's shape, using data from 114 countries for 23 years simultaneously to increase the statistical robustness of the study.

2. Background

The most fundamental economic problem of resource scarcity lies at the core of the SD because the overall objective of SD is to preserve the heart of all resources, i.e., the planet Earth. The relationship between scarcity and choice is coined as the opportunity cost. The notion of opportunity cost is that any choice causes consequences that result in loss of utility for individuals or the society (Buchanan, J.M., 1991). Currently, the world faces the century's challenge in climate change and environmental degradation as an extremely expensive opportunity cost of human activity (Mann, M.E., 2009). As the realization of this opportunity cost has increased over time, especially over the past three decades, the significance of SD has become crucial. The effort to achieve sustainable development comes from various directions, such as businesses, technological innovation, policies, and countries' joint efforts (Rogers, P.P., Jalal, K. F. and Boyd, J.A., 2012).

Sustainable development is highly linked with fundamental issues of poverty, population shocks, consumption patterns, production methodologies, trade, and legal frameworks (Rogers et al., 2012). The ideas that Roger et al. (2012) represent illustrate that it is impossible to achieve sustainability through a well-planned channel. One answer to sustainable development does not simply exist; any strategic process to achieve SD eventually has obstacles that offset, and mostly these obstacles are found within three dimensions of SD. For example, if social policies are implemented concerning subsiding water and energy for the poor, then the low costs induced by subsidizing increased demand (economic) and usage (environment) offset the social benefit gained from the policy.

There are various other cases where SD efforts offset themselves, making SD highly sensitive to any imbalance in its three dimensions. For example, evidence suggests that countries with the same GDP (economic growth) and other social development (human development) cause different consumption patterns, which lead to different rates of environmental pressure (Rogers et al., 2012). Hence, balanced growth in all three dimensions of SD is important, so there is a crucial need for indicators to measure SD. Furthermore, Rogers (2012) states that the world needs to know whether the impact of SD efforts is positive or negative; therefore, rational policy choices will be based on indicators to calculate the predicted or observed impact.

The most widely discussed environmental indicator is pollution, especially carbon dioxide emissions (CO2), because it is the main contributor to global warming (Florides, G.A. and Christodoulides, P., 2009). The Environmental Kuznets curve (EKC), an extension of the Kuznets curve, hypothesizes an inverted U-shaped relationship between air pollution and economic growth (Yandle, B., Vijayaraghavan, M. and Bhattarai, M., 2002). However, as mentioned previously, the scope of environmental degradation is broader than air quality. Thus, it can not be utilized as a comprehensive key performance indicator (KPI) to measure the environmental dimension of SD.

In 1990 Mathis Wackernagel and William Rees initiated developing the Ecological footprint (EF) (Footprintnetwork.org. 2022), capturing the environmental degradation in broader terms than pollution. EF measures the "resource consumption and waste assimilation requirements of defined human population or economy in terms of a corresponding productive land area" (Wackernagel, M. and Rees, W., 1998, p.9). In layman's terms, it estimates the pressure that a given population and economy asserts on nature, therefore, making it an inclusive KPI for measuring the environmental dimension of SD. As a result, the global Ecological Footprint (EF) of the world has seen a steady increase, and, since 1971, the ecological footprint has been more significant than the available biocapacity of the world, shown in figure 2.1.

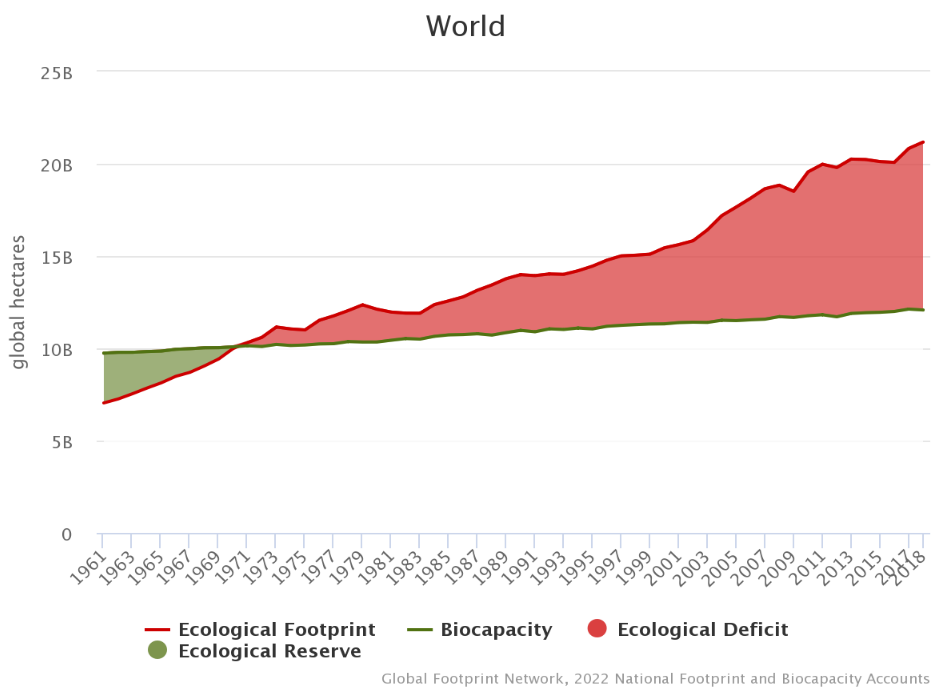

Figure 2.1 - World EF and Biocapacity over time (Data.footprintnetwork.org., 2022)

Nevertheless, the world has not been completely deteriorating in progress toward SD. Various positive changes have taken place over the last decades. Certain countries have seen decreasing pollution rates, the move towards the circular economy is increasing, and countries that have previously been deprived of basic capabilities have achieved adequate levels of human development (UNDP, 2020). Societies across the globe are developing. However, it is often hard to view all socio-economic changes, unlike the changes in pollution and EF. Social stability, diversity, political stability, and social welfare are hard to measure quantitatively (Barbier, E.B., 1987). There are, however, numerous KPIs, such as gross domestic product (GDP), human development index (HDI), and Multidimensional poverty index (MPI), which quantitatively illustrate the development within the socio-economic framework.

The most severe crisis in socio-economic issues is poverty, mainly measured by a person's income level. As argued by Mahbub Ul Haq, the pioneer of the human development index, the world requires a measure that considers human lives and social aspects, unlike the gross national product (United Nations Association – UK., 2019). HDI, thus, gives a comprehensive overview of the basic capabilities of humans as it is composed of three elements; education, health, and income (UNDP, 2020). HDI is published every year by the United Nations Development Programme (UNDP) and used as an accompanying KPI for measuring the progress of SDGs (United Nations Association – UK., 2019). The 2020 report by UNDP estimates that HDI is positively associated with the environmental performance index, concluding that human development enhances the ability to create a sustainable society and invest in environmental preservation.

Along with the improvements in HDI, the GDP has also improved worldwide, as portrayed in figure 2.2. However, whereas even the lower-middle-income countries have experienced an increase in the GDP over the last two decades, the low-income countries seem to have made no notable improvements in terms of GDP growth, as shown in figure 2.3. IN HIS BOOK THE BOTTOM BILLION, Collier P. (2007) discusses that countries with the lowest income are trapped and experiencing stagnating growth. Collier (2007) states that countries at the bottom face four common traps; conflicts, political instability, landlocked with bad neighbors, and the natural resource curse. Although the first three are political factors, the fourth trap, i.e., the natural resource curse, is an economic factor, thus potentially contributing to SD.

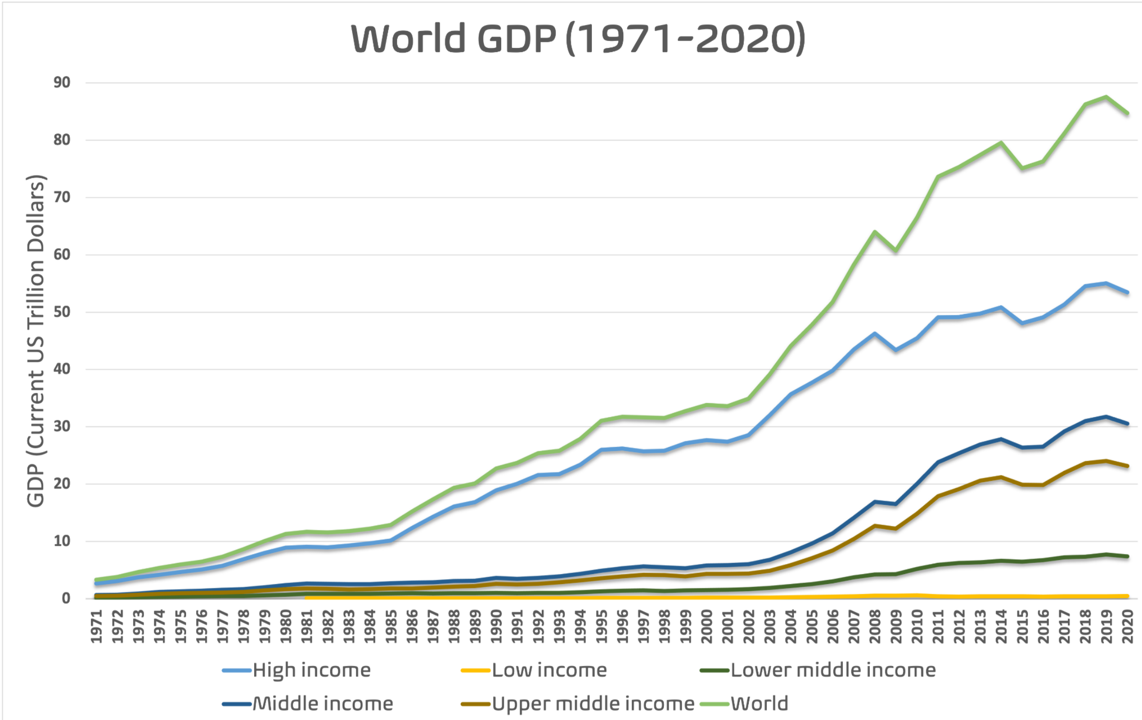

Figure 2.2 - World GDP and GDP of Income based country groups (World Bank., 2020)

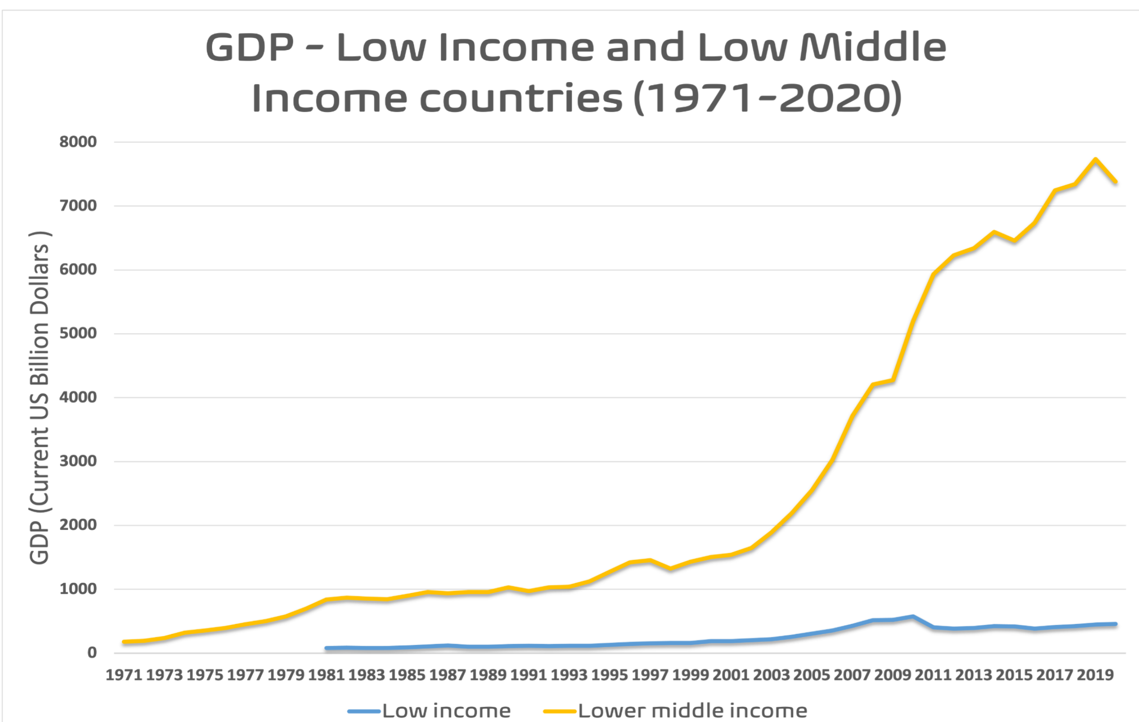

Figure 2.3 - GDP of low income and low middle income countries (1971-2020) (World Bank., 2020)

The natural resource curse essentially means that a country has an abundance of natural resources, which results in the economic growth being highly concentrated in a few primary sectors (Collier, P., 2007). Countries that depend on very few sectors for economic growth suffer from an undiversified trade basket resulting in unsustainable growth and contrary to modern growth theories, which advocate for economic diversification (Hesse, H., 2009). Trade diversification is measured through the economic complexity index (ECI), developed by Hidalgo, C.A. and Hausmann, R. (2009). Economic complexity contributes significantly to economic growth (Hesse, H., 2009), as studies have shown that ECI and economic growth are positively associated in the long run (Stojkoski, V. and Kocarev, L., 2017). The evidence further shows that economic complexity helps achieve energy transition towards renewable energy, reducing pollution and contributing to environmental sustainability.

The information presented above demonstrates the significance of EF, HDI, and ECI as the indicators of SD. The comprehensiveness these indicators offer, their acceptance, and data availability make these indicators a suitable measure for representing the three dimensions of SD. Whereas there is an abundance of research on these indicators, it has caught the attention of scholars to research the correlation between these indicators. However, there is a crucial need for a study exploring the correlation between these three indicators as representatives of SD to study the relationship between the three dimensions of SD. To the best of my knowledge, the previous literature does not explore all three indicators together within a framework of SD to analyze relationships between the three dimensions of SD. Nevertheless, it does explore the correlation between two indicators, such as EF and HDI, EF and ECI, and ECI and HDI. The findings are represented and discussed in the following section (chapter 3).

3. Theoretical model/analytical framework/scholarly debates

The core concept of this study is an expansion (figure 1.2) of the sustainable development model adapted from Barbeir (figure 1.1). The expanded model, figure 1.2, highlights the dimensions of sustainable development and the relationship between them in a holistic manner. Whereas the model in figure 1.2 explores the interaction between all three economy, environment, and social dimensions of sustainable development, the closest widely studied model to this is EKC. EKC does not explore all three dimensions but only two, which are environment and economy. Looking back at 1995 when an economist Simon Kuznets developed a theory that states that income inequality and economic growth follow an inverted U-shaped relationship (Yandle, B., Vijayaraghavan, M. and Bhattarai, M., 2002). Kuznets model became known as Kuznets Curve, and Kuznets was awarded the Nobel for his work as it had a significant contribution to development economics in understanding that Income inequality is part of the transition from low economic growth to high economic growth (Vijayaraghavan, M. and Bhattarai, M., 2002).

In 1991, research by Grossman and Krueger discovered an inverted-U relationship between air quality and income, which led to the concept of EKC (Vijayaraghavan, M. and Bhattarai, M., 2002). As described by the Vijayaraghavan and Bhattarai (2002), the EKC hypothesizes that as income grows, the air quality would deteriorate up until a certain point, after which air quality would reduce as income continues to grow, as shown by figure 3.1. However, the EKC inverted-U hypothesis has been rejected by various studies, and it has been claimed by Stern (2004) that the initial study of Grossman and Krueger was itself statistically non-robust.

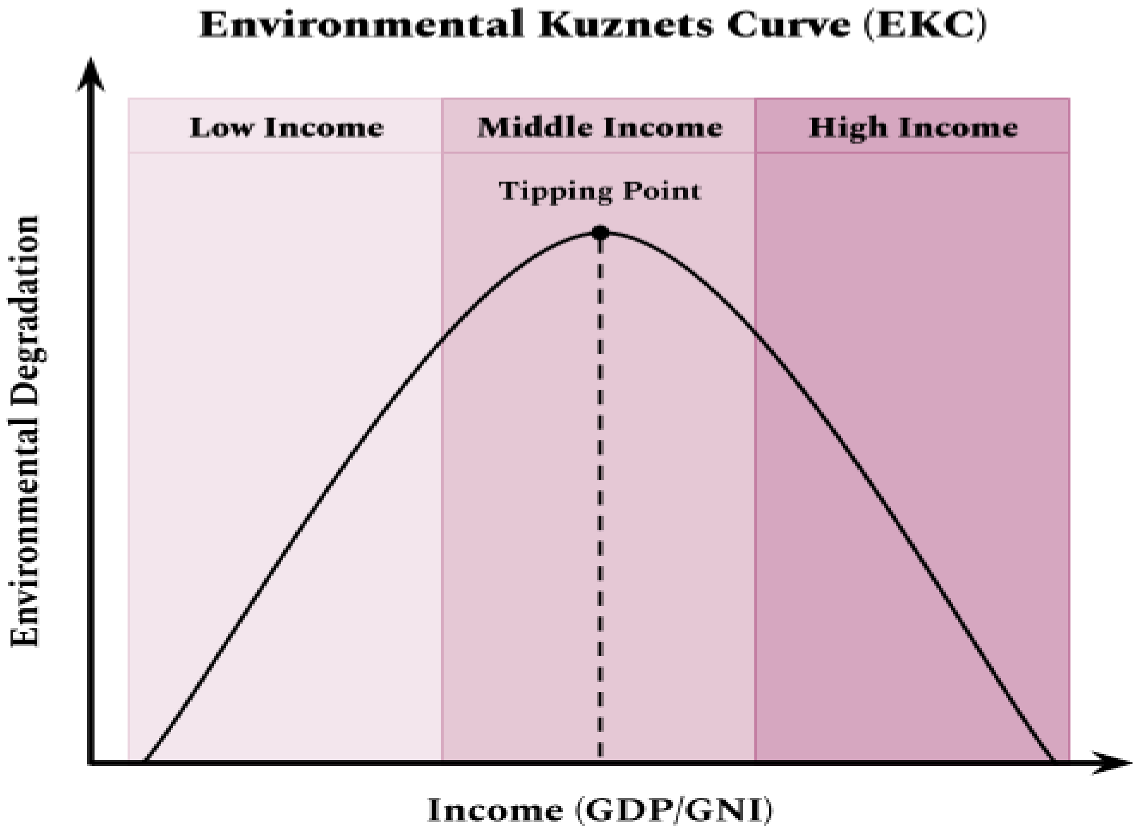

Figure 3.1 - The Environmental Kuznets Curve

Nevertheless, the EKC has been validated, mainly for specific pollutants and certain countries (Stern., 2004). The developing economies tend to focus on faster growth with little to no focus on environmental policy. Additionally, these countries are also transitioning from agrarian to industrial economies (MacDermott, R.J., Basuchoudhary, A. and Beng, J., 2019). MacDermott et al. (2019) discuss that as trade grows for poor economies, then due to low wages in poor economies, the labor-intensive industry grows and demands higher labor causing an increase in wages. As wages grow, consumption and pressure on resources grow, leading to pollution—further growth results in an industrial economy that is environmentally degrading. After certain growth levels, the consumer preferences change, the economy transitions towards a service-based economy, and the industry is transferred to pollution havens, leading to a decrease in environmental degradation (MacDermott, R.J., Basuchoudhary, A. and Beng, J., 2019).

The point to be noted here is that most studies of EKC are focused on investigating the impact that economic growth has on air quality, where air quality represents environmental degradation (Stern, 2004). Stern (2004) illustrates that EKC is valid in various studies based on the emission of specific pollutants; however, the aggregated amount of emissions and waste have increased over time. Furthermore, the pollution and environmentally degrading factors change with time, as Stern (2004) describes the research of Dasgupta, stating that over time specific emissions of pollutants decrease as new pollutants replace them.

In order to enhance the scope of EKC and theoretical foundations, this study replaced the pollution emission with the human demand for resources which is causing pressure on the planet. This demand is measured by EF, which combines the use of resources and the assimilation of waste to determine the human demand for the resources (Wackernagel, M. and Rees, W., 1998). This comprehensive measure of the environmental dimension of SD would help us determine the pressure on the environment.

Additionally, addressing the second narrow scope of EKC is that it focuses on income growth, thus, economic growth. However, the EKC initially does not focus on socio-economic development, let alone on sustainable development. Human development is an integral part of socio-economic growth and certainly a more inclusive development measure than monetary growth. The Pakistani economist Mahbub Ul Haq pioneered the theory of human development, who argued that basic monetary needs are an inadequate measure of development and for the nations to prosper, they need to invest in their people (Ul Haq, M., 1995).

Productivity does not necessarily grow with income; however, it grows with a healthy, educated, well-fed, and well-nourished population, as Ul Haq (1995) stated. Haq envisioned human development, sustainable human development, and sustainable development as fundamentally the same concept because Haq's theory of human development is keen on intergenerational equity. It indicates that human development's integral part consists of leaving the without overpressurizing it to the extent where future generations fail to obtain the same or better development opportunities.

In the context of human development, development opportunities essentially mean people's empowerment, equal opportunities for all people, and people-centered policies. Haq argues that productivity will follow the lead as an investment in people, and equitable opportunities are provided to people. Therefore, economic growth should shift toward human development, as income growth is merely a subset of human development (Ul Haq, M., 1995). This ties in with the capability approach of Amartya Sen, which is a framework with the core idea that social development should be evaluated based on people's capabilities (freedom) to promote and achieve functionings (what they want to be and what they want to do) that is valuable to individuals (Sen, A., 1999).

The human development and capability approach undoubtedly focuses on productivity gain from investing in humans, which links to human capital development. Human capital development is the foundation of modern economic growth, contrary to previous GDP and income-based growth (Balland, P.A., Broekel, T., Diodato, D., Giuliani, E., Hausmann, R., O'Clery, N. and Rigby, D., 2022). Balland et al. (2022) that expanding knowledge and technology is the key to developing economies. Therefore, countries with more significant and more complex knowledge result in a diversified growth in all sectors of the economy, which eventually causes economic development. This concept is called economic complexity, which has given rise to a new measuring toolbox that does not merely rely on aggregating, unlike GDP (Balland et al., 2022).

Economic diversification or complexity is crucial for economic development and ties in the societal (human) aspect of economic complexity rather than being merely income-based. Therefore, combining it with human development and capability approaches gives a solid foundation for estimating socio-economic development. The socio-economic development is two integral dimensions of SD; thus, to adjust the EKC to fit a sustainable dimension, this paper chooses to replace the income growth focus of EKC with the socio-economic development. Henceforth, the aforementioned six concepts: sustainable development, environmental Kuznets curve (EKC), human development theory, capability approach, and economic complexity, are utilized together to create a conceptual framework that would help analyze the hypothesis and support the study design.

To sum up, firstly, the commonly used diagram of sustainable development is enriched by turning it into a relational model of sustainable development (figure 1.1). Secondly, the exploration of two development dimensions of sustainable development, i.e., the relationship between social development and economic development, is supported by links between human development theory, capability approach, and the concept of economic complexity. That will be used in conjunction with statistical hypothesis testing regarding the correlation between human development and economic complexity, mentioned in chapter 1.1.1.

Thirdly, the environmental Kuznets curve hypothesis is discussed and combined with human development and economic complexity in order to make the EKC hypothesis more capability-oriented than economic growth-oriented. Additionally, to comprehensively capture the environmental degradation, the pollution aspect of EKC is turned into an ecological footprint, hence, investigating overall pressure on the environment. Resulting in a comprehensive and socio-economic development-oriented EKC hypothesis that hypothesizes an inverted-U relationship between the sustaining (environment) aspect and development (economy and society) of sustainable development, shown in figure 3.2.

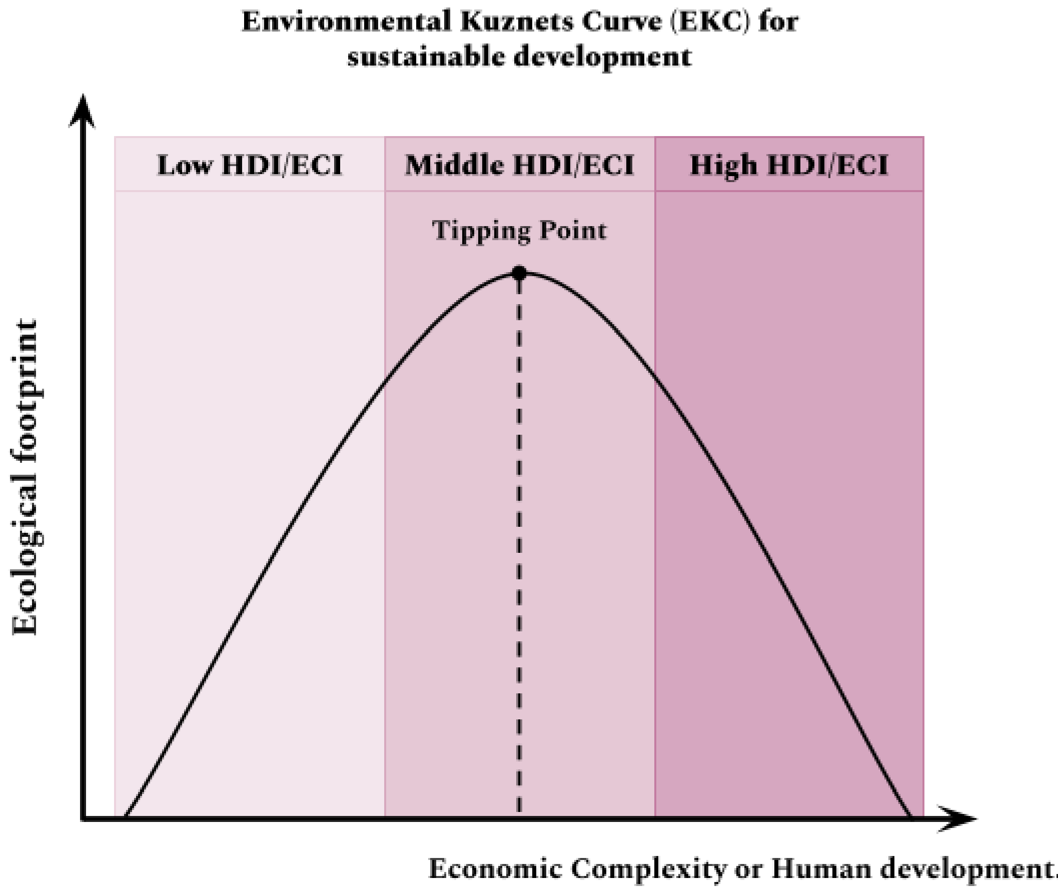

Figure 3.2 - Enriched Environmental Kuznets Curve to fit the context of sustainable development

4. Literature Review

Le Caous and Huarng (2020) state that to understand the development, especially human development, various other factors along with HDI should be considered. One of these factors is economic complexity, which can demonstrate a lot about the economy as it accounts for the knowledge circulating within the economy and the diversified basket of goods and services produced from this knowledge (Le Caous. and Huarng., 2020). The measurement of HDI relies on income growth; additionally, the GDP is associated with accelerating human development (Le Caous. and Huarng., 2020). However, Le Caous and Huarng (2020) believe that diversification and complexity of an economy have far larger significance for HDI than the GDP. According to Soyyigit et al. (2019), various previous studies have found a strong positive link between economic complexity and HDI. On the other hand, Soyyigit's analysis found a negative relationship between ECI and HDI, especially in the developed countries where the ECI is decreasing and HDI is increasing (Soyyigit et al., 2019).

On the other hand, Le Caous has found that a high level of economic complex means indicates a high of human development in the economy better-off. This is because, firstly, the increasing economic complexity significantly increases the production of goods used for well-being. Secondly, it gives more freedom of choice and capabilities to the individuals living in the economy (Le Caous. and Huarng., 2020). This also links to Amartya Sen's capability approach, which is discussed in the previous chapter. As the HDI is a rough measure to quantify an economy's basic capabilities, increasing capabilities means increasing the HDI. However, another scholar, Lapatinas A. (2016), argues that increasing economic complexity seems to have no considerable impact on the HDI; therefore, no strong relationship exists between the ECI and HDI. Lapatinas A. (2016), without going much further in-depth, states that one possible reason for this may be that ECI is not a basic human need, therefore, it may not be possible for HDI to be dependent on ECI.

The findings of Felipe J. et al. (2012) are keen on establishing the positive link between ECI and HDI. Felipe J. et al. (2012) results conclude that highly complex economies tend to have a high income. As income is a component of HDI, therefore, the higher the income higher, the higher the HDI. Hence, high HDI countries are also highly complex countries, demonstrating a positive relationship between ECI and HDI. These findings are further complemented by the study conducted by Kosifakis, G., Kampas, A., and Papadas, C.T. (2020), also closely related to the topic. However, instead of finding direct relationships between ECI and HDI, Kosifakis et al. (2020) found that the association between ECI and GDP grew stronger for countries with higher HDI. They further argue that as ECI increases GDP, which increases the ecological footprint, the ecological footprint is higher in the countries with high HDI. This relationship is further explored in the next section.

The literature on development economics has been enhanced by the concept of human development and SD, especially in the last three decades (Costantini, V. and Monni, S., 2008). The UN recognizes a hybrid of both concepts, i.e., sustainable human development, meaning human development should occur within the SD path. Integrating these two concepts has encouraged the researcher to look at their relationship. As EKC is the most commonly used theory when studying SD, Costantini and Monni (2008) studied the EKC for the general environmental stress as a function of HDI (excluding income). Their results show that at 0.6 HDI (excluding income), that is, medium development, the environmental degradation will reverse. The main explanation is that policy will shift towards environmental friendliness as the environment is no longer a luxury good since the economy is no longer underdeveloped (Costantini, V. and Monni, S., 2008). The second is that high development leads to technological innovation resulting in a changed productive structure that is more service-oriented, thus producing low emissions (Costantini, V. and Monni, S., 2008).

However, if the general environmental stress is substituted for an ecological footprint (EF) and the general development is still described by HDI, then the results differ. There are several studies done to explore the interaction between human development and EF. Most of them are concerned with exploring relationships between the UN's human development index and EF. The global footprint network allows the user to add HDI and EF to their interactive graphing web page, allowing them to explore or at least foresee the relationship between HDI and EF. However, some researchers have done it in more depth. For example, Kassouri, Y. and Altıntaş, H. (2020) analyze the trade-off between human well-being and ecological footprint, using the human development index, for seven oil-exporting and six non-oil exporting countries in the Middle East and North Africa (MENA). The results show a substantial trade-off between these two, which aligns with Moran, D.D., Wackernagel, M., Kitzes, J.A., Goldfinger, S.H., and Boutaud, A. (2008), who discovered a positive relationship between HDI and EF over 93 countries. Their findings also elaborate on the maximum HDI achievable within optimal EF, showing that only one out of 93 countries met these levels.

Altıntaş H. (2020), however, mentions that there is a need for inter-continent analysis to understand the variation of the relationship between EF and HDI across continents. Moreover, whether the relationship is measured between EF and HDI or between general environment stress and HDI, as Costantini and Monni measured, the HDI needs to be broken down into its components (Education, Health, and Income) in order to specify which factor of HDI correlates the most with environmental degradation.

Long, X., Yu, H., Sun, M., Wang, X.C., Klemeš, J.J., Xie, W., Wang, C., Li, W., and Wang, Y., (2020) take a different approach and create a new indicator by dividing HDI with EF which shows the ecological efficiency and call it Ecological Well Being Performance (EWP). EWP does not show the relationship between EF and HDI itself; however, it can be plotted against HDI to examine the relationship between ecological efficiency used to achieve the respective rate of HDI by a specific country or region. However, none of those mentioned above studies break down the HDI into its component to analyze which dimension of HDI (health, education, GNI) has the immense impact on EF.

However, Harris R. (2010) investigates the health dimension of HDI by analyzing the impact of life expectancy at birth on the ecological footprint in over 40 countries and concludes that the longevity of human life adds pressure to the biosphere. However, Harris's results also show that life expectancy at birth is not correlated with carbon emissions, making the analysis contradictory to its EF and life expectancy findings. Furthermore, Harris (2010) illustrates an interesting observation regarding the impact of health on the environment that corruption negatively correlates with life expectancy, and corruption negatively impacts the environment. Therefore, it is arguable that whereas life expectancy would increase the pressure on the biosphere, this pressure can potentially be offset by the low corruption rates that an economy with high life expectancy enjoys because low corruption rates mean low environmental degradation.

Charfeddine, L. and Mrabet, Z. (2017) contradict the findings of Harris and state that increasing life expectancy improves the environment in the long run. Their results contradict the common premises; however, Charfeddine and Mrabet argue that, for one, MENA countries rely more on agriculture relative to the industry; thus, their environmental harm is relatively low. Secondly, an economy with improved life experience indicates the economy's well-being is high. Finally, higher well-being and a longer population life span would cause them to invest more in future environmental preservation (Charfeddine, L. and Mrabet, Z., 2017).

Furthermore, Charfeddine's findings for the whole sample of tested countries found that there is undoubtedly an inverted-U shape relationship between GDP and EF conforming to the EKC curve. However, it was not the case if MENA countries were categorized into a subset of non-oil exporting and oil-exporting countries. Non-oil-exporting countries have a U-shaped EKC curve which can be explained by the fact that the is no demand for technology that can improve energy efficiency (Charfeddine, L. and Mrabet, Z., 2017). This is contrary to the case of oil-exporting countries where oil extraction causes rapid growth, thus, in high demand for energy and, therefore, increased availability of the energy-efficient technologies (Charfeddine, L. and Mrabet, Z., 2017). However, the EKC curve can be enhanced in scope by substituting the GDP with life expectancy in order to take socio-economic development into account.

Furthermore, Ahmed Z. and Wang Z. (2019) empirically analyze the impact of increasing human capital on EF in India and determine that they are negatively correlated, meaning that high human capital indicates low environmental degradation. Ahmed Z also tests the EKC hypothesis and finds no EKC curve in the short run. However, he finds that the EKC hypothesis is supported between economic growth and EF in the long run. Ahmed states that the impact of human capital on EF is not widely researched; however, Hassan et al. (2018) and Danish et al. (2019) have contributed to the research on human capital and EF. Their research aims to find a relationship between human capital and EF in Pakistan, and their results state that there is an insignificant relationship. Ahmed's (2019) findings do not support this and instead state that human capital will reduce EF. Nevertheless, Ahmed states that his study lacks a comprehensive view of human capital as the human capital should also include the health factor account and education.

Further, Ahmed (2019) argues, based on Shukla's results, that human capital promotes economic growth and development, which is highly likely supported by numerous studies and theories (Mincer, J., 1984). Based on this, it should follow that an economy with high income would have high human capital, therefore, a low EF. This aligns with the EKC, as it states that economies with high economic growth would have low environmental degradation. The relationship between GDP and EF is extensively studied because GDP is the most commonly used measure of economic growth. As p previously stated, Charfeddine, L. and Mrabet, Z. (2017) confirmed the EKC hypothesis except for non-oil exporting countries, whereas Toth, G. and Szigeti, C. (2016) state that there is a positive correlation between EF and GDP in the long run instead of inverted-U.

However, Charfeddine's (2017) findings show an impact of the trade basket on EKC, making it worthwhile to analyze EF correlation with trade. Moreover, there are more measures of economic growth which capture economic development more comprehensively than merely income growth, and ECI is one of them, as mentioned in the previous chapter. Thus, ECI captures trade basket and economic development, making it a more comprehensive measuring relationship between economic development and EF while broadening the scope of the EKC hypothesis by substituting income growth for ECI.

Previous studies attempting to analyze the relationship between EF and ECI are relatively recent, indicating a lack of intensive research. One of them is by Neagu O. (2020), which shows a positive correlation between ECI and EF among the 40 most complex economies of the world. Neagu notes that 75% of countries in the study are currently ecological deficient, and their economic complexity is hampering their way to the SD path. Higher complexity is linked with higher energy demand, therefore, policies that encourage renewable energy and energy-efficient technologies should be implemented. Furthermore, ECI is linked with high human capital and education (Neagu O., 2020). Therefore, according to higher Ahmed (2019), ECI means higher human capital; thus, higher human capital should indicate low EF. However, the findings of Neagu do not necessarily align with the findings of Ahmed (2019) since Neagu stresses that high ECI and human capital would result in high EF. Therefore, it is possible that after a certain level of ECI, the EF would decrease, conforming to the EKC hypothesis. However, Neagu did not analyze the EKC hypothesis. Nevertheless, Neagu (2020) mentions certain studies that have supported the EKC hypothesis for complex production and industrial structures. Therefore, there is a further need to study ECI and EF from the EKC perspective.

Yilanci V. (2020) discusses that there are merely a handful of studies that test EKC with EF as environmental degradation variable and ECI as an explanatory variable (economic development variable). However, whereas the findings for Yilanci confirm a positive relationship between ECI and EF, his discussion only explores EKC for EF from a perspective of GDP as the explanatory variable and not ECI. Neagu (2019) studied EKC, where ECI was used as an explanatory variable for European Union countries from 1995 to 2017. Neagu's (2019) findings argue that EKC is valid for CO2 emissions, using ECI as the explanatory variable. However, Neagu's (2019) study does not test EKC for EF, only for emissions.

Although Pata, U.K. (2020) tests EKC for CO2 emissions and EF using ECI as an explanatory variable, confirming that EF and emissions increase at first, the EF and emission decrease after a particular ECI value. Thus, confirming the EKC hypothesis, their findings are restricted to the United States of America (USA). Pata (2020) also examines the negative relationship between globalization and EF, which corroborates Nathaniel's (2021) findings that globalization reduces the EF, whereas economic complexity increases the EF. Unlike Pata (2020), Nathaniel (2021) does not find an inverted-U relationship between ECI and EF. However, Nathaniel recognizes the need for enriching the examination of non-linear relationships between ECI and EF.

Similar to Pata (2020), Khan, Yahong, and Chandio (2022) also find results that support the EKC for EF when ECI is used as an explanatory variable; however, their results are only valid for G-7 economics. G-7 economies are a group of seven economies: Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States (Khan, Yahong, and Chandio, 2022). Furthermore, Khan et al. (2022) state that the increasing demand for renewable energy that G-7 economies have faced in the long run, along with high ECI, has resulted in reduced EF. Thereby, the possible explanation behind the inverted-U relationship between EF and ECI is perhaps due to the increasing demand for renewable energy. Nevertheless, the findings regarding the EKC hypothesis for EF and ECI may show different results if the data sample is increased to incorporate more countries. Therefore, Khan (2022) also states the need to incorporate more variables, such as human capital, while analyzing the correlation between EF and ECI.

The information mentioned above clarifies that various studies measure the relationship between HDI and ECI, between HDI and ecological footprint, and between ECI and ecological footprint. The relationship is mostly found to be positive, however, some studies point towards a negative correlation between each of them as well. Firstly, to the best of the author's knowledge, there are no studies that take on a holistic view into combining all three indicators (ecological footprint, HDI, and ECI) and utilize them as a proxy to clarify the relationship between them and the three dimensions of sustainable development. Secondly, very few studies that take a global overview into account by combining data for large numbers of countries are case-study-based. Thirdly, there are studies regarding the relationship between HDI and ecological footprint. However, to the best of the author's knowledge, none of them breaks down HDI to investigate which HDI components are most correlated with the ecological footprint. Fourthly, there have been studies testing the EKC for ecological footprint instead of pollutants; however, the independent variable of EKC is still economic growth, and there is a lack of a more capability-oriented EKC hypothesis. Henceforth, this thesis using the theoretical framework that has been constructed and the revised version of the EKC hypothesis aims to contribute to filling in these gaps.

5. Methods and data/sources

5.1 Study design

The thesis relies on quantitative research methodology by analyzing the pre-existing data through regression analysis – a statistical method used for establishing a relationship between response and explanatory variables (Montgomery, D.C., Peck, E.A. and Vining, G.G., 2021). As this paper is concerned with estimating the correlation between ecological footprint, human development index, and economic complexity index, the regression analysis is a well-suited methodology to utilize. The choice of variables is based on the indicators that can appropriately and comprehensively capture the three dimensions of SD. As illustrated in chapter 2 (Background), EF, HDI, and ECI are indicators that comprehensively represent the Environment, Social and Economic dimensions of SD, respectively. These indicators also align with the modern economic view of development that is more capability-oriented, as discussed by the theories of human development and economic complexity, than total production and income growth-oriented. Moreover, this study will examine data from 114 countries as this research aims to offer a comprehensive understanding and not a case-specific understanding.

The study design can be summed up in four significant steps. First, the study will collect data for the concerned indicators, mainly from official sources. Secondly, the data will be cleansed and processed, making it suitable for applying regression analysis and visualization. Thirdly, the results will be presented and statistically interpreted based on the regression analysis. Fourthly, these results will be analyzed and explored in-depth based on the literature review (previous studies) and the theoretical framework of this thesis.

5.2 Data collection and processing

This thesis relies on collecting historical secondary data from reliable sources and then cleaning and formatting it. The data is taken from the different sources for the four indicators (HDI, EF, EF per capita, and ECI). However, these sources are official organizations that have created these indicators and publish them every year as well; thus, they are reliable and trustworthy. The sources are summarized in table 5.1, which also shows the available data period.

Indicator	**Years of availability**	**Source**
Ecological Footprint	1961 to 2018	Global Footprint Network
Ecological Footprint per capita	1961 to 2018	Global Footprint Network
Human Development Index	1990 to 2018	United Nations Development Programme
Economic Complexity Index	1995 to 2017	Atlas Of Economic Complexity

Table 5.1 - Indicators and their respective data sources

The ECI has the data available for the least number of years, as shown above. Therefore, the years 1995 to 2017 were chosen for all variables. That is because regression relies on using the same data amount for all variables (Montgomery et al., 2021). Furthermore, the data was only selected for 114 countries because some countries lacked data for at least one indicator out of EF, HDI, and ECI. Therefore, one hundred fourteen countries make up a suitable amount of data for regression analysis.

The data for all variables are combined, constructing a database of ECI, HDI and EF, and EF per capita. The mean value of each indicator for each country from 1995 to 2017 is calculated as well. The variables are also normalized in order to standardize the scale for better visual representation for Appendix J.

5.3 Data analysis

In order to perform the regression analysis, the ordinary least squares (OLS) linear regression model was used for each year; the general form of linear regression is shown by Eqn 5.1.

Eqn 5.1: $Y_i = \alpha + \beta X_i + \epsilon_i$

Y is the dependent variable, and i is the iteration of data points. Alpha stands for the y-intercept of the regression line of best fit, and Beta stands for change in Y due to a unit change in X, which is the independent variable (Montgomery et al., 2021). Lastly, e stands for random error, the distance between original Y values and predicted (line of best fit) Y values (Montgomery et al., 2021).

5.3.1 Statistical relationship between HDI and ECI

The analysis commences by first looking at two dimensions of SD, social and economic, thereby observing the correlation between HDI and ECI. Then, Eqn 5.2 represents the equation for linear regression that examines the linear relationship between ECI as an independent variable and HDI as a dependent variable. The choice of the dependent variable is motivated based on the previous studies, which assume that a "country that focuses on innovation and is economically diversified will have a greater freedom of choice, capabilities, and well-being" (Le Caous, E. and Huarng, F., 2020, p.5).

Eqn 5.2: $HDI_i = \alpha + \beta(ECI)_i + \epsilon_i$

5.3.2 Statistical relationship between EF and HDI

The second step of analysis focuses on the relationship between the environment dimension and social dimension of SD by observing the relationship between the EF per capita (EFPC) as a dependent variable and HDI as an independent variable. The linear equation for this model is given by Eqn 5.3. The reason why EF per capita is chosen is that as each regression will be composed of data points from 114 countries, it is essential to consider the population.

Eqn 5.3: $EFPC_i = \alpha + \beta(HDI)_i + \epsilon_i$

However, in the case of the Eqn 5.3 regression, the residual plot was not satisfactory. The residual plot should look like noise rather than displaying a pattern (Montgomery et al., 2021). The residual plot (Fig 5.1) shows a nearly inverted-U pattern, which would indicate a non-linear relationship between EFPC and HDI (Montgomery et al., 2021). To overcome this issue, a transformation of variables can be applied (Montgomery, et al., 2021), therefore, using log transformation, the linear model presented in Eqn 5.3 was converted into a log-linear model. In a log-linear model, given by Eqn 5.4, the dependent variable (Ln(EFPC)) is a natural log transformation of the original EFPC variable.

Eqn 5.4: $Ln(EFPC)_i = \alpha + \beta(HDI)_i + \epsilon_i$

In order to fulfill the gaps that this thesis addresses, the HDI was further broken down into its components (education index, life expectancy index, and income index) in order to analyze specific impacts. For this purpose, a multiple linear regression model was constructed, given by Eqn 5.5. Edu, LE, and Income denote the education index, life expectancy index, and income index, respectively.

Eqn 5.5: $Ln(EFPC)_i = \alpha + \beta(EDU)_i + \beta(LE)_i + \beta(Income)_i + \epsilon_i$

The model Eqn 5.5 is composed of explanatory variables that may or may not be highly correlated. This concept is known as multicollinearity, due to which the regression losses it accurately because the model would give wrong estimations of the relationship (Montgomery, et al., 2021). However, every case of multicollinearity is not problematic, and there is a method for measuring multicollinearity, known as variance inflation factor (VIF) (Montgomery et al., 2021). The calculation of VIF is conducted in two steps, first performing a regression that measures the relationship of each dependent variable (Edu, LE, and Income) with the other two (Montgomery et al., 2021). Secondly, calculate the VIF value by the following formula, Eqn 5.6, where r-square denotes the coefficient of determination (Montgomery et al., 2021).

$$\textbf{Eqn 5.5: } \frac{1}{1-r^2}$$

There is a general rule regarding the results of VIF, which states that if multicollinearity is higher than five, then the regression model would yield unreliable results; otherwise, multicollinearity would not cause problems (Montgomery et al., 2021). The result, given in appendix A, shows that multicollinearity has become a problem for income variables from 2008 to 2017. Thereby the income variable was dropped from the regression equation, and Eqn 5.6 was used for performing a regression that measured the impact of the education index and life expectancy index (components of HDI) on EFPC.

$$\textbf{Eqn 5.6: } Ln(EFPC)_i = \alpha + \beta(EDU)_i + \beta(LE)_i + \epsilon_i$$

Lastly in order to test the EKC hypothesis, a HDI squared variable was introduced into the regression analysis making the model a polynomial (non-linear) of second degree, i.e., a quadratic relationship. Quadratic curves either model a concave up (U-shaped) or concave down (inverted-U shaped) relationship which would enable the analysis to determine whether the EKC hypothesis holds for human development and ecological footprint per capita (Wood, M., (2012). Three nonlinear regression model are featured:

1. First one models a nonlinear relationship between EFPC (environmental pressure/degradation) against HDI (human development):

$$\textbf{Eqn 5.7: } EFPC_i = \alpha + \beta(HDI)_i + \beta(HDI)_i^2 + \epsilon_i$$

2. Second one models a nonlinear relationship between EFPC (environmental pressure/degradation) against education index (human development):

Eqn 5.8: $EFPC_i = \alpha + \beta(EDU)_i + \beta(EDU)_i^2 + \epsilon_i$

3. Third one models a nonlinear relationship between EFPC (environmental pressure/degradation) against life expectancy index (human development):

Eqn 5.9: $EFPC_i = \alpha + \beta(LE)_i + \beta(LE)_i^2 + \epsilon_i$

5.3.3 Statistical relationship between EF and ECI

The third step of analysis focuses on the relationship between the environment dimension and economic dimension of SD by observing the relationship between the ecological footprint per capita (EFPC) as a dependent variable and economic complexity (ECI) as an independent variable. Similar to above, a linear model is formed first, testing the correlation between ECI and the natural log of EFPC, given by Eqn 5.10. Further, in a similar manner as for EFPC and HDI, for testing the EKC hypothesis, a non-linear relationship between ECI and EFPC is observed by taking ECI and ECI-squared as independent variables, given by Eqn 5.11.

Eqn 5.10: $Ln(EFPC)_i = \alpha + \beta(ECI)_i + \epsilon_i$

Eqn 5.11: $EFPC_i = \alpha + \beta(ECI)_i + \beta(ECI)_i^2 + \epsilon_i$

6. Results and Discussion

6.1 Correlation between human development and economic complexity

Figure 6.1 shows the correlation coefficient – which measures the strength and direction of the relationship (Montgomery et al., 2021) – for the year-based (2017-1995) regressions given by Eqn 5.2. The coefficient clarifies that there is a positive correlation between HDI and ECI. However, the coefficients for each regression over the years are not highly stable, especially around the 2008 financial crisis. Albeit still positive, it weakens a lot. Therefore, it can be concluded that there is a moderately positive correlation between the HDI and the ECI; however, the strength of the correlation is not stable over time. Additionally, the r-square value also fluctuated around the time of the 2008 financial crisis, when it decreased. The instability of r-square in layman's terms means that the regression fit is good in some years and not so good in others. However, overall the r-square still advocates for a moderate positive correlation, even at the lowest point of 2008. Based on the mean value that was calculated for the correlation coefficient and r-square for regressions from 1995 to 2017. Then the correlation between economic complexity and human development index is 0.78 (appendix B), strongly positive, with an r-squared of 61%. Hence, 61% of the change in HDI can be explained by economic complexity.

Figure 6.2 represents the beta value for the regression model Eqn 5.2 for every year, and the beta value indicates what impact one unit increase in the independent variable would have on the dependent variable (Montgomery et al., 2021). Beta values for regression over the year have decreased, meaning that the slope of the regression line of best fit is getting more shallow. This indicates the impact that the ECI has on HDI is decreasing over the years. Nevertheless, the beta value was high until 2006, conveying that a unit increase in ECI would create a change of 0,12 - 0,13 in HDI. In later years, it decreased with time, conveying that a unit increase in ECI would change circa 0,11 in HDI. The mean of all beta values over the years is 0.12, appendix x. Whereas the change in the HDI value by ECI is not highly dramatic, it is important to note that

HDI is bounded between 0-1; therefore, a change of 0,11 to 0,13 is a highly significant change in terms of HDI.

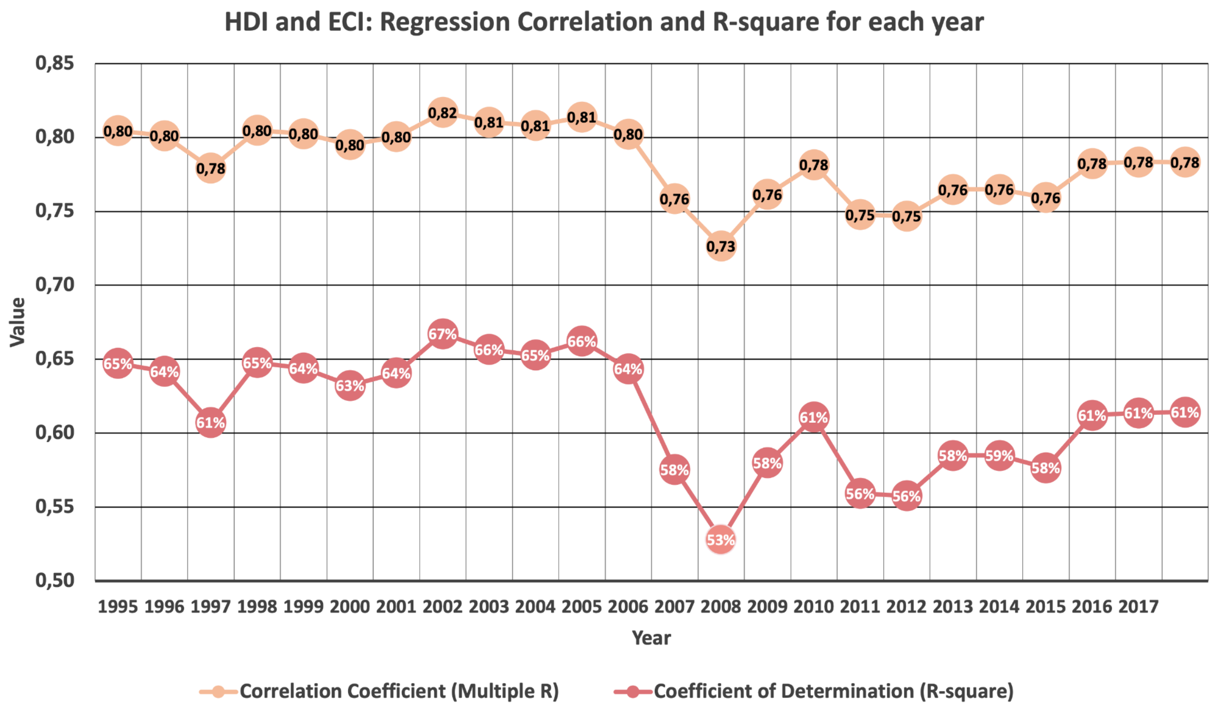

Fig 6.1 - HDI and ECI: Regression Correlation and R-square for each year

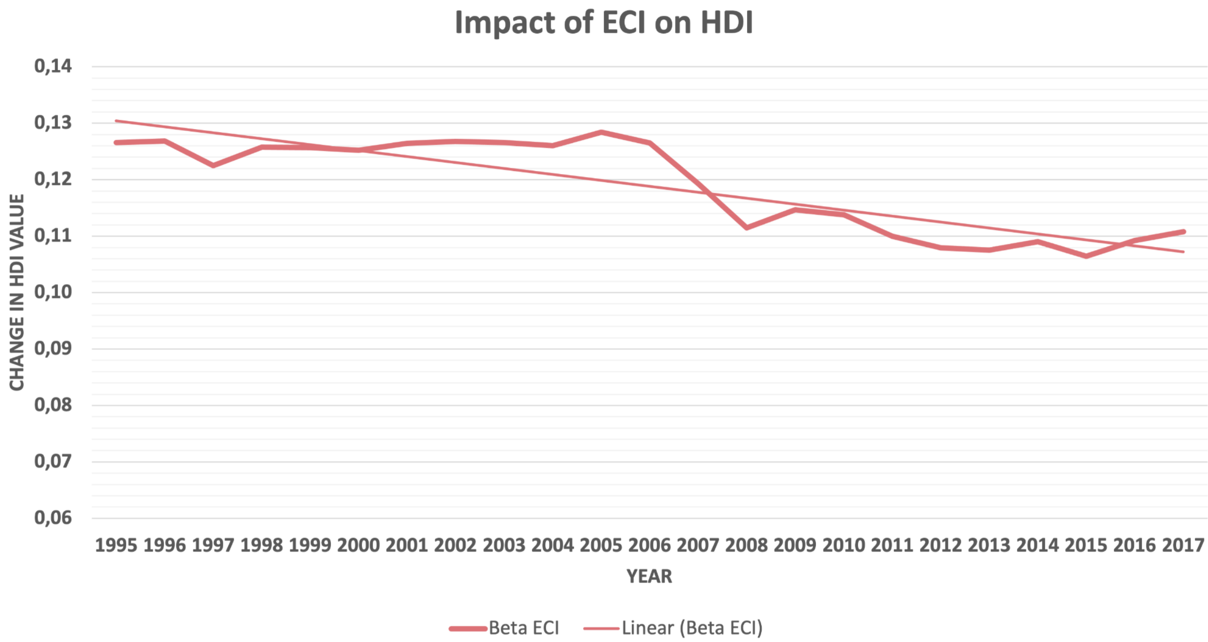

Fig 6.2 - Impact of ECI on HDI

According to the findings of this paper, which are statistically significant, the ECI and HDI have a strong positive correlation. The findings tie back to the theoretical framework explained in the previous section, that human development is essentially linked to the capabilities of the society or economy and since the complexity of the economy also indirectly measures the capabilities of society (Balland et al., 2022). Thereby, the complexity and capabilities are linked. This also complements the findings of Felipe J. et al. (2012), who argue that high-income countries have high economic complexity and high income also leads to the high HDI since income is a one-third component of HDI. Thus, there shall be a strong correlation between the two variables. However, it is observed that, according to linear regression, the impact that ECI has on HDI is decreasing with each year. Still, the correlation between them is not weakening, it has weakened for a period of time between the years 2006 to 2015; nevertheless, it seems to strengthen again since then. The previous studies that have been reviewed for this research do not focus on why the fluctuations occurred during the financial crisis of 2008. Perhaps the strength of the correlation over time has to do with where the economies are in the business cycle, however, that is something that can be further studied.

6.2 Correlation between ecological footprint per capita and human development

Similarly to regression between ECI and HDI, a linear regression model was constructed to measure the relationship between ecological footprint per capita (EFPC) and HDI. However, the results of the residual plot were not satisfactory, as mentioned previously. Thus, the graph above presents the regression model Eqn 5.5, where Ln(EFPC) is a dependent variable and HDI is the independent variable. The correlation between EFPC and HDI is a very strong positive correlation, with a high R-square value of 0.72, indicating that 72% of the change in EFPC can be explained by the change in HDI, as shown in figure 6.3. This indicates that higher human development is negatively correlated with a good environment because the higher the ecological footprint higher the pressure on the environment. These regressions are highly statistically significant, with a significance (p-value) smaller than 0.005.

The beta of the regression model Eqn 5.5 shows a varying trend bouncing between the values of 60 gha per capita and 50 gha per capita, illustrated by figure 6.4. It is observed that this is a relatively steep increase to a beta of 66 gha per capita from the years 2006 to 2008. Then 2008 to 2009 marked a sharp decline in the value of beta. However, the linear trendline shows a stable fit of almost a horizontal line for the beta of regressions. The mean value of all the regressions based on the Eqn 5.5 over time has a mean value of 55.64. This means that the linear regression analysis advocates that over the years, on average, a unit increase in HDI would cause the ecological footprint to have an increase of 55.64 gha per capita. However, HDI can not practically change 1 unit as the highest value of HDI is one and the lowest is 0, therefore, it is extremely difficult to have a unit increase in the short run, however, using simple mathematics, we can interpret the results for an increase of 0.1 unit in HDI. Thereby, 0.1 is a considerably good increase in HDI for a country that would illustrate effective efforts and results achieved in human development by an economy. Hence, based on the regression 0.1 unit increase in HDI would lead to an increase of 1.5 gha per capita, which is quite massive.

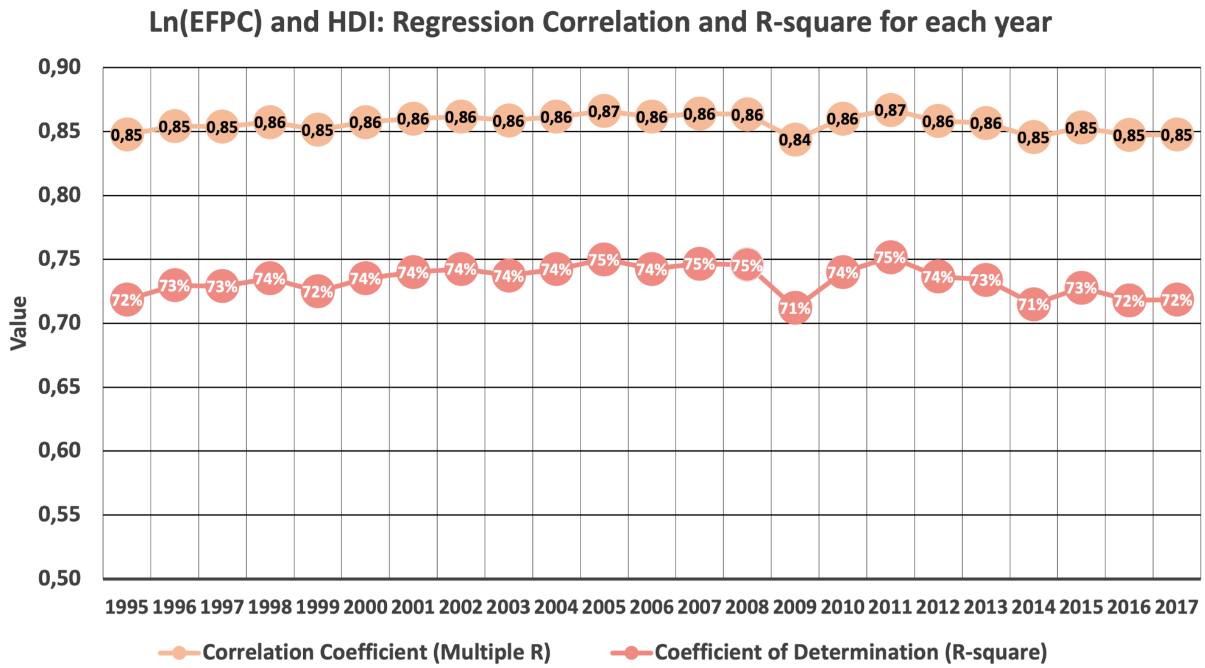

Fig 6.3 - Ln(EFPC) and HDI: Regression Correlation and R-square for each year

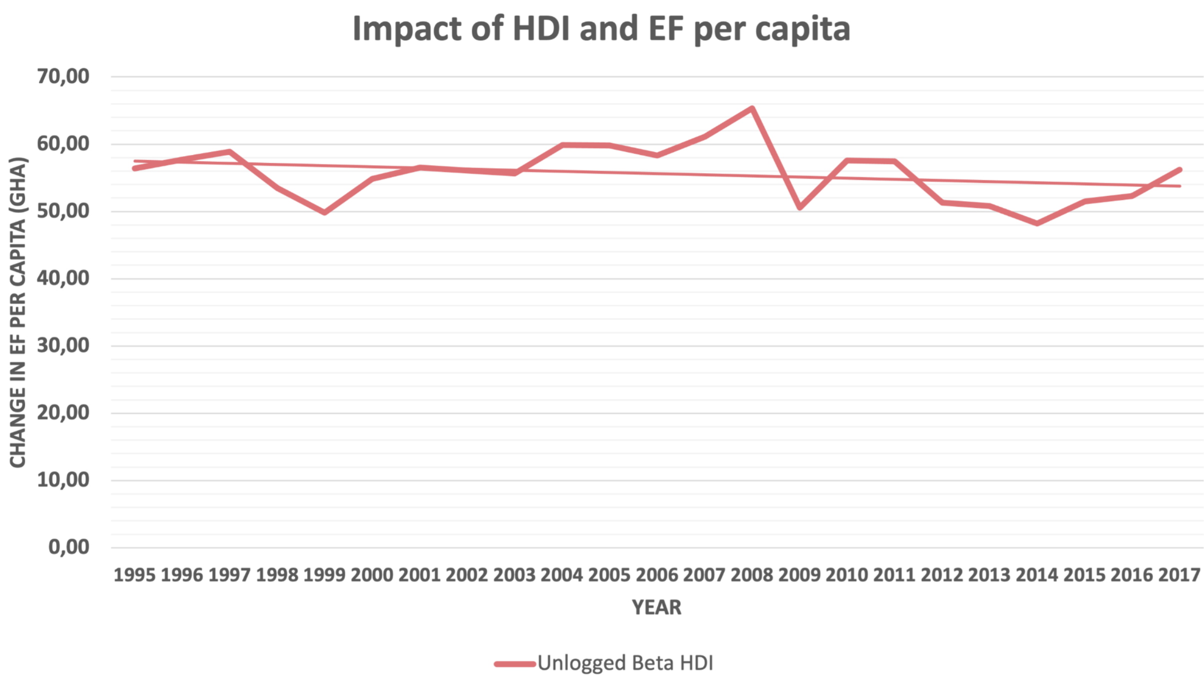

Fig 6.4 - Impact of HDI and EF per capita

The stability of the beta value and the correlation coefficient clarify a strong positive correlation between ecological footprint and HDI, which means that the environment and human development are negatively correlated. The higher the human development, the greater the negative impact on resources and planetary pressure. These findings complement previous studies concluded in the literature review, which show a positive association between human development and ecological footprint. As of 2019, the limit of maximum ecological footprint per capita is 1.6 gha, as this is the biocapacity available for one person globally (Footprintnetwork.org., 2022). The graphical representation, shown in the appendix J, clarifies that there are countries with moderate HDI and good ecological footprint per capita regardless of the strong correlation. Some of the countries in this group are Bangladesh, Pakistan, Indonesia, and Sri Lanka. According to the representation in the appendix J, there is only one country, Uruguay, that had HDI above 0.8 and an ecological footprint per capita below 1.6 gha in 2017. Hence, Uruguay's policies can be researched and studied to understand strategies to create a balance between human development and environmental degradation.

However, this study is mainly concerned with exploring which components of HDI (education, income, life expectancy) are most correlated with the ecological footprint. This regression model shows the correlation between ecological footprint per capita and the sub-indices of HDI. The following graphs show the regression model results given by Eqn 5.6.

The correlation of education and life expectancy with ecological footprint per capita is strong and positive, similar to the relationship between HDI and per capita ecological footprint. However, the HDI has an overall high value for the strength of the correlation between HDI and ecological footprint per capita and the fit of the regression (r-squared value). This may be due to the fact that the multiple regression model of Eqn 5.6 does not include the income index of HDI. Anyhow, both education and life expectancy has a strong positive correlation with ecological footprint per capita.

However, the unlogged beta coefficient shows a relatively mild impact. Based on the mean beta value over the years, a change of 0.1 units in the education index would change the value of EFPC by 1.28 gha per capita. As for the life expectancy index, a 0.1 change would result in an average change of 1.14 per capita. Additionally, the unlogged beta value for education seems to get higher for the regression model over the years, whereas it gets lower for the life expectancy.

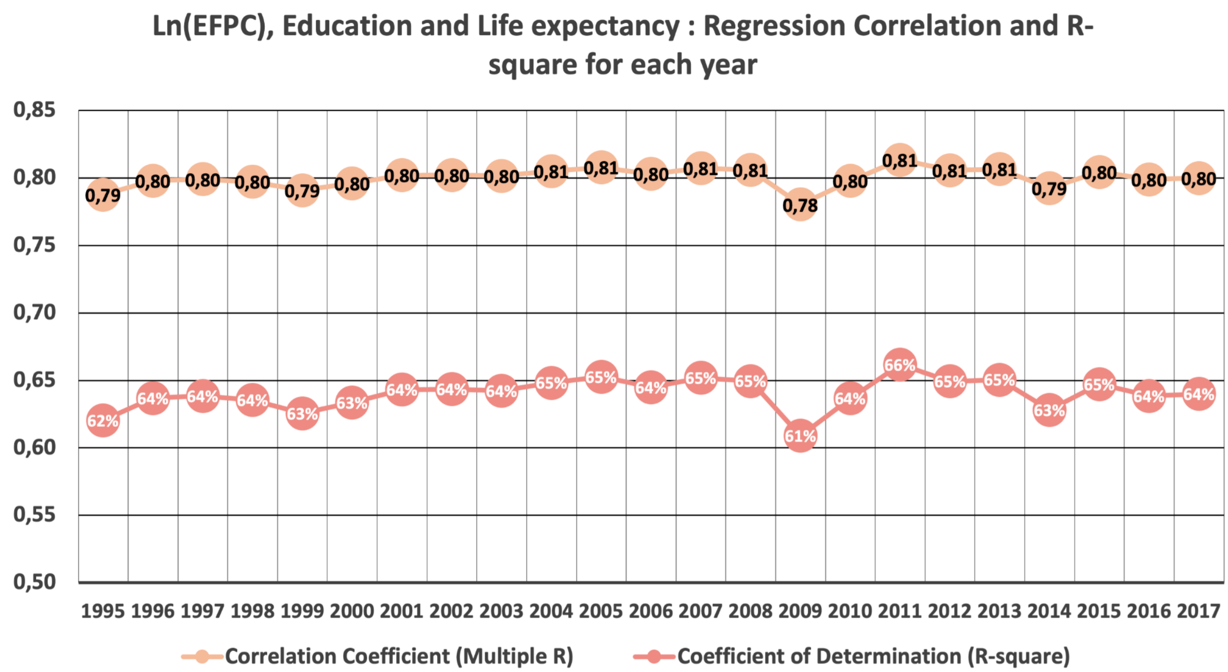

Fig 6.5 - Ln(EFPC), Education and Life expectancy: Regression Correlation and R-square for each year

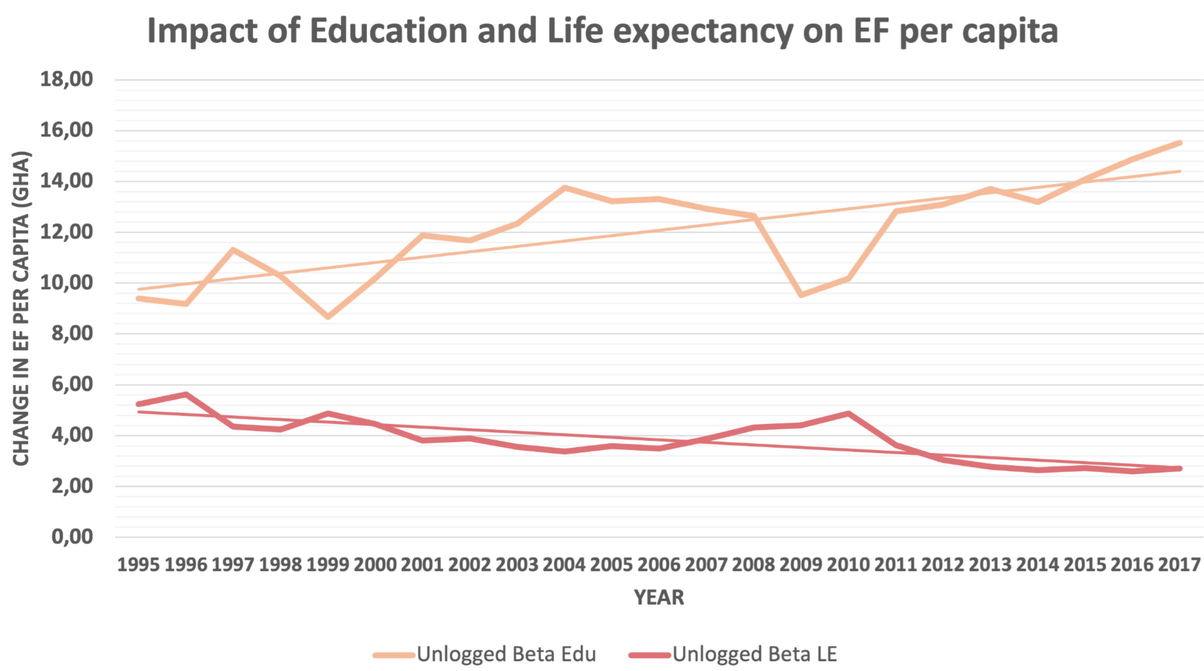

Fig 6.6 - Impact of Education and Life expectancy on EF per capita

One thing is certainly clear from the regression analysis, life expectancy has a less impact on ecological footprint per capita than education. Meaning that education is more environmentally deteriorating or pressuring than the longevity of human life as the beta of the regression model for life expectancy decreases over the years meaning that there is less impact of life expectancy on ecological footprint over time. Thereby, these findings hint toward the findings of Charfeddine, L. and Mrabet, Z. (2017), who state that in the long run, the life expectancy would improve the environment or at least would not deteriorate it. Additionally, regardless of the positive correlation between life expectancy and ecological footprint per capita, Harris (2010) has clarified that there are certainly other factors that impact the environment negatively; therefore, even if life expectancy has a negative impact on the environment, through policy, there is room for offsetting that impact by reducing other factors that impact the environment negatively.

Regarding education, the findings of this paper do not align with a previous study by Ahmed Z. and Wang Z. (2019) because they stated that there is a negative correlation between education and ecological development. However, as their study was case-specific to India, therefore, there is a possibility that India is an outlier from the positive correlation between education and ecological footprint per capita. Therefore, Indian policy can be studied in order to form policies that balance the education environment. As far as this study goes, overall, the best fit is a positive correlation between education and ecological footprint, apart from the period after the year 2008 to 2010. These fluctuations occurred around the time of the financial crash, the same as the fluctuation in the correlation coefficient and beta value of the regression model between HDI and ECI. Hence, the findings of this study indicate that there is a need to investigate if the trend of the business cycle has an impact on the relationship between economic complexity, human development, and ecological footprint.

Furthermore, a non-linear regression analysis was conducted to test the EKC hypothesis between EFPC and HDI (Eqn 5.7), EFPC and education index (Eqn 5.8), and EFPC and life expectancy index (Eqn 5.9), results shown by appendix E, appendix F and appendix G, respectively. Results show that the correlation is strongly positive for all along with a high r-square value. However, the main concern is the shape of the quadratic curve, as it would aid in understanding whether the relationship is U-shaped or inverted U-shaped. The signs of the beta of regression for the HDI, Edu, and LE should be opposite for their squared term, i.e., HDI-squared, Edu-squared, and LE-squared, respectively, for there to be a U-shaped relationship. Especially for there to be an inverted U-shaped fit, the sign of the squared term has to be negative.

Graphs in appendix F show, the beta values of the education index squared (Edu square) are positive, and the beta value for the education index (Edu) is negative, indicating that the quadratic relationship between education and EFPC is concave up, i.e., U-shaped. Similar results are shown for Eqn 5.8, demonstrated by appendix G. The beta of life expectancy squared is positive, and the beta of life expectancy is negative, demonstrating a U-shaped relationship between life expectancy and EFPC. Overall, for nonlinear regression of HDI (Eqn 5.7), the HDI-square is also positive, shown in appendix E. Therefore, it is arguable that the EKC hypothesis does not hold for the relationship between EFPC (environmental degradation) and HDI, education index, and life expectancy index (human development).

Interestingly, there is a high fluctuation between the years 2006 to 2010. For all the indices, the squared value is approaching zero, especially for the education index. It shows a very likely potential that there can be a negative Edu-squared beta; however, for the regressions performed for the years 2010 and onwards, the beta value starts to become the same as it was for the years 1995 to 2005. Overall the findings do not point towards an inverted u-shaped fit, indicating that there is a u-shaped fit between ecological footprint per capita and human development indicators. The theoretical framework hypothesizes that as human development increases, the ecological footprint will decrease. It is built upon the theorized curve of EKC, which states that there is an inverted-U relationship between income and environmental degradation. However, the findings reject this hypothesis and rather show that as human development progresses, it negatively impacts the environment. Sen (1999) views human development as progressive for the capabilities of individuals in society. However, if the environment is negatively impacted by human development, then, in the long run, human development is not progressive for the capabilities as it would comprise the environment. Consequently, it would compromise people's ability to achieve functioning (what they want to be and what they want to do) and overall sustainable development.

6.3 Correlation between ecological footprint per capita and economic complexity

The regression model for ecological footprint per capita and economic complexity index, eqn 5.10, shows a bit more fluctuating findings than the ones mentioned in previous sections. Figure 6.13 illustrates that there is an adequately strong correlation between EFPC and ECI based on the regressions for the years 1995 to 2006, afterwards the correlation for each year weakens up until 2014, then it seems to improve. In addition the regression results for all the years are highly significant with a p-value of less than 0.005, shown in appendix H.

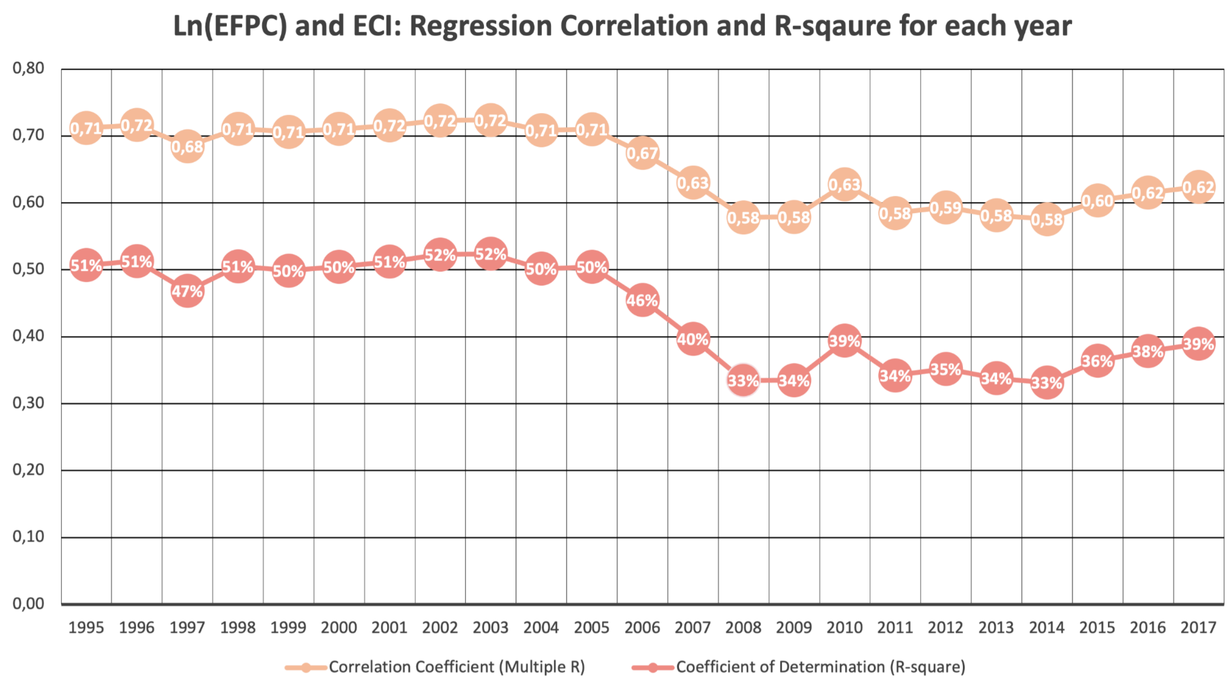

Fig 6.13 - Ln(EFPC) and ECI: Regression Correlation and R-square for each year

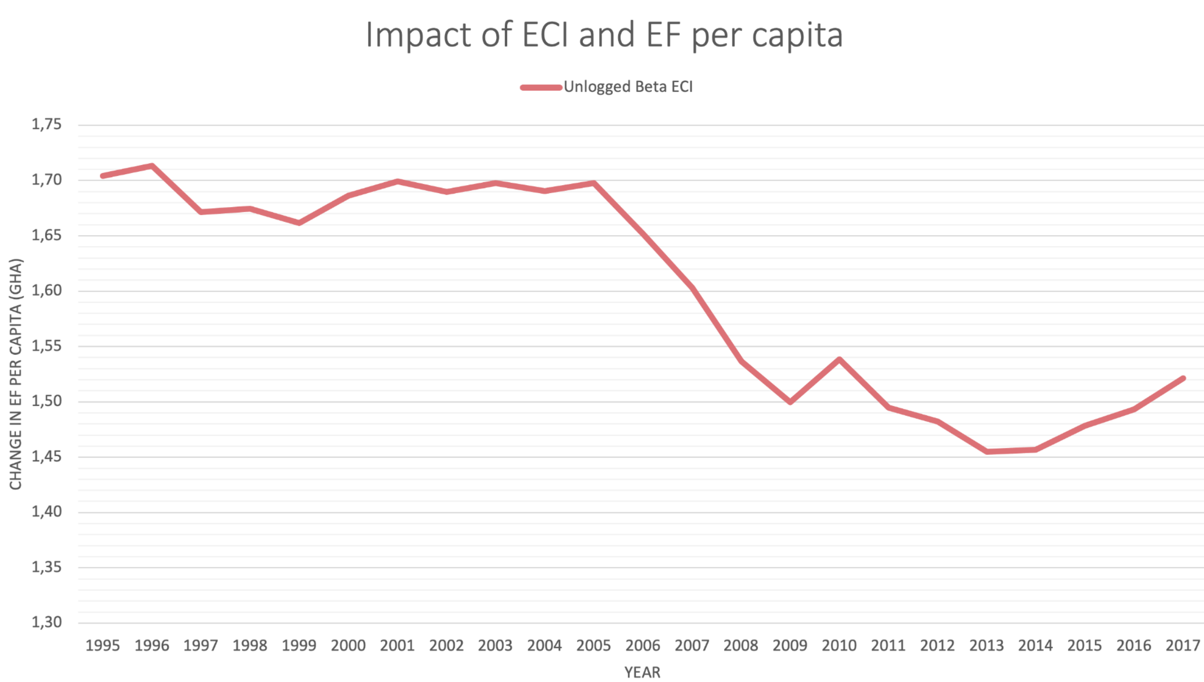

Fig 6.14 - Impact of ECI and EF per capita

However, as for the beta value, the impact of ECI on ecological footprint, according to the regression model, starts to decline significantly from the years 2005 up until 2013. The findings of this paper complement Neagu O. (2020) that states high ECI would lead to high energy demand, thus, high pressure on the environment. However, Ahmed (2019) states that high human capital would lead to high ECI, but since high human capital is linked to a low ecological footprint, therefore, high ECI and human capital should be linked to a low ecological footprint. Our findings regarding the correlation between the ECI and ecological footprint and between education and ecological footprint contradict Ahmed's findings and illustrate that the higher the human capital and economic complexity, the higher the pressure on the environment. This again links to the fact that the trade-off between human development and environment and between economic development and environment may mean that environmental capabilities of the future will be reduced in the long run if socio-economic development is pursued.

However, that may not be the case as the non-linear regression model, Eqn 5.11, for economic complexity and ecological footprint per capita, follows the same pattern as the linear regression model in terms of the correlation strength and r-squared value (appendix I). As for the beta, the regressions for 2000 to 2006 have a negative ECI-squared, indicating that the regression fit is inverted-U shaped, shown by appendix I. However, the beta of ECI-squared become positive up until 2015, after which it started to get negative again. These findings suggest that there are time periods when the EKC hypothesis for ECI and ecological footprint can be rejected and time periods when the EKC hypothesis holds true. Neagu (2019) found out that EKC is valid and to some extent, so do the findings of this paper. Theoretically, this means that capabilities and sustainability can be achieved without harming the environment in the long run. However, the findings of this paper do not confirm that there is an inverted-U relationship between ECI and ecological footprint that is true for all periods of time. There is also a need to identify why the shape of the relationship between ECI and ecological footprint per capita changes and what causes that.

7. Conclusion

This paper conceptualized the sustainable development model by breaking it down and viewing it as a relationship between the three pillars of dimensions of sustainable development. These three dimensions consist of synergies and trade-offs. Using quantitative indicators as a proxy to represent each dimension of sustainable development. ECI for economic complexity, HDI for human development, and ecological footprint per capita for the environment. The findings illustrate that all three of them are positively correlated from the years 1995 to 2017.Further, the HDI was broken down into its components to investigate which factor of HDI has the most impact on the environment. The findings show that education impacts ecological footprint per capita more than life expectancy. ECI is also positively correlated with ecological footprint per capita, showing that complex economies have higher footprint.

The capability approach of Amartya Sen advocates that education and human development add to the choice and abilities of people. Additionally, the concept of economic complexity is centered around measuring more than GDP, stating that the higher capabilities and diverse, productive structure of the economy add to the economic complexity. This is clear from the findings that ECI and HDI are positively correlated. However, both factors, ECI and HDI, which relate to socio-economic development, have a trade-off with the environment, shown by their positive correlation with the ecological footprint per capita. Furthermore, this paper developed an EKC curve based on the development of ECI and HDI and their correlation with the environmental degradation based on ecological footprint. The results reject the existence of the EKC hypothesis for HDI and ecological footprint per capita, meaning that countries with higher human development do not have a lower ecological footprint. The EKC hypothesis for ECI and ecological footprint per capita is true but only for certain time periods. Therefore, further research is needed to develop insights into that and investigate why that happens.

This paper raises new questions, especially regarding investigating fluctuations in the regression correlations that come around the period of regression or the 2008 financial crisis. However, this research is limited by the scope of its methodology since advanced and more statistically rigorous methods can understand not only correlation but also casual relationships. Future research can focus on using advanced non-linear frameworks to add value to the understanding of the relationship between the three dimensions of sustainability. Turns out Uruguay is a special case of high HDI and low ecological footprint, therefore, case-study can reveal useful insights. Nevertheless, this research gives a comprehensive global cross-sectional overview of the correlation between environment, economy, and society. Additionally, it conceptualized a modified EKC curve that is more capability-oriented. This understanding can be used in policy implementation, and future research can develop an advanced understanding of sustainable development and lead the economy and society to a feasible path towards sustainability.

8. Bibliography

Ahmed, Z. and Wang, Z. (2019). Investigating the impact of human capital on the ecological footprint in India: an empirical analysis. *Environmental Science and Pollution Research*, 26(26), pp.26782-26796. Available at: doi: https://doi.org/10.1007/s11356-019-05911-7. [Accessed 14 April 2022].

Anyaehie, M.C. and Areji, A.C. (2015). Economic diversification for sustainable development in Nigeria. *Open journal of political science*, 5(02), pp.87-94. Availabe at: doi: 10.4236/ojps.2015.52010. [Accessed 15 April 2022].

Felipe, J., Kumar, U., Abdon, A. and Bacate, M. (2012). Product complexity and economic development. *Structural Change and Economic Dynamics*, 23(1): 36-68. Available at: doi: https://doi.org/10.1016/j.strueco.2011.08.003. [Accessed 21 April 2022].

Balland, P.A., Broekel, T., Diodato, D., Giuliani, E., Hausmann, R., O'Clery, N. and Rigby, D. (2022). The new paradigm of economic complexity. *Research Policy*, 51(3), p.104450. Available at: doi: https://doi.org/10.1016/j.respol.2021.104450. [Accessed 23 April 2022].

Barbier, E.B. (1987). The concept of sustainable economic development. *Environmental conservation*, 14(2), pp.101-110. Available at: doi: 10.1017/S0376892900011449. [Accessed 13 April 2022].

Benoit, K. (2011). Linear regression models with logarithmic transformations. London School of Economics, London, 22(1), pp.23-36. Available online: https://kenbenoit.net/assets/courses/ME104/logmodels2.pdf [Accessed 13 May 2022].

Can, M. and Gozgor, G. (2017). The impact of economic complexity on carbon emissions: evidence from France. *Environmental Science and Pollution Research*, 24(19), pp.16364-16370. Available at: doi: 10.1007/s11356-017-9219-7. [Accessed 13 April 2022].

Charfeddine, L. and Mrabet, Z. (2017). The impact of economic development and social-political factors on ecological footprint: A panel data analysis for 15 MENA countries. *Renewable and sustainable energy reviews*, 76, pp.138-154. Available at: doi: 10.1016/j.rser.2017.03.031. [Accessed 14 April 2022].

Costantini, V. and Monni, S. (2008). Environment, human development and economic growth. *Ecological Economics*, 64(4), pp.867-880. Available at: doi: https://doi.org/10.1016/j.ecolecon.2007.05.011. [Accessed 5 May 2022].

Danish, Hassan, S.T., Baloch, M.A., Mahmood, N. and Zhang, J. (2019). Linking economic growth and ecological footprint through human capital and biocapacity. *Sustainable Cities and Society*, 47, p.101516. Available at: doi: 10.1016/J.SCS.2019.101516. [Accessed 10 May 2022].

Farhani, S., Mrizak, S., Chaibi, A. and Rault, C. (2014). The environmental Kuznets curve and sustainability: A panel data analysis. *Energy Policy*, 71, pp.189-198. Available at: doi: 10.1016/j.enpol.2014.04.030. [Accessed 21 April 2022].

Florides, G.A. and Christodoulides, P., (2009). Global warming and carbon dioxide through sciences. *Environment international*, 35(2), pp.390-401. Available at: doi: 10.1016/j.envint.2008.07.007. [Accessed 16 April 2022].

Harris, R. (2010). Life expectancy and ecological footprint: societal sustainability and health equity. *The International Journal of Environmental, Cultural, Economic and Social Sustainability*, 6(2), pp.187-199. Available at: doi: 10.18848/1832-2077/CGP/v06i04/54811. [Accessed 21 April 2022]

Hassan, S.T., Xia, E., Khan, N.H. and Shah, S.M.A. (2018). Economic growth, natural resources, and ecological footprints: evidence from Pakistan. *Environmental Science and Pollution Research*, 26(3), pp.2929-2938. Available at: doi: 10.1007/s11356-018-3803-3. [Accessed 10 May 2022].

Hidalgo, C.A. and Hausmann, R. (2009). The building blocks of economic complexity. *Proceedings of the national academy of sciences*, 106(26), pp.10570-10575. Available at: doi: https://doi.org/10.1073/pnas.0900943106. [Accessed 18 April 2022].

Jha, R. and Murthy, K.B. (2003). An inverse global environmental Kuznets curve. *Journal of Comparative Economics*, 31(2), pp.352-368. Available at: doi: 10.1016/S0147-5967(03)00042-8. [Accessed 15 April 2022].

Kassouri, Y. and Altıntaş, H. (2020). Human well-being versus ecological footprint in MENA countries: a trade-off?. *Journal of environmental management*, 263, p.110405. Available at: doi: 10.1016/j.jenvman.2020.110405. [Accessed 19 April 2022].

Khan, S. and Yahong, W. (2021). Income inequality, ecological footprint, and carbon dioxide emissions in Asian developing economies: what effects what and how?. *Environmental Science and Pollution Research*, pp.1-12. Available at: doi: 10.1007/s11356-021-17582-4. [Accessed 22 April 2022].

Khan, S., Yahong, W. and Chandio, A.A. (2022). How does economic complexity affect ecological footprint in G-7 economies: the role of renewable and non-renewable energy consumptions and testing EKC hypothesis. *Environmental Science and Pollution Research*, pp.1-14. Available at: doi: 10.1007/s11356-022-19094-1. [Accessed 2 May 2022].

Kosifakis, G., Kampas, A. and Papadas, C.T., 2020. Economic complexity and the environment: some estimates on their links. *International Journal of Sustainable Agricultural Management and Informatics*, 6(3), pp.261-271. Available at: doi: 10.1504/IJSAMI.2020.10034330. [Accessed 13 April 2022].

Kroll, C., Warchold, A. and Pradhan, P. (2019). Sustainable Development Goals (SDGs): Are we successful in turning trade-offs into synergies?. Palgrave Communications, 5(1), pp.1-11. Available at: doi: 10.1057/s41599-019-0335-5. [Accessed 19 April 2022].

Lapatinas, A., 2016. Economic complexity and human development: A note. *Economics Bulletin*, 36(3), pp.1441-1452. Available at: https://ideas.repec.org/a/ebl/ecbull/eb-16-00323.html. [Accessed 30 April 2022].

Le Caous, E. and Huarng, F. (2020). Economic complexity and the mediating effects of income inequality: Reaching sustainable development in developing countries. *Sustainability*, 12(5), p.2089. Available at: doi: https://doi.org/10.3390/su12052089. [Accessed 29 April 2022].

Long, X., Yu, H., Sun, M., Wang, X.C., Klemeš, J.J., Xie, W., Wang, C., Li, W. and Wang, Y. (2020). Sustainability evaluation based on the Three-dimensional Ecological Footprint and Human Development Index: A case study on the four island regions in China. *Journal of Environmental Management*, 265, p.110509. Available at: doi: 10.1016/j.jenvman.2020.110509. [Accessed 21 April 2022].

Mann, M.E. (2009). Do global warming and climate change represent a serious threat to our welfare and environment?. *Social Philosophy and Policy*, 26(2), pp.193-230. Available at: doi: https://doi.org/10.1017/S0265052509090220. [Accessed 18 April 2022].

Mincer, J. (1984). Human capital and economic growth. *Economics of education review*, 3(3), pp.195-205. Available at: doi: https://doi.org/10.1016/0272-7757(84)90032-3. [Accessed 10 May 2022].

Moran, D.D., Wackernagel, M., Kitzes, J.A., Goldfinger, S.H. and Boutaud, A. (2008). Measuring sustainable development—Nation by nation. *Ecological economics*, 64(3), pp.470-474. Available at: doi: 10.1016/j.ecolecon.2007.08.017. [Accessed 20 April 2022].

Nathaniel, S.P. (2021). Economic complexity versus ecological footprint in the era of globalization: evidence from ASEAN countries. *Environmental Science and Pollution Research*, 28(45), pp.64871-64881. Available at: doi: 10.1007/s11356-021-15360-w. [Accessed 21 April 2022].

Neagu, O. (2020). Economic complexity and ecological footprint: Evidence from the most complex economies in the world. *Sustainability*, 12(21), p.9031. Available at: doi: https://doi.org/10.3390/su12219031. [Accessed 22 April 2022].

Neagu, O. (2019). The link between economic complexity and carbon emissions in the European Union countries: a model based on the Environmental Kuznets Curve (EKC) approach. *Sustainability*, 11(17), p.4753. Available at: doi: https://doi.org/10.3390/su11174753. [Accessed 2 May 2022].

Parris, T.M. and Kates, R.W. (2003). Characterizing and measuring sustainable development. *Annual Review of environment and resources*, 28(1), pp.559-586. Available at: doi: https://doi.org/10.1146/annurev.energy.28.050302.105551. [Accessed 29 April 2022].

Pata, U.K. (2020). Renewable and non-renewable energy consumption, economic complexity, CO2 emissions, and ecological footprint in the USA: testing the EKC hypothesis with a structural break. *Environmental Science and Pollution Research*, 28(1), pp.846-861. Available at: doi: 10.1007/s11356-020-10446-3. [Accessed 5 May 2022].

Soubbotina, T.P. (2004). Beyond economic growth: An introduction to sustainable development. World Bank Publications. Available at: http://hdl.handle.net/10986/14865. [Accessed 22 April 2022].

Soyyigit, S., Ercan, E.R.E.N. and Elife, A.K.İ.S., 2019. Investigation of the relationship between economic complexity level and human development level: Comparison of developed and developing countries. *Journal of Management Marketing and Logistics*, 6(3), pp.162-174. Available at: doi: https://doi.org/10.17261/Pressacademia.2019.1129. [Accessed 17 April 2022].

Stern, D.I. (2004). The rise and fall of the environmental Kuznets curve. *World development*, 32(8), pp.1419-1439. Available at: doi: https://doi.org/10.1016/j.worlddev.2004.03.004. [Accessed 13 May April 2022].

Stojkoski, V. and Kocarev, L. (2017). The relationship between growth and economic complexity: evidence from Southeastern and Central Europe. Available at: https://mpra.ub.uni-muenchen.de/id/eprint/87432. [Accessed 24 April 2022].

Toth, G. and Szigeti, C. (2016). The historical ecological footprint: From over-population to over-consumption. *Ecological Indicators*, 60, pp.283-291. Available at: doi: 10.1016/j.ecolind.2015.06.040. [Accessed 19 April 2022].

Yandle, B., Vijayaraghavan, M. and Bhattarai, M., 2002. The environmental Kuznets curve. A Primer, PERC Research Study, pp.02-01. Available at: https://www.perc.org/wp-content/uploads/2018/05/environmental-kuznets-curve-primer.pdf. [Accessed 24 April 2022].

Yilanci, V. and Pata, U.K. (2020). Investigating the EKC hypothesis for China: the role of economic complexity on ecological footprint. *Environmental Science and Pollution Research*, 27(26), pp.32683-32694. Available at: doi: https://doi.org/10.1007/s11356-020-09434-4. [Accessed 25 April 2022].

Books

Buchanan, J.M. (1991). Opportunity cost. In The world of economics (pp. 520-525). Palgrave Macmillan, London. DOI: https://doi.org/10.1007/978-1-349-21315-3_69. [Accessed 5 May 2022].

Collier, P. (2007). The bottom billion. ECONOMIC REVIEW-DEDDINGTON-, 25(1), p.17.

Hesse, H. (2009). Export diversification and economic growth. Breaking into new markets: Emerging lessons for export diversification, 2009, pp.55-80.

MacDermott, R.J., Basuchoudhary, A. and Beng, J. (2019). Trade, Trade Agreements, and the Environment.

Montgomery, D.C., Peck, E.A. and Vining, G.G. (2021). Introduction to linear regression analysis. John Wiley & Sons.

Rogers, P.P., Jalal, K.F. and Boyd, J.A. (2012). An introduction to sustainable development. Routledge.

Sen, A. (1999). Commodities and capabilities. OUP Catalogue.

Solow, R.M. (1991). Sustainability: an economist's perspective.

Ul Haq, M. (1995). Reflections on human development. Oxford university Press.

Wackernagel, M. and Rees, W. (1998). Our ecological footprint: reducing human impact on the earth (Vol. 9). New society publishers.

Wood, Michael. (2012). BOOTSTRAPPING CONFIDENCE LEVELS FOR HYPOTHESES ABOUT QUADRATIC (U-SHAPED) REGRESSION MODELS. University of Portsmouth Business School. Available at: https://arxiv.org/pdf/0912.3880.pdf#:~:text=For%20an%20inverted%20U%20shape,%3E0.1%20in%20both%20cases). [Accessed 4 May 2020]

Other

Brundtland, G. (1987). Report of the World Commission on Environment and Development: Our Common Future. United Nations General Assembly document A/42/427. Available at: https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf.

Data.footprintnetwork.org. (2022). Open Data Platform. [online] Available at: https://data.footprintnetwork.org/?_ga=2.148119989.320937507.1650131354-1259033390.1645820732#/countryTrends?cn=5001&type=BCtot [Accessed 17 Apr. 2022].

Footprintnetwork.org. (2022). Available at: www.footprintnetwork.org [Accessed 16 April 2022].

United Nations Association – UK (2019). Sustainable Development Goals: Transforming our World. [online] Available at: http://e18ae03e1260dd9ded72-d7e6b827052477908ce254f8898d3b2d.r17.cf2.rackcdn.com/SDGs%20Transforming%20our%20world.pdf [Accessed 2 May April 2022].

United Nation Development Programme (2020). The Next Frontier: Human Development and the Anthropocene. Human Development Report 2020. [online] Available at: https://hdr.undp.org/sites/default/files/hdr2020.pdf [Accessed 17 April 2022].

World Bank. (2020). "GDP (current US$)" World Development Indicators. [online] Available at: https://databank.worldbank.org/reports.aspx?source=2&series=NY.GDP.MKTP.CD&country=#. [Accessed 17 April 2022].

9. Appendices

Appendix A

VIF analysis summary									
Year	R^2 EDU	VIF	R^2 LE	VIF LE	R^2 Income	VIF Income	Multicollinearity EDU	Multicollinearity LE	Multicollinearity Income
1995	0,65	2,90	0,75	3,98	0,75	3,96	Non problematic	Non problematic	Non problematic
1996	0,65	2,87	0,74	3,90	0,75	3,97	Non problematic	Non problematic	Non problematic
1997	0,66	2,91	0,73	3,69	0,75	3,95	Non problematic	Non problematic	Non problematic
1998	0,66	2,91	0,72	3,58	0,75	3,93	Non problematic	Non problematic	Non problematic
1999	0,66	2,92	0,72	3,52	0,75	4,01	Non problematic	Non problematic	Non problematic
2000	0,66	2,95	0,71	3,50	0,76	4,17	Non problematic	Non problematic	Non problematic
2001	0,67	3,03	0,71	3,43	0,76	4,23	Non problematic	Non problematic	Non problematic
2002	0,67	3,04	0,71	3,43	0,77	4,36	Non problematic	Non problematic	Non problematic
2003	0,67	3,07	0,71	3,40	0,77	4,41	Non problematic	Non problematic	Non problematic
2004	0,69	3,18	0,71	3,44	0,78	4,60	Non problematic	Non problematic	Non problematic
2005	0,69	3,23	0,71	3,47	0,79	4,69	Non problematic	Non problematic	Non problematic

2006	0,69	3,24	0,72	3,56	0,79	4,86	Non problematic	Non problematic	Non problematic
2007	0,70	3,31	0,73	3,67	0,80	5,00	Non problematic	Non problematic	Non problematic
2008	0,70	3,29	0,74	3,82	0,81	5,20	Non problematic	Non problematic	Problematic
2009	0,70	3,33	0,74	3,82	0,80	5,01	Non problematic	Non problematic	Problematic
2010	0,71	3,40	0,75	3,94	0,80	5,12	Non problematic	Non problematic	Problematic
2011	0,74	3,85	0,76	4,21	0,82	5,71	Non problematic	Non problematic	Problematic
2012	0,75	3,95	0,76	4,13	0,81	5,34	Non problematic	Non problematic	Problematic
2013	0,76	4,13	0,77	4,31	0,83	5,78	Non problematic	Non problematic	Problematic
2014	0,77	4,39	0,78	4,47	0,83	6,05	Non problematic	Non problematic	Problematic
2015	0,79	4,73	0,78	4,48	0,84	6,36	Non problematic	Non problematic	Problematic
2016	0,80	4,93	0,78	4,54	0,85	6,60	Non problematic	Non problematic	Problematic
2017	0,80	4,96	0,78	4,58	0,85	6,61	Non problematic	Non problematic	Problematic

Appendix B

Regression analysis summary ECI and HDI						
Year	Alpha(a)	Beta ECI			Significance F	Significant or not?
1995	0.63	0.13	Correlation Coefficient (Multiple R)	Coefficient of Determination (R-square)	4.26E-22	Yes
1996	0.63	0.13	0.8	65%	1.00E-22	Yes
1997	0.64	0.12	0.8	64%	1.79E-19	Yes
1998	0.65	0.13	0.78	61%	3.90E-22	Yes
1999	0.65	0.13	0.8	65%	7.10E-22	Yes
2000	0.65	0.13	0.8	64%	4.40E-21	Yes
2001	0.66	0.13	0.8	63%	1.19E-23	Yes
2002	0.67	0.13	0.8	64%	1.58E-23	Yes
2003	0.67	0.13	0.82	67%	9.39E-23	Yes
2004	0.68	0.13	0.81	66%	1.72E-23	Yes
2005	0.68	0.13	0.81	65%	3.66E-24	Yes
2006	0.69	0.13	0.81	66%	7.52E-22	Yes
2007	0.7	0.12	0.8	64%	1.44E-17	Yes
2008	0.7	0.11	0.76	58%	5.68E-15	Yes
2009	0.71	0.11	0.73	53%	7.90E-18	Yes
2010	0.71	0.11	0.76	58%	1.06E-19	Yes
2011	0.72	0.11	0.78	61%	1.19E-16	Yes
2012	0.72	0.11	0.75	56%	1.45E-16	Yes
2013	0.73	0.11	0.75	56%	4.03E-18	Yes
2014	0.73	0.11	0.76	58%	3.97E-18	Yes
2015	0.74	0.11	0.76	59%	1.23E-17	Yes
2016	0.74	0.11	0.76	58%	8.88E-20	Yes
2017	0.74	0.11	0.78	61%	6.94E-20	Yes
Mean	0.69	0.12	0.78	61%	2.60E-16	Yes

Appendix C

Regression analysis summary Ln(EFPC) and HDI							
Year	Alpha(a)	Beta	Unlogged Beta	Correlation Coefficient (Multiple R)	Coefficient of Determination (R-square)	Significance F	Significant or not?
1995	-1,65	4,03	56,37	0,85	72%	1.34E-27	Yes
1996	-1,68	4,05	57,68	0,85	73%	1.34E-28	Yes
1997	-1,72	4,08	58,86	0,85	73%	1.56E-28	Yes
1998	-1,67	3,98	53,49	0,86	74%	4.22E-29	Yes
1999	-1,65	3,91	49,84	0,85	72%	3.62E-30	Yes
2000	-1,73	4,00	54,85	0,86	74%	4.21E-29	Yes
2001	-1,76	4,03	56,49	0,86	74%	1.55E-30	Yes
2002	-1,76	4,03	56,07	0,86	74%	8.71E-30	Yes
2003	-1,76	4,02	55,68	0,86	74%	2.67E-29	Yes
2004	-1,82	4,09	59,90	0,86	74%	9.07E-30	Yes
2005	-1,82	4,09	59,79	0,87	75%	1.69E-30	Yes
2006	-1,82	4,07	58,32	0,86	74%	8.94E-31	Yes
2007	-1,86	4,11	61,11	0,86	75%	3.55E-30	Yes
2008	-1,93	4,18	65,33	0,86	75%	4.54E-30	Yes
2009	-1,81	3,92	50,59	0,84	71%	4.74E-27	Yes
2010	-1,89	4,05	57,57	0,86	74%	1.55E-29	Yes
2011	-1,91	4,05	57,43	0,87	75%	1.14E-30	Yes
2012	-1,87	3,94	51,34	0,86	74%	3.22E-29	Yes
2013	-1,88	3,93	50,84	0,86	73%	5.48E-29	Yes
2014	-1,86	3,88	48,18	0,85	71%	2.65E-27	Yes
2015	-1,93	3,94	51,52	0,85	73%	1.98E-28	Yes
2016	-1,97	3,96	52,27	0,85	72%	1.48E-27	Yes
2017	-2,02	4,03	56,23	0,85	72%	1.32E-27	Yes
Mean	-1,82	4,02	55,64	0,86	0,73	0,00	

Appendix D

Regression analysis summary Ln(EFPC). Edu Index and LE index

Year	Alpha(a)	Beta Edu	Unlogged Beta Edu	Beta LE	Unlogged Beta LE	Correlation Coefficient (Multiple R)	Coefficient of Determination (R-square)	Significance F	Significant or not?
1995	-1.5	2.24	9.4	1.66	5.24	0.79	62%	1.34E-27	Yes
1996	-1.55	2.22	9.18	1.73	5.62	0.8	64%	1.34E-28	Yes
1997	-1.51	2.43	11.31	1.47	4.35	0.8	64%	1.56E-28	Yes
1998	-1.45	2.33	10.28	1.44	4.24	0.8	64%	4.22E-29	Yes
1999	-1.5	2.16	8.67	1.58	4.88	0.79	63%	3.62E-30	Yes
2000	-1.54	2.32	10.19	1.49	4.46	0.8	63%	4.21E-29	Yes
2001	-1.52	2.47	11.88	1.34	3.81	0.8	64%	1.55E-30	Yes
2002	-1.54	2.46	11.68	1.36	3.89	0.8	64%	8.71E-30	Yes
2003	-1.51	2.51	12.35	1.27	3.56	0.8	64%	2.67E-29	Yes
2004	-1.54	2.62	13.76	1.22	3.37	0.81	65%	9.07E-30	Yes
2005	-1.58	2.58	13.22	1.28	3.58	0.81	65%	1.69E-30	Yes
2006	-1.57	2.59	13.3	1.25	3.49	0.8	64%	8.94E-31	Yes
2007	-1.64	2.56	12.93	1.36	3.88	0.81	65%	3.55E-30	Yes
2008	-1.74	2.54	12.64	1.46	4.33	0.81	65%	4.54E-30	Yes
2009	-1.64	2.25	9.53	1.48	4.41	0.78	61%	4.74E-27	Yes
2010	-1.76	2.32	10.17	1.58	4.87	0.8	64%	1.55E-29	Yes
2011	-1.69	2.55	12.82	1.29	3.62	0.81	66%	1.14E-30	Yes
2012	-1.61	2.57	13.1	1.11	3.04	0.81	65%	3.22E-29	Yes
2013	-1.59	2.62	13.7	1.02	2.77	0.81	65%	5.48E-29	Yes
2014	-1.55	2.58	13.2	0.97	2.64	0.79	63%	2.65E-27	Yes
2015	-1.64	2.65	14.09	1	2.72	0.8	65%	1.98E-28	Yes
2016	-1.66	2.7	14.88	0.95	2.59	0.8	64%	1.48E-27	Yes
2017	-1.72	2.74	15.52	1	2.71	0.8	64%	1.32E-27	Yes
Mean	-1.59	2.48	12.08	1.32	3.83	0.8	0.64	0.00	

Appendix E

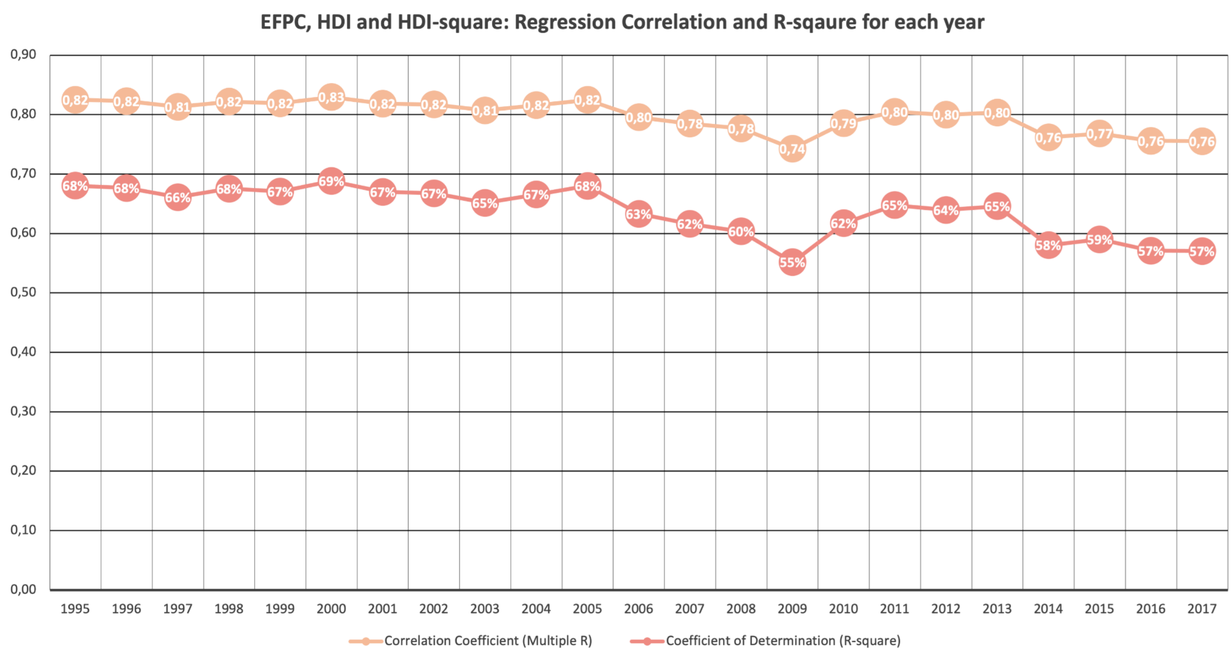

Fig 6.11 - EFPC, HDI and HDI-square: Regression Correlation and R-square for each year

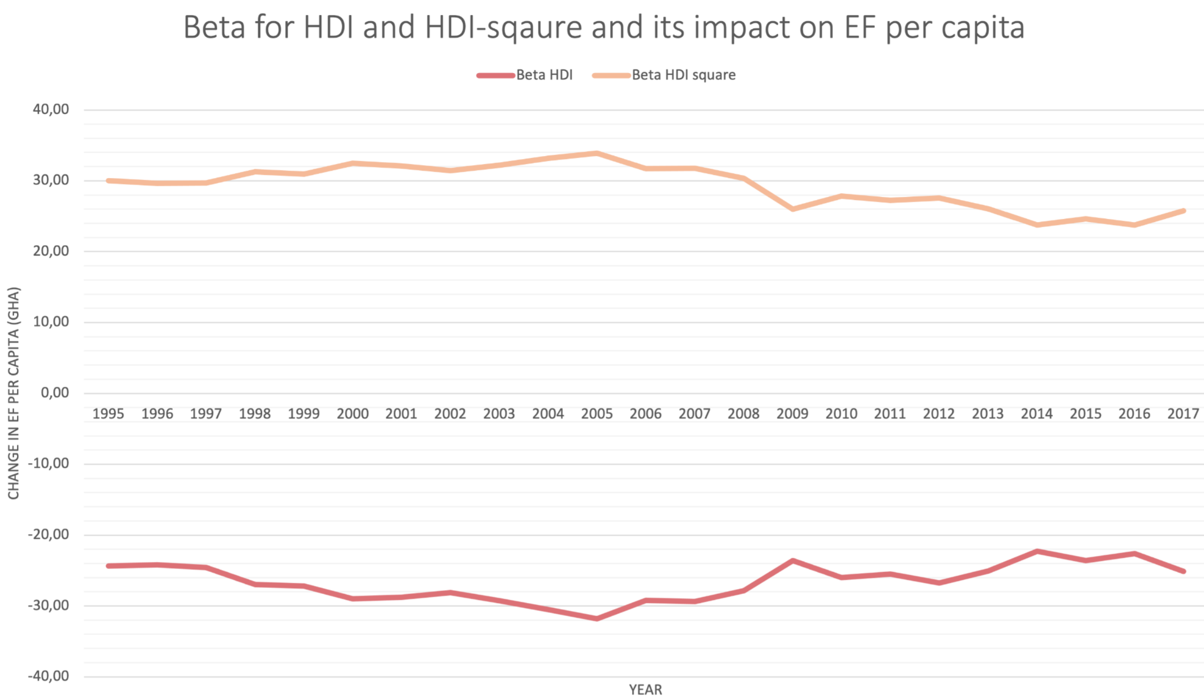

Fig 6.12 - Beta for HDI and HDI-square and its impact on EF per capita

Nonlinear regression: EFPC. HDI and HDI-square							
Year	Alpha(a)	Beta HDI	Beta HDI square	Correlation Coefficient (Multiple R)	Coefficient of Determination (R-square)	Significance F	Significant or not?
1995	5.87	-24.36	30.04	0.82	68%	3.11E-24	Yes
1996	5.86	-24.17	29.65	0.82	68%	6.23E-23	Yes
1997	6.01	-24.57	29.72	0.81	66%	8.31E-22	Yes
1998	6.78	-26.95	31.25	0.82	68%	7.59E-23	Yes
1999	6.96	-27.17	30.93	0.82	67%	1.70E-22	Yes
2000	7.43	-28.99	32.45	0.83	69%	8.19E-25	Yes
2001	7.41	-28.75	32.11	0.82	67%	1.89E-22	Yes
2002	7.28	-28.13	31.45	0.82	67%	2.87E-22	Yes
2003	7.65	-29.27	32.21	0.81	65%	3.79E-21	Yes
2004	8.02	-30.52	33.19	0.82	67%	4.03E-22	Yes
2005	8.49	-31.8	33.91	0.82	68%	3.24E-23	Yes
2006	7.79	-29.23	31.69	0.8	63%	6.98E-20	Yes

2007	7.85	-29.38	31.76	0.78	62%	8.51E-19	Yes
2008	7.44	-27.83	30.32	0.78	60%	5.05E-18	Yes
2009	6.45	-23.59	25.98	0.74	55%	4.56E-15	Yes
2010	7.16	-25.97	27.86	0.79	62%	7.11E-19	Yes
2011	7.07	-25.5	27.25	0.8	65%	7.25E-21	Yes
2012	7.62	-26.74	27.57	0.8	64%	2.52E-21	Yes
2013	7.17	-25.08	26.07	0.8	65%	9.66E-22	Yes
2014	6.34	-22.27	23.77	0.76	58%	1.19E-16	Yes
2015	6.76	-23.57	24.6	0.77	59%	3.18E-17	Yes
2016	6.48	-22.64	23.78	0.76	57%	3.91E-17	Yes
2017	7.22	-25.12	25.78	0.76	57%	4.21E-16	Yes
Mean	7.09	-26.59	29.28	0.80	64%	0	

Appendix F

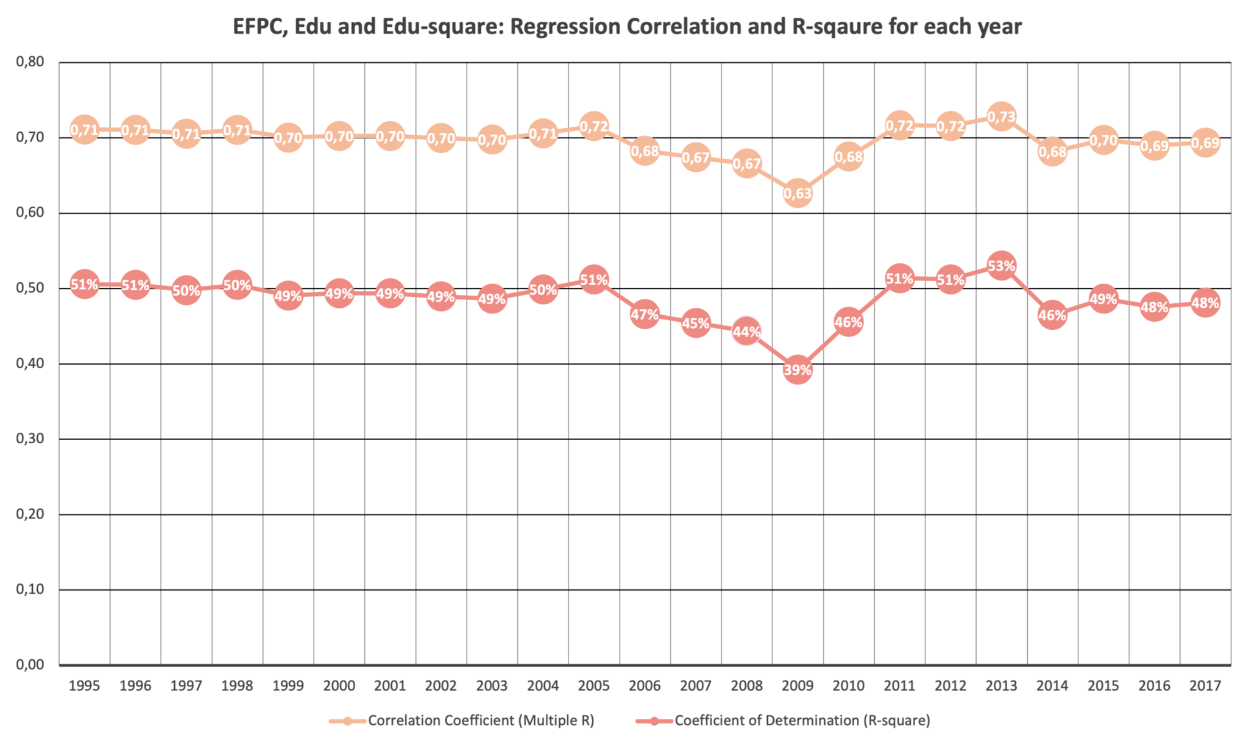

Fig 6.7 - EFPC, Edu and Edu-square: Regression Correlation and R-square for each year

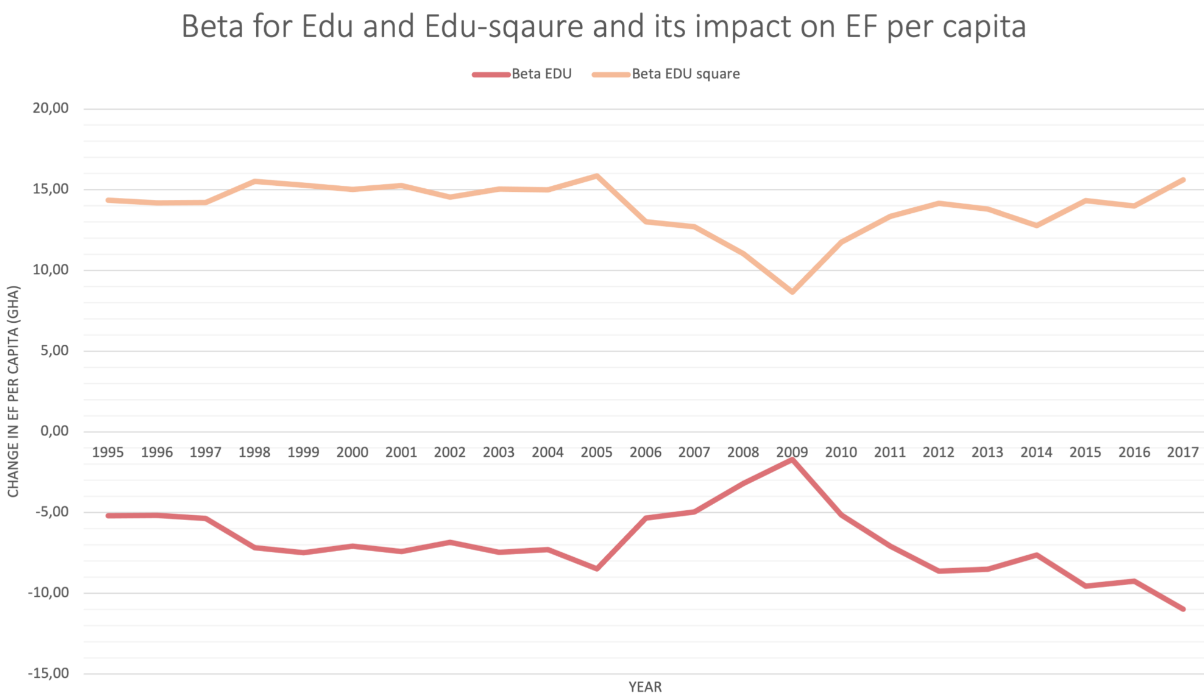

Fig 6.8 - Beta for Edu and Edu-square and its impact on EF per capita

Nonlinear regression: EFPC. Edu and Edu-square							
Year	Alpha(a)	Beta EDU	Beta EDU square	Correlation Coefficient (Multiple R)	Coefficient of Determination (R-square)	Significance F	Significant or not?
1995	1.48	-5.19	14.35	0.71	51%	1.02E-12	Yes
1996	1.46	-5.18	14.19	0.71	51%	1.11E-12	Yes
1997	1.47	-5.35	14.21	0.71	50%	2.47E-12	Yes
1998	1.93	-7.18	15.51	0.71	50%	1.13E-12	Yes
1999	2.04	-7.48	15.28	0.7	49%	5.42E-12	Yes
2000	1.88	-7.09	15.03	0.7	49%	3.93E-12	Yes
2001	1.95	-7.42	15.26	0.7	49%	4.00E-12	Yes
2002	1.84	-6.83	14.54	0.7	49%	6.23E-13	Yes
2003	1.99	-7.47	15.05	0.7	49%	8.43E-12	Yes
2004	1.91	-7.3	14.99	0.71	50%	2.25E-12	Yes
2005	2.23	-8.48	15.87	0.72	51%	5.02E-13	Yes

2006	1.45	-5.35	13.01	0.68	47%	7.44E-11	Yes
2007	1.32	-4.95	12.71	0.67	45%	2.46E-10	Yes
2008	0.85	-3.19	11.03	0.67	44%	7.60E-10	Yes
2009	0.64	-1.7	8.66	0.63	39%	9.65E-08	Yes
2010	1.5	-5.14	11.75	0.68	46%	2.16E-10	Yes
2011	1.96	-7.09	13.34	0.72	51%	4.10E-13	Yes
2012	2.44	-8.64	14.17	0.72	51%	4.91E-13	Yes
2013	2.45	-8.52	13.8	0.73	53%	5.81E-14	Yes
2014	2.29	-7.63	12.77	0.68	46%	8.47E-11	Yes
2015	2.77	-9.57	14.33	0.7	49%	8.67E-12	Yes
2016	2.66	-9.24	14	0.69	48%	2.76E-11	Yes
2017	3.09	-10.97	15.62	0.69	48%	1.51E-11	Yes
Mean	1.90	-6.82	13.89	0.70	0.48	0.00	

Appendix G

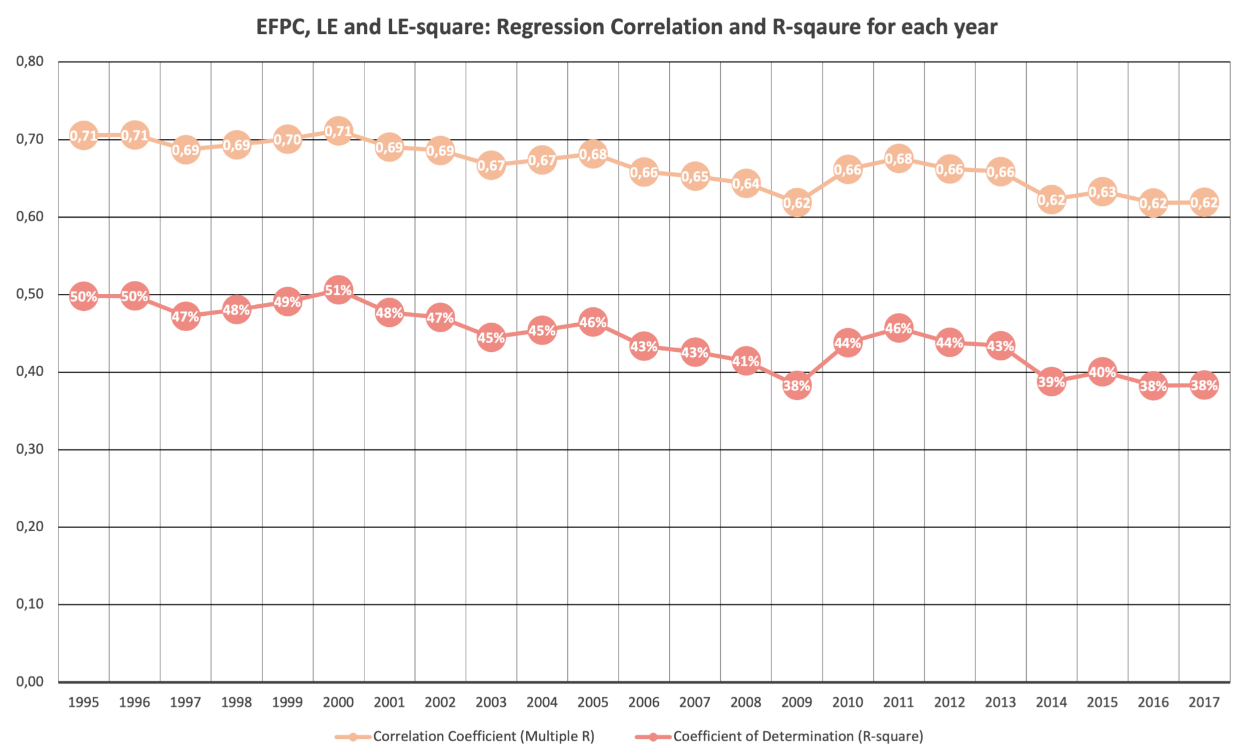

Fig 6.9 - EFPC, LE and LE-square: Regression Correlation and R-square for each year

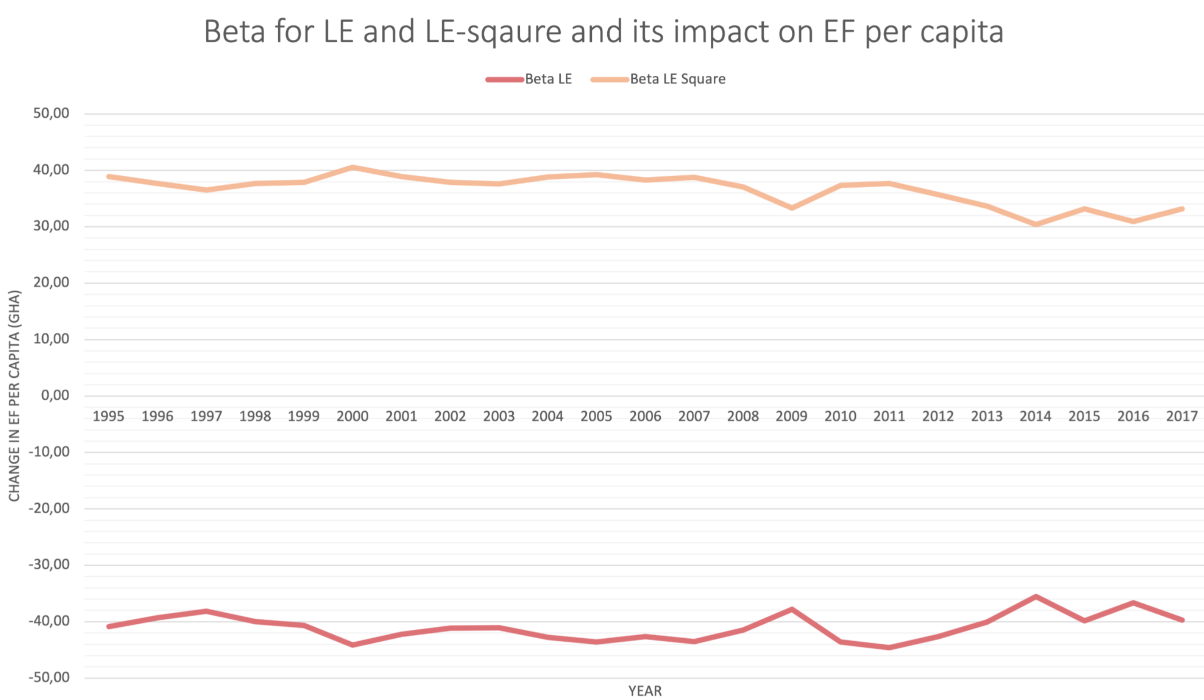

Fig 6.10 - Beta for LE and LE-square and its impact on EF per capita

Nonlinear regression: EFPC. LE and LE-square							
Year	Alpha(a)	Beta LE	Beta LE Square	Correlation Coefficient (Multiple R)	Coefficient of Determination (R-square)	Significance F	Significant or not?
1995	11.63	-40.86	38.87	0.71	50%	2.44E-12	Yes
1996	11.12	-39.29	37.65	0.71	50%	2.34E-12	Yes
1997	10.83	-38.12	36.52	0.69	47%	3.97E-11	Yes
1998	11.5	-40	37.67	0.69	48%	1.60E-11	Yes
1999	11.76	-40.65	37.89	0.7	49%	5.28E-12	Yes
2000	12.82	-44.12	40.51	0.71	51%	9.78E-13	Yes
2001	12.33	-42.25	38.92	0.69	48%	2.42E-11	Yes
2002	12.08	-41.13	37.87	0.69	47%	4.58E-11	Yes
2003	12.17	-41.05	37.6	0.67	45%	6.39E-10	Yes

2004	12.77	-42.78	38.85	0.67	45%	2.52E-11	Yes
2005	13.14	-43.58	39.21	0.68	46%	8.54E-12	Yes
2006	13.01	-42.66	38.26	0.66	43%	2.00E-09	Yes
2007	13.36	-43.5	38.77	0.65	43%	4.17E-09	Yes
2008	12.81	-41.51	37.06	0.64	41%	1.25E-08	Yes
2009	12	-37.83	33.3	0.62	38%	2.30E-07	Yes
2010	14.01	-43.62	37.34	0.66	44%	1.28E-10	Yes
2011	14.53	-44.59	37.64	0.68	46%	1.94E-10	Yes
2012	14.09	-42.65	35.67	0.66	44%	1.23E-09	Yes
2013	13.29	-40.07	33.64	0.66	43%	1.87E-09	Yes
2014	11.71	-35.51	30.41	0.62	39%	1.50E-07	Yes
2015	13.32	-39.88	33.19	0.63	40%	4.54E-08	Yes
2016	12.14	-36.64	30.94	0.62	38%	2.38E-07	Yes
2017	13.17	-39.73	33.18	0.62	38%	2.21E-08	Yes
Mean	12.59	-40.96	36.56	0.67	44%	0	

Appendix H

Regression analysis summary Ln(EFPC) and ECI							
Year	Alpha(a)	Beta	Unlogged Beta ECI	Correlation Coefficient (Multiple R)	Coefficient of Determination (R-square)	Significance F	Significant or not?
1995	0.88	0.53	1.7	0.71	51%	6.69E-14	Yes
1996	0.89	0.54	1.71	0.72	51%	3.23E-14	Yes
1997	0.89	0.51	1.67	0.68	47%	4.56E-12	Yes
1998	0.9	0.52	1.67	0.71	51%	8.06E-14	Yes
1999	0.89	0.51	1.66	0.71	50%	1.70E-13	Yes
2000	0.89	0.52	1.69	0.71	50%	8.53E-14	Yes
2001	0.9	0.53	1.7	0.72	51%	3.62E-14	Yes
2002	0.92	0.52	1.69	0.72	52%	1.03E-14	Yes
2003	0.93	0.53	1.7	0.72	52%	9.05E-15	Yes
2004	0.96	0.52	1.69	0.71	50%	1.18E-13	Yes
2005	0.97	0.53	1.7	0.71	50%	8.96E-14	Yes
2006	0.99	0.5	1.65	0.67	46%	1.90E-11	Yes
2007	1.01	0.47	1.6	0.63	40%	5.79E-09	Yes

2008	1.02	0.43	1.54	0.58	33%	1.57E-06	Yes
2009	0.98	0.41	1.5	0.58	34%	1.51E-06	Yes
2010	1	0.43	1.54	0.63	39%	7.59E-09	Yes
2011	1	0.4	1.49	0.58	34%	8.26E-07	Yes
2012	0.98	0.39	1.48	0.59	35%	3.50E-07	Yes
2013	0.99	0.37	1.45	0.58	34%	1.17E-06	Yes
2014	0.98	0.38	1.46	0.58	33%	2.07E-06	Yes
2015	0.98	0.39	1.48	0.6	36%	1.20E-07	Yes
2016	0.97	0.4	1.49	0.62	38%	3.25E-08	Yes
2017	0.98	0.42	1.52	0.62	39%	1.18E-08	Yes
Mean	0.95	0.47	1.60	0.66	43%	0.00	

Appendix I

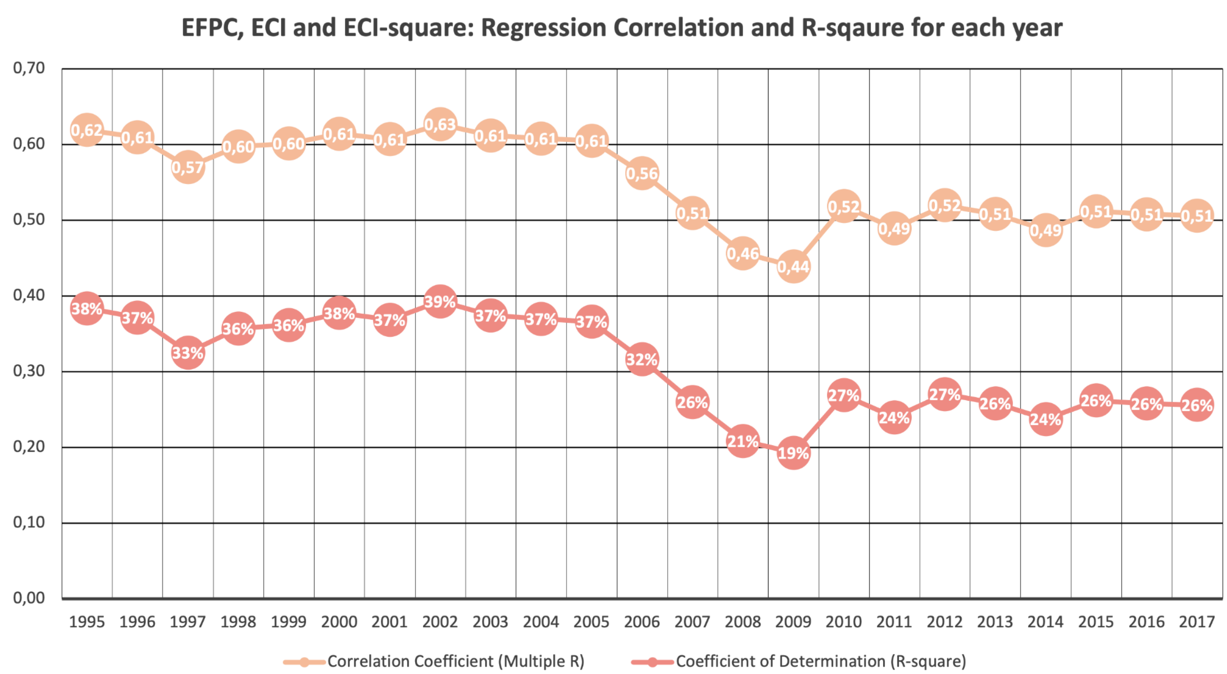

Fig 6.15 - EFPC. ECI and ECI-square: Regression Correlation and R-square for each year

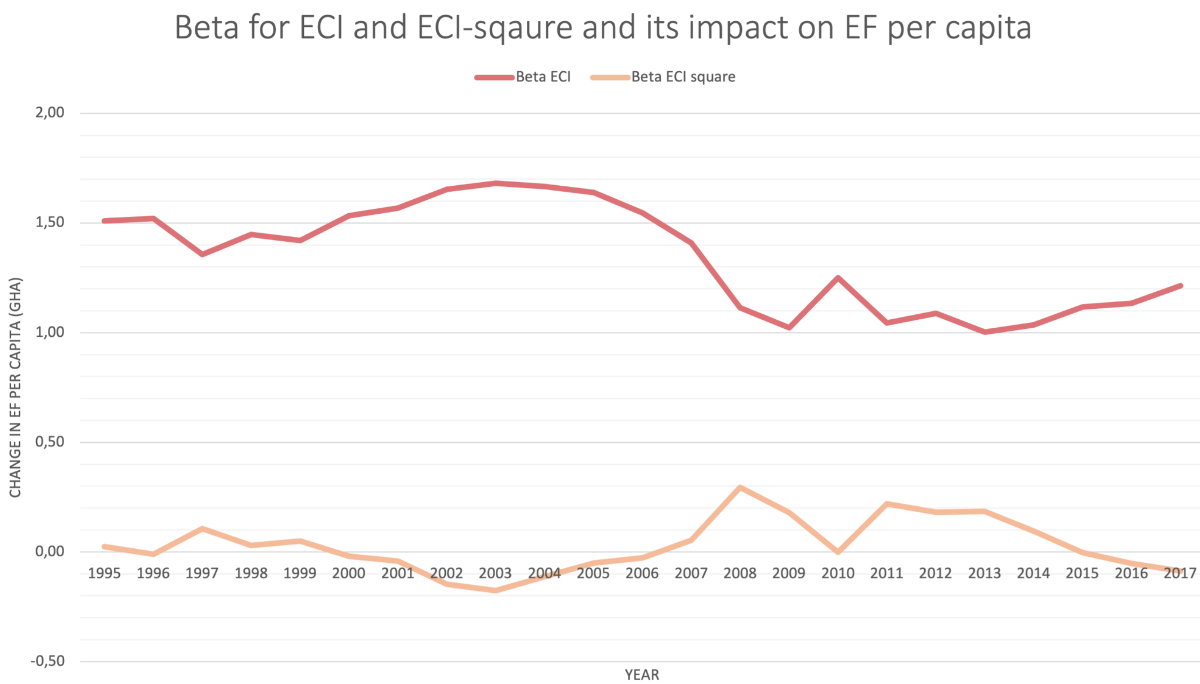

Fig 6.16 - Beta for ECI and ECI-square and its impact on EF per capita

Nonlinear regression: EFPC. ECI and ECI-square							
Year	Alpha(a)	Beta ECI	Beta ECI square	Correlation Coefficient (Multiple R)	Coefficient of Determination (R-square)	Significance F	Significant or not?
1995	3.17	1.51	0.02	0.62	38%	2.18E-07	Yes
1996	3.21	1.52	-0.01	0.61	37%	6.28E-07	Yes
1997	3.11	1.36	0.11	0.57	33%	3.26E-05	Yes
1998	3.19	1.45	0.03	0.6	36%	2.22E-07	Yes
1999	3.12	1.42	0.05	0.6	36%	1.51E-06	Yes
2000	3.21	1.53	-0.02	0.61	38%	3.72E-07	Yes
2001	3.29	1.57	-0.04	0.61	37%	8.29E-07	Yes
2002	3.44	1.65	-0.15	0.63	39%	9.37E-08	Yes
2003	3.51	1.68	-0.18	0.61	37%	4.85E-07	Yes
2004	3.54	1.67	-0.11	0.61	37%	7.43E-07	Yes
2005	3.49	1.64	-0.05	0.61	37%	1.03E-06	Yes
2006	3.53	1.55	-0.03	0.56	32%	6.81E-05	Yes
2007	3.54	1.41	0.05	0.51	26%	5.55E-03	Yes

2008	3.35	1.11	0.29	0.46	21%	2.32E-02	Yes
2009	3.22	1.02	0.18	0.44	19%	6.83E-01	Yes
2010	3.46	1.25	0	0.52	27%	2.81E-04	Yes
2011	3.23	1.05	0.22	0.49	24%	2.50E-02	Yes
2012	3.14	1.09	0.18	0.52	27%	2.54E-03	Yes
2013	3.13	1	0.18	0.51	26%	6.26E-03	Yes
2014	3.2	1.03	0.1	0.49	24%	2.96E-02	Yes
2015	3.29	1.12	0	0.51	26%	4.73E-03	Yes
2016	3.31	1.13	-0.05	0.51	26%	6.44E-03	Yes
2017	3.41	1.21	-0.09	0.51	26%	7.34E-03	Yes

Appendix J

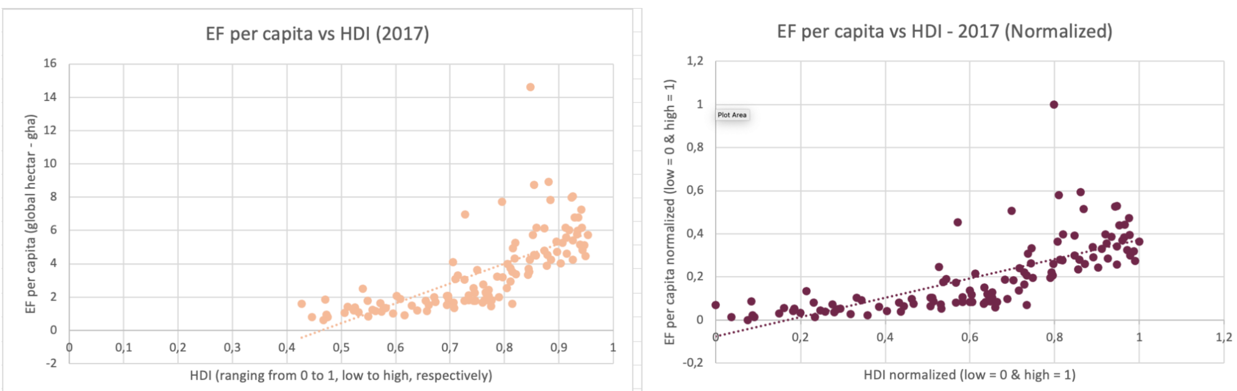

Fig 6.1 - Graphical representation of year 2017 - EF per capita vs HDI