IN SEARCH OF A LIMIT TO ANTHROPOGENIC IMPACTS ON ECOSYSTEMS: "FAIR USE" OF ENERGY

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ABSTRACT

IN SEARCH OF A LIMIT TO ANTHROPOGENIC IMPACTS ON ECOSYSTEMS: "FAIR USE" OF ENERGY

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The physical scale of material and energy throughput of human activity continues to threaten the critical natural boundaries of the ecosystem. Energy efficiency and decarbonization efforts are not alone sufficient to counterbalance the impacts of fast-growing demand due to population and economic growth. Further, efficiency improvements often come with rebound effects that offset achievements. In order to carry the human activities within safe boundaries, a limit to total throughput could be targeted. We need to increase human well-being without increasing energy consumption to the ecologically dangerous levels. This could partly be possible by technological efficiency improvements and conservation. On the other hand, it could also be achieved by re-distributing the total available energy resources in the society. In our study, we attempt to develop an approach for measuring a benchmark which may be used to identify excessive uses of energy that do not lead to significant increases in well-being. We call this the "fair energy use level", for the reason that it also refers to energy justice. We investigate decoupling between energy consumption and some quality of life indicators at the country level via cross-sectional analysis. Different from previous studies, we use residential energy consumption instead of primary energy consumption as it tends to mask the true responsibility of a country. In order for a fair comparison of countries' energy-wellbeing performances, we corrected energy consumption data for climatic differences and excluded energy-rich countries and biomass dependent countries to control for resource endowment and energy quality. Using the “knee” (maximum curvature) of the function we were able to compute the point after which well-being improvements are negligible. We find approximate levels of per capita energy consumption which could be considered as a boundary for “fair use” under certain conditions.

Keywords: Energy consumption, Ecological Economics, Energy Justice, Resouce cap

ÖZ

EKOSİSTEMLER ÜZERİNDEKİ ANTROPOJENİK ETKİLER İÇİN BİR SINIR ARAYIŞI: "ADİL ENERJİ KULLANIMI"

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İnsan kaynaklı enerji ve madde akışı hacmi ekosistemin kritik sınırlarını zorlamaya devam etmektedir. Enerji verimliliği ve dekarbonizasyon çabalarının, nüfus ve ekonomideki büyümeyle artan çevresel etkileri dengelemekte tek başına yetersiz kaldığı görülmektedir. Enerji verimliliğini artırması beklenen yeni gelişmeler, kazanımlarının yanında gelen geri-tepme (sekme) etkisi nedeniyle azaltım hedeflerine ulaşmada yeterince etkili olamamaktadır. Bu nedenle insan aktivitelerini güvenli ekosistem sınırlarının içinde devam ettirebilmek için, toplam kümülatif enerji akış hacmi için bir sınırlamaya gidilmesi gereği ortaya çıkıyor. Bu doğrultuda yapılması gereken refahı artırırken enerji kullanımını ekolojik olarak güvenli seviyelerde tutabilmek. Bu, enerji verimliliği ve tasarrufu ile yapılabileceği gibi, mevcut kaynakların yeniden adil dağıtımı ile de yapılabilir. Çalışmanın asıl amacı, bize bu adil olmayan kullanım seviyeleri konusunda fikir verebilecek referans noktaları bulabilmek. Bu referans seviyesi enerjide "adil kullanım seviyesi" olarak isimlendirmeyi tercih edildi. Ülkelerarası kesitsel bir çalışmayla, enerji kullanımı ve ülke refahını temsil eden bazı hayat kalitesi indikatörleri arasındaki ilişki analiz edildi. Hayat kalitesi artışı ile ilişkilendirilemeyecek enerji kullanım seviyelerinin, ilişkiyi en iyi modelleyen eğri üzerinde sistematik olarak tespit edilebilmesi için maksimum eğrilik denklemi kullanımı önerildi. Literatürdeki diğer çalışmalardan farklı olarak toplam enerji kullanımı yerine hane enerji tüketimi değerleri kullanıldı. Ayrıca bu ilişkiyi daha sağlıklı analiz edebilmek için veriler iklim etkisinden soyutlandı ve enerji ihracatçısı ülkelerin ve geleneksel biyoyakıtlara bağımlı ülkelerin verileri dışarıda bırakıldı. Çalışma sonunda, belirli iklim, kaynak zenginliği ve mevcut teknoloji gibi koşullar altında yaklaşık olarak adil kullanım seviyesi olarak öne sürülebilecek bir enerji kullanım değer aralığı belirlendi.

Anahtar Kelimeler: Enerji tüketimi, Ekolojik İktisat, Enerji adaleti, Doğal kaynak limiti

to Gül Deniz, my beloved one

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CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

Current geological epoch has been proposed to be named as the Anthropocene as a result of the evidences showing that consequences of anthropogenic activities are significant enough to influence the ecological processes [1]. In the last century, human population has exponentially increased up to around 8 billion. The volume of economic activity also followed this exponential growth. Therefore, the biophysical requirements of the humans (also called the social metabolism) increased tremendously. These increases triggered exploitation of nature to dangerous levels. In the mid-20th century, environmental consequences of rapid industrialization and fossil fuel usage first become visible at local scales as air and water pollution. In the following decades, the range of the environmental issues turned in to more global like climate change, biodiversity loss, deforestation, trans-boundary waste disposals. The global dimension of these problems forced international community to get in action together. Stockholm Conference, at 1972, was one of the earliest global meetings to discuss the environment and sustainability. The scope of this UN conference was largely pollution and acid rain problems. "Our Common Future" report of World Commission on Environment and Development is an important milestone in bringing the need for global solutions to environmental problems to the agenda. It popularized the term sustainable development and draw attention to the intergenerational responsibilities of current people. It is followed by an extensive UN conference held in Rio, declaring an international action plan to combat climate change and biodiversity. Taking an action in a global issue was not an easy task. The main discussion has been on how to share the burdens of these actions among worlds countries. The benefits of the appropriation of nature has been disproportionately shared in the history, mostly in favor of the Global North. Besides this conflictual asymmetry between North and South in terms of resource use and contribution to global environmental problems, the material and energy requirements of the South countries for further developmental needs add another complication to this debate. The inequalities not only exist on the international axis but also within the countries among different groups. Environmental justice literature reveals an extensive discussion of cases of inequality in sharing the burdens and benefits of environment among races, genders, income groups. The rapidly growing consumer class of developing nations will be also responsible of the significant part of the future global environmental problems. Intergenerational dimension of these inequalities is also another important concern of the sustainability debate.

Although global community decided to act together against global environmental challenges nearly 50 years ago, it is not possible to say that human related impacts on ecosystems could be stabilized to safe levels. Efficiency improvements hardly compensate a part of the growing impacts arising from the expansion of the population and volume of the economic activity. Despite the fact that per capita and per dollar impact are reduced down to certain levels, total scale of the ecological impact continues to grow to the critical boundaries of the earth after where irreversible changes are highly possible. In order to stabilize and revert the degradation, before it hits and passes beyond the critical boundaries, besides efforts improving technological efficiency, putting limits on resource consumption is also necessary. The problem with resource limits is that natural resources are vital to human activities. The other point is that it is difficult to exactly estimate the critical ecological boundaries, due to uncertainty and complexity of the earth systems. The question is whether it is possible to derive a viable and justifiable social boundary for resource consumption which could be used to limit the growing scale of the total ecological impacts considering these challenges. The scope of the thesis is energy consumption as it is central in fueling both human development and global environmental problems. Instead of seeking a limit for energy use through evaluating its burden on ecosystems, this study offers a limit by discussing the benefits people get from it and try to develop a response by examining the relation between energy use and well-being.

Environmental sustainability discussions mainly focus on intergenerational justice and argues less on intragenerational justice. On the other hand, environmental justice focus primarily on fair distribution of goods and bads but not directly takes in to account the environmental sustainability. There are scholars asserting the inseparability of sustainability considerations and intragenerational equality [2] [3]. Also many ecological economists argue that maintaining equity and sustainable scale of human activities are interconnected concerns. This study follows the same line of argument and while it proposes a limit level for energy consumption, it also aims to seek a fair distribution both among future and present generations and within present generation. It should be denoted that this is not a thesis engaging in a sociological discussion of well-being and environmental justice or fairness but it utilizes existing understandings of these concepts for the purpose of developing a model for limiting energy consumption.

1.2 Proposed Methods and Models

In order to investigate the possibilities of determining a social boundary for energy use, the relationship between energy consumption and human wellbeing is analyzed. A static cross-sectional regression analysis is held in order to be able to detect a level of energy consumption where further increase does not contribute to significant improvements in human well-being. Objective non-income social indicators are used as representatives of human well-being. Residential energy consumption is used as it could more directly be related to well-being. Residential energy data is corrected for different climate. 4 different saturation models are tested for better fit to the data. Maximum curvature formula is proposed for detection of the level of "fair use" energy as it best describes the point where well-being improvements sharply levels off. Results are compared with the other alternative methods.

1.3 Contributions and Novelties

Our contributions are as follows:

- This study is one of the few that offers a social upper boundary for energy consumption.

- There are studies that determine a level of primary energy consumption, after where human well-being shows little improvement. To our knowledge, our study is the first to use residential energy consumption. This enables us to obtain some figures that could be useful for energy and climate policies.

- Residential energy consumption data is corrected for climate. We kept our analysis apart from the inconvenience of comparing countries' energy consumption performances as if they have the same climate.

- Instead of visually detecting a saturation point (knee point of the curve) on the model curve, we proposed using maximum curvature formula in determining the fair use level we suggested.

1.4 The Outline of the Thesis

In the second chapter, major philosophical and economic thoughts on human-nature relationship will be presented. What these perspectives provide us in response to the recent crisis of human and nature and the reasons why humans have to employ resource limitations will be discussed.

In the third chapter, means of determining a boundary for energy consumption is examined. Chapter starts with explaining why we prefer looking for a social boundary instead of using ecological boundaries as reference for a resource cap. It follows with a discussion of energy consumption and human wellbeing relationship, and chapter ends with our proposal for an upper social boundary for energy consumption which we prefer to name as "Fair use" level.

The fourth chapter is the empirical part of our study. It starts with a review of the studies which similarly investigate the relationship between energy consumption and well-being indicators. We introduce the data, indicators and the methodology that are used in determining the fair use level of energy consumption. Empirical analysis and the results are revealed at the end of the chapter.

The study ends with the conclusion part where all conceptual and empirical outputs of the thesis is reviewed.

CHAPTER 2

THE HUMAN-NATURE RELATIONSHIP: NEED FOR A RESOURCE CAP

2.1 Introduction

The whole human history could be mainly divided in to three important stages, if we are to investigate the human-nature relationship: Hunter-gatherer's era, Agricultural era, and Industrial era. If the time homo-sapiens appeared chosen to be the beginning of human history, 88 percent of the time humans were hunter-gatherers. Along this era, population density was very low, ranging from 0.2 to 2 people per km2. Population was determined in the same ways as those of other species, and were ultimately constrained by dynamics of the tropic pyramid [4]. Population growth was very small and total world population was estimated to be roughly around 4 million at the time when early applications of agriculture emerged. Transition to agriculture was not an abrupt change. This extensive transition took place from around 10000 B.C. to 4000 B.C.. Humans changed from nomads to settlers. They started to control the nature. Apart from animals, they also have used the power of wind and water as fueling basic machineries. Agricultural system could feed 25 to 1000 people per km2 [4]. They cut trees for opening space to agricultural land and grazing animals and for timbre supply which they use for energy. Agricultural food production caused much greater environmental impact than hunter-gatherer system. However, the total impact of human to nature was still very limited. Most of the land in Europe was covered by wild forests around year zero. This agricultural transition also created space for human culture to evolve. Urbanization emerged around fertile farmlands. Since not everyone had to work for food production social organization changed, stratified. Population size has increased at a factor of 200 and reached to 0.9 billion by the time when the industrial revolution started. When compared with recent population growth rates, hunter-gatherer era and the agricultural era population change could be considered negligible (Figure 2.1 [5]). In the industrial era everything has changed dramatically. Coal and oil fueled this rapid and intense growth era. Population increased up 6 billion by the end of the 20th century and 7 billion in the last 20 years. This has been accompanied by an enormous growth in the stock of capital in the form of buildings, machines, tools and equipment [4]. Transportation became easier and huge increases in mobility and trade raised up the demand to resources. Relatedly, large amounts of waste is produced. According to a rough estimate reported in 1997, the proportion of land transformed or degraded by human activity range from 39 per cent to 50 per cent of total land available on earth[6]. The scale of human impact showed an incremental growth in the last two centuries of human history and this brought the human and nature to the edge of a very serious crisis. Boulding's [7] analogy is useful to understand the changing position of human in the nature in the early history and today. Boulding characterizes the economy before industrial revolution as a "cowboy economy" where human was like a cowboy in large, infinite-like plains. It does not have enough critical mass to cause significant impact on earth. While today there is a "spaceship economy", where humans are depicted as spacemen in a spaceship.

Humans are no doubt facing a great challenge in their relation with the nature that has never been experienced before. For a few decades, debate on how to cope with these environmental challenges is on the agenda of both the scientific community and the politicians. In the rest of this chapter, selected philosophical and economic views on human-nature relationship will be demonstrated briefly. We emphasized the arguments helped us to draw our perspective through constructing our response to this emerging crisis of human with nature.

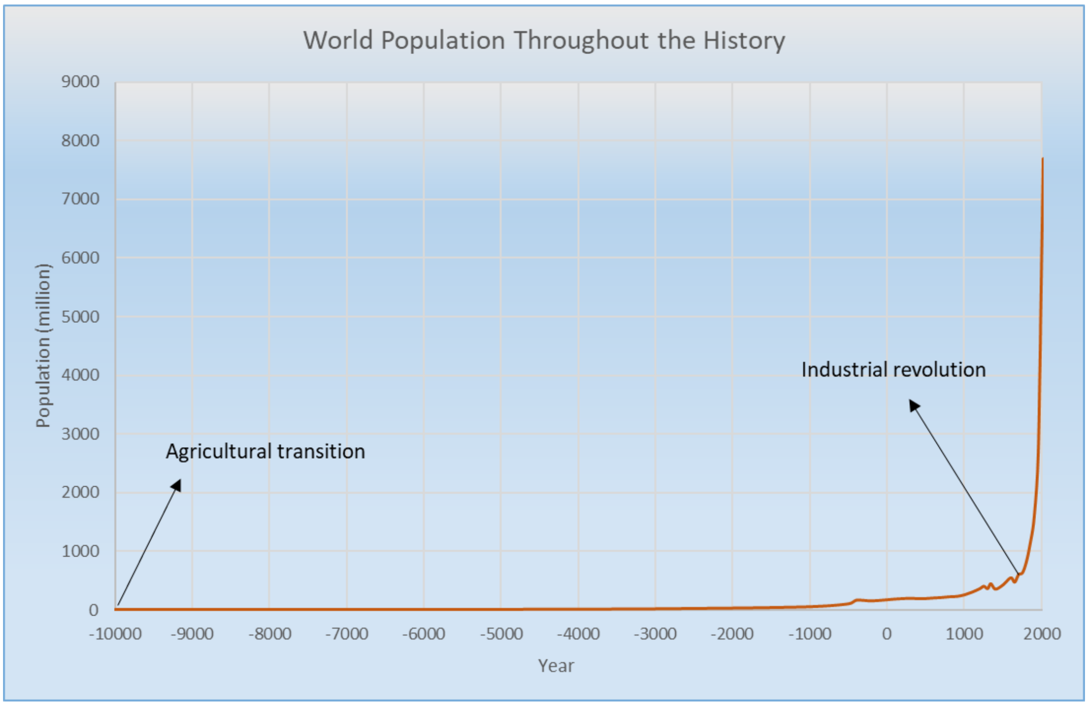


Figure 2.1: Human Population throughout History (Data: U.S. Census Bureau and United Nations, Department of Economic and Social Affairs, Population Division)

2.2 Philosophical Thoughts

Although traditional western philosophy has focused on nature and human relationship in the early history, contemporary environmental ethics emerged as a distinct academic subject just after 1960's. Early thoughts on nature can be traced back to Aristotle who mainly see nature only having instrumental value and argue that "nature has made all things specifically for the sake of man"[8]. Throughout the history, traditional ethics has been dominated by this strong anthrophocentrism. There has been deviations from this main axis such as acknowledging the duties of human to animals [9]. With no doubt, religious texts and beliefs were also main sources shaping the view of human towards nature. For instance, in Christian theology, everything was created for the sake of human but also humans are regarded as stewards of nature and have duties to it [10]. It should be noted that different understandings could find support from the same religious text due to different interpretations. 18th century philosopher Bentham [11] made an extension to the mainstream thought and included the interests of sentient beings (beings which can feel pain and pleasure) to the ethical framework.

Contemporary interest on human-nature relation was ignited by rapid industrialization in the late 19th and early 20th century. Aldo Leopold was one of the pioneers of this new era, with his concept of Land Ethic. He extended the ethical concern from humans and living things to all nature [12]. It was not a open claim for equal rights to all living things and nature but rather it was a recognition of the intrinsic value of the nature itself[13]. White[14] argued on how traditional anthropocentric ethics and Christian theology provided support for the overexploitation of the nature. On the other side, Ecologists' books like "Population Bomb" [15] and "Silent Spring" [16] helped increasing awareness about the ongoing crisis between human and nature in the third quarter of the 20th century. Since then, a remarkable number of scholars proposed arguments in different aspects of the relationship between human and nature, giving rise a new huge discipline. Since it would be difficult and confusing to mention each and every arguments here, a few main distinct understandings, that could be related to resource use, will be included briefly in our discussion.

At one extreme,following the long-established tradition, there is the strong anthropocentric view, which excessively privileges human needs and desires over all other living things. Deep Ecology, proposed firstly by Arna Naess [17], stands at the other extreme of these contemporary environmental thoughts. Deep Ecologists reject the privileged position of human in nature. They do not characterize nature as a resource to be used by human. In stead, they emphasize the intrinsic value of all ecosystems. According to deep ecologists, humans have no right to interfere the nature except to satisfy their vital needs.

Bookchin's social ecology idea challenges both anthropocentric view and deep ecology in different aspects. He acknowledges the intrinsic value of nature but unlike deep ecologists he suggests human intervention on nature is necessary. Social ecologists distinguish the first nature (the physical environment) and the second nature (the cultural and social environment) which is emerged out of first. Deep ecologists, however, view all beings in the first nature and denies the boundary between the first and second nature [10]. Basically, social ecologists define the crisis as social rather than ecological and criticize deep ecologists' view that draws human as an homogeneous species which is responsible of the over exploitation as a whole. As Bookchin [18] states "Social ecology rejects a "biocentrism" that essentially denies or degrades the uniqueness of human beings, rationality, aesthetic sensibility, and the ethical potentiality". Instead it acknowledges the potential of an ecological society to change everything reverse. On the other side, it also rejects an "anthropocentrism" that gives the right to a class of human to exploit the nature irresponsibly.

On the other side, there are other anthropocentric views which can be considered as weak or enlightened anthrophocentrism. Norton [19] proposes an ethical perspective which rejects assigning intrinsic value to ecosystem but still favor of protection of environment. He makes a distinction between felt preferences and considered preferences of human. In strong anthrophoncetrism value is determined by satisfaction of human's felt preferences, while weak anthrophocentrism deals with considered preferences. Considered preferences are attached to a world view. And that world view could be living in harmony with nature. This also leads us to preserving resources without being non-antrophocentric.

Justice theories have been also important in shaping the perspective of human towards nature. Early social justice theories, although not explicitly emphasizes arguments about nature, represent ideas about the distribution of the natural resources among human. The concept of Environmental Justice emerged as the consequence of social movements started in the late 1970's to 1980's in the USA. Environmental justice mainly argues fair distribution of the environmental benefits and burdens, or in other words environmental goods and bads among humans. Like other social justice theories environmental justice could also be said to have an anthropocentric perspective. Most theorists of Justice, from Rawls to Barry, have not extended the community of justice from human to non-human [13]. A more recent view that incorporates all inhabitants of the planet to the community of justice is the concept named Ecological Justice. It argues to distribute the environmental goods and bads among all inhabitants of the biosphere [20].

It is difficult to fit our study on a singular perspective. On one side, this thesis could not be considered to stand at an eco-centric (deep ecology) position, since it does not require all wilderness should leave intact. We do not reject people using nature as resources for their well-being. On the other side, this study suggests to reduce and stabilize the total energy consumption and that is expected to reduce the pressures on ecosystems. As it will be discussed in the following chapters, fair use is conceptualized on a needs based distribution perspective. From this perspective, it is not close to strong anthropocentrism as it does not privilege human desires.

2.3 Economic Thoughts

In the early period of economics, namely classical economics era, nature has not been considered as an important factor to include in the analysis. When it is included, most of the interest is given to the resource scarcity. Thomas Malthus was one of the first who argued about the possible consequences of the trends in population growth and the diminishing returns of agricultural production. According to Malthus [21], population growth will outpace the level of agricultural production and human will face a scarcity of good quality land. Malthus was right to worry about the consequences of rapid increase in population, but he largely overlooked the pace of technological progress in productivity. Mill was another influential economist, who related economic progress to the competition between technological progress and diminishing returns in agriculture [22]. However, he was more optimistic about what technology can achieve [23]. In the first half of the 20th century, Neoclassical economists' relation to nature was through the concerns agriculture and optimal resource depletion [24]. Hotelling's [25] theory about non-renewable resource exhaustion lead to the emergence of resource economics as a new sub-discipline of Neoclassical economics. 1960's and 1970's were the years when the environmental consequences of the rapid industrialization became significantly evident in Europe and in the USA. Concordantly, especially in USA, a new sub-discipline called environmental economics appeared as a response to the growing pollution problems. Some other important studies also released in 1970's paved the way of the emergence of a new economic school of thought called Ecological Economics. Meadow et al's [26] seminal work, "Limits to Growth", was one of the most influential ones. Georgescu-Roegen's [27] studies, which extensively incorporate biophysical realities into economics, also provided a basis for the Ecological economics vision. Degrowth or Zero growth movement is also influenced much from the Roegen's works. They advocate that continued economic growth is not a necessary condition of human development rather it is possible to shrink the economies without undermining the well-being of people. During the 1980's, a new concept called Sustainable Development emerged and became very popular later on in the international community [28]. It could be considered as a third path or an effort to reconciliate proponents of unconstrained growth and limits to growth [29]. There is also another line of argument Despite the fact that the borders between these fields has become more blurry and there are studies lying in between, it is still useful to understand the fundamentals of these most common ideas on nature and economics relationship. Later in this section, we will elaborate on these different point of views.

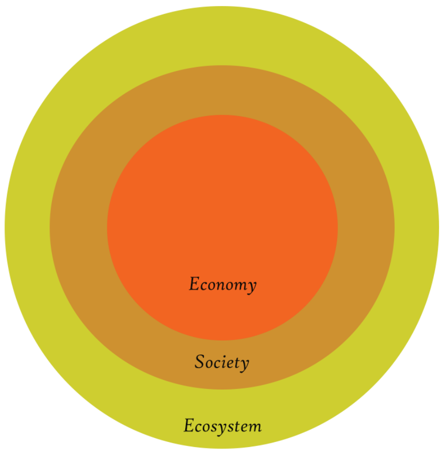


Figure 2.2: Ecological Economics Perspective

One of the main distinctions between Neoclassical economics and Ecological Economics is how they positioned the nature within the whole system. For neoclassical economics environmental problems are just one of the other issues which can be solved with a patch to the existing theories or mechanisms. Whereas ecological economics take it more foundational and acknowledges that all economic activity takes place within the ecosystem (Figure 2.2) [4]. Ecological economists envision the human social-economic system as an open subsystem of a larger system, the biosphere, which is finite, non-growing, and closed with respect to matter while open to a flow of solar energy that is also non-growing [30].This vision of Ecological economists makes them worry about the scale of the human activity with respect to the scale of the ecosystem and provides the base for their main argument, limits to growth. On the other side, according to mainstream view, consistent economic growth is necessary and also possible. This idea is grounded by their belief in technological development and well-functioning market mechanisms. According to neoclassical approach, when resource scarcity appears, either it forces technology to be developed to provide solution via introducing new substitutes and accessing new deposits or higher prices followed by a scarcity stimulates conservation and efficient technologies [24]. Neoclassical economists also develop a similar approach for the growing environmental pollution and waste: Environmental Kuznets Curve (EKC) hypothesis [31]. EKC hypothesis has been very popular in the last 20 years among scholar from both fields. It briefly argues that environmental degradation rapidly increases in early to medium development level, however it slows down and after some certain point of affluence is achieved environmental quality improves (Figure 2.3) [32]. Main basis for this idea is again the assumption that technological improvements will make us more efficient in using natural resources and human made capital will be able to replace natural capital in most cases[33]. Proponents justify this idea also by claiming that people will be more demanding about environmental quality with increasing affluence and willing to pay for environmental improvement or put pressure on politicians to solve the problem [34]. An Ecological economists would object this neoclassical approach to growing pollution and resource depletion, basically from three points: Substitutability of natural capital, total scale of the economy,and price mechanisms perspective.

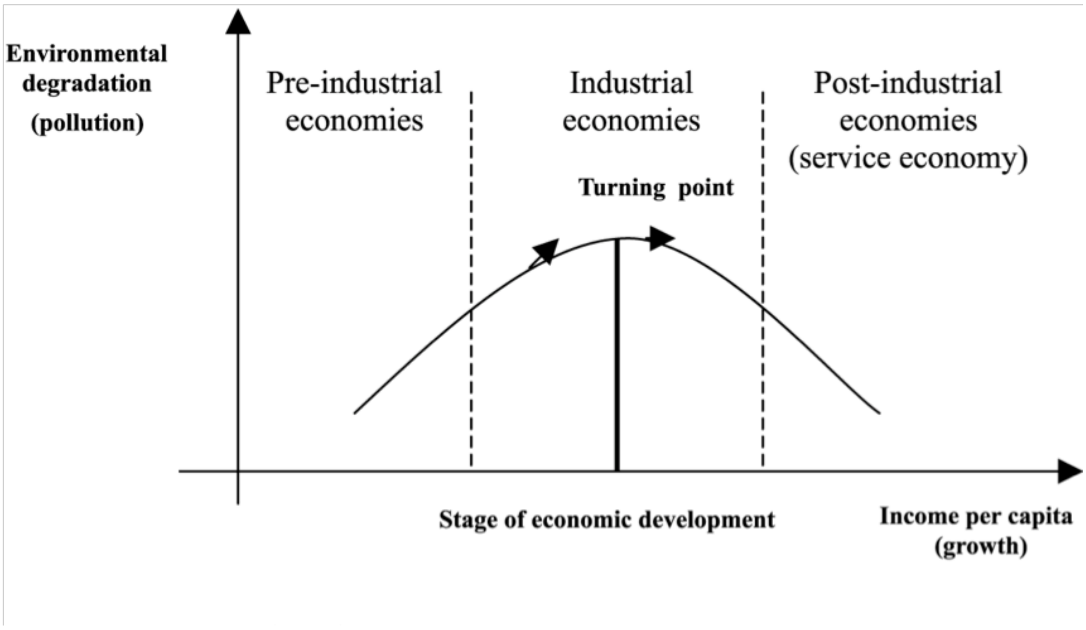


Figure 2.3: Environmental Kuznets Curve (Source: Panayotou, 2000)

Contrary to mainstream economic view that assumes natural and human-made capital as almost perfect substitutes, in ecological economics, they are considered as complements with a very limited substitutability [30]. This approach is grounded on the fact that there is a critical natural capital or irreversible nature which could not be substituted with human-made capital and should be preserved as they are. Main arguments of ecological economists on scale and substitutability are rooted in the studies of Georgescu-Roegen [35] , which he theorizes whole economic system through thermodynamic principles. According to second law of thermodynamics, the entropy law, no productive matter and energy change activity is possible without an irreversible entropic degradation process that generates waste; it is possible to reduce the amount of waste by efficiency, but beyond a certain point there are insurmountable entropic limits [29].

Another objection of ecological economists is the neoclassical economist's commitment to invoke price mechanisms to solve environmental problems. According to neoclassical view, the problem with environmental pollution or emissions is basically due to incorrect prices or in other words the market failure [36]. Environmental economics literature, as considered to be an extension to mainstream economics, focuses mainly on ways to internalize the environmental externalities and monetary valuation of nature through a range of methods like travel cost, hedonic pricing, contingent valuation [24].

Ecological economics, contrarily, could not said to have much confidence in market mechanisms ability to solve the environmental problems. Prices usually fail at reflecting the scale of the economy and distribution of the resources. As pointed out by Daly (1996), the prices reflect the availability of each resource regardless of the total stock of resources, thus preventing them from being used to signal an optimal extraction process from the standpoint of sustainability [29]. Another important concern of ecological economists is equity, which is also not guaranteed to be maintained through market mechanisms. While neoclassical economists do not completely deny the importance of equity, they exclusively focus on efficient allocation rather than fair distribution [4]. Theoretically, if at any distribution Pareto-optimal allocation is hold, then there is no mean to ask for a redistribution. On the other hand equity and scale concerns are not said to be completely distinct. Scale of the economy, equity and efficient allocation are the complementary concerns of the core vision of the ecological economics.

All the debates mentioned above are also central to the discussion over sustainability. These debates between growth oriented neoclassical view and proponents of "limits to growth" idea gave birth to a new concept called "Sustainable Development". UN World Comission on Environment and Development's report [28], named as "Our Common Future", introduced a new perspective called Sustainable development which is simply defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. While proponents of this concept do not deny the necessity of growth of economy, it calls for an international intervention to pursue a growth that is environmentally and socially sustainable [4]. At this point, another question arises: What is sustainability? Different approaches to the concept of substitutability also shapes the view on what is sustainability. Since ecological economics view suggests limited substitutability between natural and human made capitals, in their vision sustainability necessarily requires to maintain a certain amount of natural resources. This type of sustainability is termed as "strong sustainability". By contrast, many mainstream environmental economists assume that human made inputs can substitute extensively for natural inputs. They argue that sustainability could be achieved as long as sufficient investment is made in human produced capital. This is referred to as “weak sustainability” [36].

While sustainable development view defends the need for continued economic growth for alleviating poverty and maintaining progress as neoclassical economists, on the other side it overlaps with ecological economists in its emphasis to social equity. Its emphasis to intergenerational justice also positions sustainable development closer to ecological economics perspective.

This study develops a perspective consistent with the ecological economics framework as it tends to take in to account both scale and equity principles while proposing the fair use level for energy consumption.

2.4 Need for a Cap

It may be possible to observe a decoupling between increasing affluence and per capita carbon dioxide emissions in some highly developed countries as suggested in EKC hypothesis however this does not necessarily mean that there is really a decoupling occuring. What lies behind the carbon reduction success of some developed countries is mainly their ability to transfer the carbon-intensive production activities to other countries. Therefore, when a country seems like becoming more environmentally efficient, it maybe just having a structural change in its economy. This does not guarantee a decline in total global emission budget which is an important concern for ecological economics view.

The total impact of humans on ecosystems is often described by the formula called IPAT. In brief, the formula implies that the human impact(I) is the product of population(P), affluence(A) and technology(T) [37]. The median of world population projections estimates an increase from 7.3 billion in 2015 up to 9,7 billion for the year 2050 [5]. In most of the projections it is predicted that the world population will continue to increase in the second half of the century but in a slower pace and UN’s report at 2015 predict a peak around 11 billion [5]. Majority of this population will be consisting of developing country citizens. Total economy of the World is also projected to enlarge by more than double until 2050 [38]. If developing countries follow the same path of development as their predecessors, there will be a very heavy burden for the ecosystems. What counterbalances the negative impact of population and GDP increase are improvements in efficiency (which is represented by technology in the formula). However, the relationship between these parameters is not that straight forward due to strong interdependencies between population, affluence and technology. Alcott [39] presents a detailed analysis of possible interdependencies between the parameters of IPAT equation which may offset the expected impact. Direct impact caps and limits on resource use are offered as better tools for controlling ecological impact, in stead of changing the parameters at the right side of the IPAT equation. This is consistent to what Jevons [40] observed more than a century ago; efficiency does not always lead to a reduction in total resource consumption (Jevons Paradox).

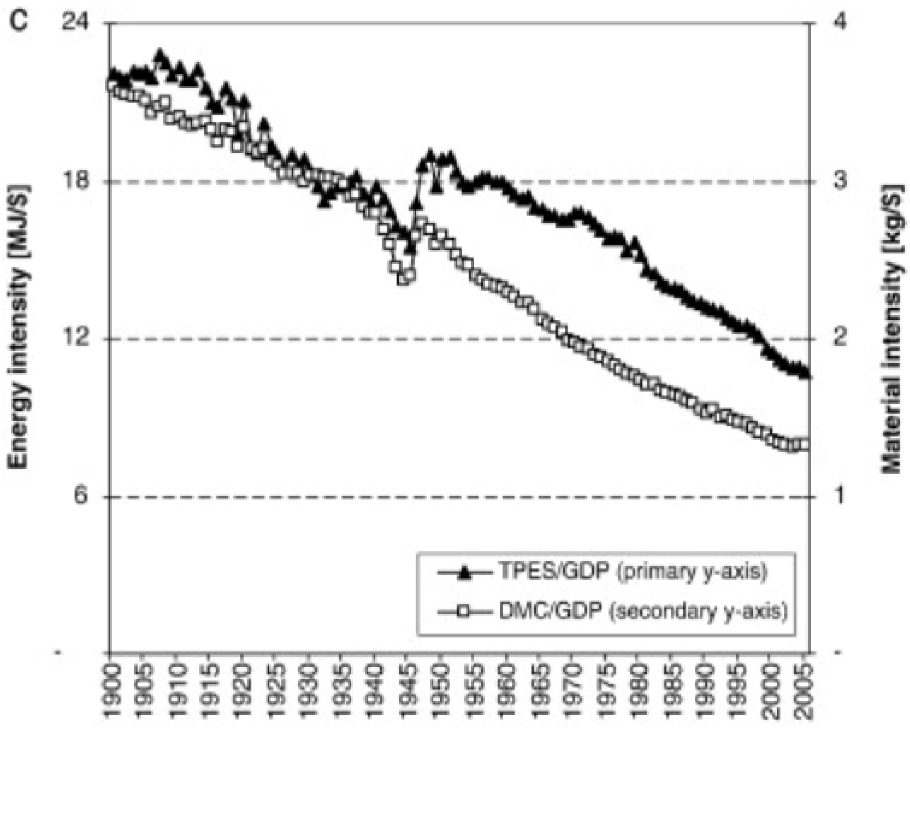


Figure 2.4: Global Material and Energy Intensity Trends (Source: Krausmann et al. 2009)

In particular, energy consumption, which is responsible for an important share of our contribution to the ecological degradation, is expected to increase for a long time as the population and GDP increases [41]. Therefore, energy efficiency has been one of the most promising environmental policies towards fighting climate change and other ecological problems. Energy efficiency has received more attention among other environmental measures since it presents a win-win situation, at least in theory. Financial and environmental gains are possible at the same time. However, what seems like a win-win situation, may actually turn into a win-lose situation when long term impacts are considered. Most of the time when energy efficiency measures are applied, a rebound effect occurs in which consumption patterns offset the energy savings achieved by energy efficiency measures. A simple example of this behavioral rebound effect is our tendency to drive more kilometers when we get a more fuel efficient car. The extra kilometers driven causes to fail in achieving the targeted energy savings by a fuel efficiency improvement. There are a vast number of empirical studies observing significant rebound effects after many diverse efficiency improvements [42]. This may be a consequence of the fact that energy efficiency has also widely been considered as a tool for greater economic growth at macro scale. Furthermore, economic growth, driven also partly by efficiency improvements, is another factor that offsets some part of the environmental achievements of energy efficiency [43]. Many energy efficiency programs put financial considerations to the center and fail to consider the long term aggregate energy savings and therefore the corresponding ecological impact. This does not mean energy efficiency is totally useless but its impact and capacity to counterbalance degradation should be carefully examined and not to be overrated. Efficiency is not a cure for everything. Improving technological efficiency does not guarantee a decline in environmental degradation in total. Historical evidence shows that during the 20th century material intensity (kg/dollar) and energy intensity(MJ/dollar) of the world economy decreased by 50 and 30 percent, respectively [44] (Figure 2.4). It can be translated in to an energy efficiency growth by 0.68 percent per year, and material efficiency growth 1 percent per year. However, these significant improvement in efficiency has not been accompanied by a decline in total energy and material consumption. Total world energy and material consumption roughly increased 10 times in accordance with the fact that population quadrupled and economy grew 24 times of the level at year 1900 [44] (Figure 2.5). Therefore, downward trends of per capita consumption should not be seen as an indicator of a success where the total consumption continues to increase and drags us fast to the critical limits of the ecosystems where irreversible damages are highly possible. As it is mentioned in Section 2.3, in regard to the second law of thermodynamics, ecological economists and bio-physical economists claim that there are limits to growth, limits to efficiency and therefore total scale of the aggregate economy, and relatedly, aggregate material and energy throughput should be taken in to account [45]. In order not to hit the boundaries of biosphere, focus should be on limiting total energy consumption by energy conservation rather than only energy efficiency. Sachs [46] states that "Efficiency without sufficiency is counterproductive, the latter must define the boundaries of the former". Without capping the total energy consumption, it is not guaranteed that we develop within safe ecological boundaries.

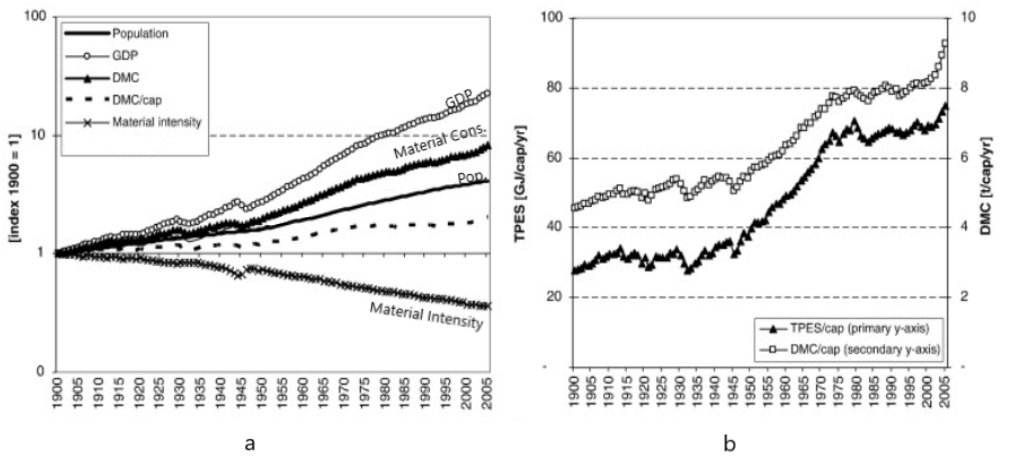


Figure 2.5: Global Trends in Economic Growth, Population Growth and Material-Energy Throughput Growth (Source: Krausmann et al. 2009)

One may argue that an energy cap is not needed when fossil energy resources are substituted 100 percent with renewable and zero-carbon emitting resources. That may not be true. Increasing the total energy supply with renewable resources will possibly lower the prices and will probably cause a further demand increase and encourage energy and therefore material intensive lifestyles (Energy boomerang effect) [47]. This abundance signal may lead to a more consumerist behavior. For instance, cheaper and cleaner fuel for cars may encourage more people to buy cars or drive more. Vehicle industry and related industries will enlarge. More roads will be built and eventual ecological effects of a clean energy technology may lead to worse. Another point is that substituting all fossil resources with renewable and zero carbon resources is not an easy task both technically, economically and politically. It may take decades to replace all resources and set up infrastructures for renewable and zero carbon energy resources where 70 percent of the primary energy use is from fossil fuels. This does not mean that we should not undertake this transformation. As we do not know how long this transition period will last, we should at least minimize the possible damage by simultaneously phasing out fossil fuel consumption and limiting the energy use. Limiting the quantity of energy used and improving the quality of energy (making it decarbonized and renewable) should go hand in hand. Therefore, whether non-renewable or renewable, energy consumption should be constrained to a certain level in order not to get closer to the critical ecological boundaries. Clean energy is less energy [47].

Limiting total energy throughput could be considered as ignoring the underdeveloped populations' right to access higher energy amounts which they require to satisfy basic developmental needs. As stated in the previous section, scale and the equity are related concerns. Redistribution could be seen as part of the effort to progress within safe ecological boundaries. In the light of all these discussions, we can say that our study is consistent with the ecological economics point of view in its emphasis to total energy throughput (scale) and fair distribution and it can be said to be inspired by the social ecology tradition as it tries to respond to the conflict of human and nature within social dynamics rather characterizing it a technical or ecological problem.

CHAPTER 3

IN SEARCH OF A LIMIT TO ENERGY CONSUMPTION: FAIR USE

3.1 Ecological Boundaries

As stated in Chapter 2, limiting total material and energy throughputs are necessary for an absolute lowering of pressures on ecosystems in order to prevent irreversible damages. In order to limit our impact and explore our safe playground, we have to be able to quantify both the impact of our energy consumption and the critical natural boundaries or carrying capacities of the ecosystem. (As our study particularly focuses on energy, material consumption, which is as important as energy consumption will only be mentioned where relevant to energy consumption.) Using energy resources causes pressure both on the source and sink capacities of the ecosystems. Considering these capacities, Daly [48], sets up 3 general rules in order for maintaining sustainability in resource use:

- All resource use should be limited to the rates that wastes caused by these resources can be safely absorbed by the ecosystem.
- In particular, renewable resources should be used at rates that the ecosystem can regenerate
- Non-renewable resources can be depleted at rates that do not exceed the rate of development of the renewable substitutes.

In order for sustainability, all these three requirements must be hold at the same time. For the first one, the carrying capacities of the ecosystem have to be known. There have been attempts to quantify the earth's critical thresholds in especially Earth System Science and Biophysical Economics fields. Rockström et al. [49] made one of the most comprehensive studies in which they tried to identify 9 of the planetary boundaries (Atmosphere's sink capacity of GHG, ocean acidification, stratospheric ozone, biogeochemical nitrogen cycle and phosphorus cycle, global freshwater use, land system change, the rate at which biological diversity is lost, chemical pollution, atmospheric aerosol loading). They quantified the 7 of these 9 boundaries which they suppose humanity can operate safely. They make a distinction between critical thresholds of the Earth System and the planetary boundaries. Thresholds are defined as intrinsic features of the Earth systems and transgressing them will trigger non-linear, abrupt changes and irreversible consequences. On the other hand, they define planetary boundaries as human determined, normative levels which is set at a safe distance from critical thresholds. Therefore, these boundaries are determined based on a decision of uncertainty and risk. In order to determine the critical thresholds or the planetary boundaries, one have to deal with many difficulties. Earth system processes are intrinsically complex and interdependent. Estimating how and when they react to impacts is full of uncertainties due to lack of scientific knowledge. Most of the time a control variable, that best represents the Earth system processes, has to be chosen. The fact that regional and global dynamics could differ in many cases leads to difficulties in defining a safe global threshold [49]. While appreciating the efforts to determine carrying capacities of the ecosystem, we should not ignore that these boundaries are still rough estimates and surrounded by large uncertainties and knowledge gaps which is also indicated by the authors. For instance, in particular for non-renewable fossil energy resources, sink capacity of atmosphere could be a boundary for sustainability. However, climate change scientists' estimations for critical threshold for global average temperature increase range from 1.5 to 2 degrees. Presupposition of each has different implications.

Daly [50] conceptualizes an optimal scale for the human activity that is assumed to be safely distant from the critical thresholds. Daly transfers the optimality concept from microeconomics to macroeconomics and defines the optimal scale of human activity as where the marginal benefits are equal to the marginal costs of the economic growth. The growth after this optimal scale is named as uneconomic growth. He does not attempt to empirically determine an optimal scale in his studies but he discusses the concept. The difficulty in determining an optimal scale in economy is that it requires normative decisions about valuing services of natural capital. Economic growth has both ecological and social costs. Ecological costs are not always obvious and some may appear in long term. Detecting ecological costs bears the same difficulty as determining planetary boundaries. Further obstacle here is that classical cost-benefit analysis requires all values to be translated in to prices. This reductionism is much criticized by ecological economists and mainly incommensurability is favored instead [51]. Therefore, any analysis trying to evaluate ecological costs and benefits is contradictory. Determining an optimal scale, in particular for energy consumption, would require us to deal with similar difficulties. There are many different possible ecological impacts of energy consumption ranging from climate change to biodiversity loss. Measuring the GHG emissions and air pollution caused by energy use may seem relatively feasible, but some other impacts may not be that observable and predictable. For instance, considering Deepwater Horizon oil spill disaster at 2010, it is not possible to perfectly assess the aggregate impact of the spill to the ecosystem or appraise the damage caused by a loss of endemic species in that ocean ecosystem. Futhermore, if one would like to be more biocentric, determining an optimal scale will be more complicated when intrinsic values are included in the discussions [50]. From an antrophocentric point of view, again, putting a limit for biodiversity loss sounds like letting some species to be lost although we don't have enough information about its consequences (Critical species tend to create a domino effect). Similarly, an allowance for greenhouse gas emissions is like allowing people to emit a certain amount, where complete decarbonization is theoretically possible. There are efforts suggesting caps to greenhouse gas emissions. While we admit that these caps will help to lower the impacts, for a holistic solution it will not be sufficient alone. Capping the source is easier than capping the wastes, since the energy is in low entropy on the source side [52].

Daly [30] states that "the efforts to stabilize consumption do not have to wait us to identify the exact ecological scales. Otherwise, knowing boundaries will only enable us to wave goodbye as we grew through it". It seems better to avoid using ecological measures for the sake of the ecosystem itself. Certainly, this does not mean ignoring environmental concerns. Bearing in mind the difficulty and uncertainty in assessing the ecological costs, we suggest searching a cautious social boundary for energy consumption by elaborating on the benefits we get from it.

3.2 From Ecological to Social Boundaries

In this section, we are going to investigate the means of a social limit to energy use through discussing why we consume energy and how much energy can be considered enough.

3.2.1 Energy Consumption and Society

Energy is the essential substance of all natural processes and also of all human activities. It is a common source to survive for all living things. Animals utilize the energy acquired by food intake and converts it into work, growth and heat. This energy is called somatic energy [4]. Humans do it in the same way as animals. However, humans differ in their ability to exploit extrasomatic energy, which began when they learned to use fire. This was the time that they started to utilize more power than their muscles can and came over a limitation. This energy surplus is also considered as one of the driving forces of the human's cultural evolution. Need for energy shaped human societies even in the prehistoric times. For hunter-gatherers, for instance, large fatty mammals were better sources for energy comparing with plants and small animals. However, hunting these mammals required better hunting strategies and cooperation or division of labor, in other terms a social organization [53]. Obviously, energy could not alone explain all the cultural evolution. When we track the historical social development, not only we can observe that there are different energy resources which dominates a certain period, but also transition to a more efficient energy resource has been accompanied by some prime mover technology [54]. Each prime movers helped humans to increase the amount of energy surplus harnessed from the dominant fuel of the age. The property of the fuel and the technology (efficiency) of the prime mover have been determinant in shaping the social dynamics of the era. In early prehistoric times human muscles were prime mover and the solar energy taken by the food was the fuel of that era. The energy available was barely enough for survival needs. Then, humans started to utilize water and wind energy by using windmills and they domesticated animals and thus increased the available surplus energy to the society. This enabled more foods being harvested by agriculture and gave way to settled societies and totally different social dynamics. Coal became the dominant fuel by the invention of steam machine and ignited the industrial revolution. Society transformed in a dramatical way. Population, production and consumption boosted and so the energy consumption. And lately internal combustion engines and fossil fuels cooperation started a new era. Mobility increased. Population grew incrementally. Daily practices, habits, needs and wants changed with each transformation. Human activities diversified in several ways. Available energy is now much far from enabling survival of humans. Hunter-gatherer human was using only somatic energy for its survival needs (which is defined 1 HEE, Human Energy Equivalent). Human doubled this amount by extra-somatic energy after the discovery of fire. In the agricultural era, animals, wind and water power helped to increase the average energy available to a person to 3-4 HEE. Coal and steam machine increased it significantly and lately fossil fuels and internal combustion engines lead to an average per capita available energy to 19 HEE at the end of 20th century. It should be noted that this is the average of 93 HEE at USA and 4 HEE at Bangladesh [4]. This makes us to investigate whether the amount of energy still indicative of societal development.

The fact that there is an interaction between humans' energy use and social and cultural evolution is clear, however the extend of the dependence and the direction of causality have been questions to be answered. There have been energy theorists of cultural evolution who analyze the relationship with a holistic approach, from prehistoric to modern industrial societies. This global point of view would provide useful insights in our analyses over restricted time periods. An anthropologist, Leslie White [55], one of the pioneers of the energy theory of society, asserts that cultural advances are consequences of the ability of human to harness more energy and put it to work. Cotrell [56], a sociologist, holds that energy is the limiting factor over what people can do. Odum, [57] an influential ecologist, admits the vital role of energy as a universal unit, which can determine every phenomena and process in the earth. He also argues that the basic cause of the latest population explosion is the fossil fuel energy resources. However, he does not go further to claim that energy use is the primum mobile of all human society. Odum remains the causality discussion open. He asserts that the amount of energy a society gets is only a starting point. Control of the energy flow and the feedback loops by which the energy is channeled into useful work is also determinant on the impact of energy use over society [58]. Most theorists agree that energy availability constrains the possibilities of the social change and action. It is widely acknowledged that the size and the complexity of human societies and culture triggered by the amount of energy they harness. However, there is no clear agreement on whether this greater size and complexity brings with a higher quality of life every time [58]. Adams [59] , argues about the inevitable deterioration in the quality of life of some members in the society with the aggressive growth of energy flows. Nader and Beckerman [58] argue both rapid decreases and increases in energy suppy and consumption could lead to a decline in well-being. Rapid decreases of energy supply in oil boycotts bring unemployment, shortages of products, food and disruption in economic conditions. They also state that rapid growth in energy consumption, as in the cases England, Germany and Japan, has been accompanied by wild fluctuations in the roles of social institutions; unmanageable inequalities in the distribution of power and political conflicts. High energy demand bring many environmental and economic and political negative side effects which in turn effect the well being of the citizens. The causality between energy consumption and societal advance seems to be more complex than we would think and it is also influenced by other factors.

The relationship between energy consumption and well-being is most obvious in low income levels and residential consumption. Especially since 1980's, concerns about the impact of underconsumption of energy (expressed as fuel poverty or energy poverty) on human well-being gained attention. Urban household energy poverty and rural poverty have different dynamics, however. For the urban poor, in general, the problem is affordability of energy, on the other side in the rural areas households do not have access to good quality energy resources and carriers. In the latest energy transition, the most remarkable advance for the domestic users is the widespread of natural gas and electricity systems which are clean, efficient and practical. However, these transitions are not synchronical all over the world. According to International Energy Agency, by the year 2015, 1.2 billion people still live without access to electricity while many developed countries had already 100 percent electrified their households decades ago. These large rural populations depend on mostly traditional biomass and partly coal for cooking, heating house and water, which evidently makes daily life practices difficult to carry on. Collecting and preparing fuel, which are mostly done by woman and children, requires long time and effort. It restricts the education possibilities and leaves limited time for income generating work. Burning low grade fuels causes dangerous levels of indoor air pollution which diversely affect the health of households. Lacking electricity means lacking access to several other benefits like keeping foods cooled, life facilitating home appliances etc. Therefore, energy poverty is more about the quality of energy than quantity in rural low income households. It should be noted that low income households of developed countries still suffer from energy affordability. Many urban low income households living in cold climates, have not access to enough amounts of energy especially for heat comfort. Furthermore, people with low income are more harshly effected by the indirect costs of transformation of the energy technology and infrastructure caused by the accelerating demand on energy. It is easier to observe the relationship of energy and well-being, when people lacks basic energy services. On the other hand, dependence of well-being to higher levels of energy consumption is not a simple case.

How to interpret this change between different ages and places is important through our purpose to determine boundaries to energy use. Energy is not consumed for its own sake. People do not need energy, but the services it provides. The demand for these services is strongly influenced by cultural practices, social norms and lifestyles [60]. American people prefers to live in detached houses, drive large cars. This can be considered as cultural ideal of an American citizen. Urban sprawl leads to long distances to be driven for commuting. On the other side, North Europeans, in general, live in smaller, high density apartments and prefers to use public transportation. Eastern societies live in larger families which means lowering the consumption per person in a house. These choices in lifestyles make a significant difference in the energy needed. Moreover, perception of heating comfort changes between different cultures. Swedish people finds American homes overheated and overcooled in general [60]. In Japan, it is common not to have a space heating system as one considers in Europe or USA. They frequently use small heaters under a table. This is largely unacceptable for people living in Ankara, who experience similar temperatures. On the other hand, what is common in many eastern and western societies is the influence of modern capitalism. As a whole, the economic system is dependent on growing consumption. Dominant consumerist culture causes direct and indirect energy use as a consequence of the promoted overconsumption of market goods and services. At this point, how we define overconsumption arises as a tough topic to be discussed. As it is in the American case, whether high consumption per capita can be justified as being part of the culture and lifestyle or as being source of well-being is left a question to be answered.

3.2.2 Defining and Measuring Well-being

As mentioned, energy consumption is not an end itself. Energy is means to carry out activities in the need for survival and to reach a level of well-being. At this point, we have to clarify what we mean by well-being. Defining and measuring well-being has long been a debated topic. Well-being has no easy definition. It may also refer to different concepts in different disciplines. Furthermore, quality of life and well-being are used interchangeably in many instances [61]. We prefer to use well-being to refer human development in general means throughout this study.

The interest on well-being is not new. The discussion over what 'good life' or "desirable society" is can be traced back to ancient Greek philosophers. Broadly, there are two main schools of thought which are considered as origins of contemporary views on well-being: Hedonic and Eudamonic schools. Hedonic school of thought, originated from the thoughts of Epicurus, conceptualizes well-being mainly as happiness which can be achieved by maximizing pleasure and minimizing pain (kahnemann 1999). On the other side, Aristotle argues well-being is related with living a life of virtue rather than a life seeking pleasure [61]. Following Aristotle, Eudaimonic school defends that a good life is achieved by realizing individual's own potentialities and personal development [62].

Diener [62] analyses Hedonic tradition under two different lines of thought. Therefore, he asserts that there are three main philosophical views seeking answer to what wellbeing is and he associates each tradition to a contemporary approach that describes and measures well-being. Similar to the previous classification, he admits there is Eudaimonic line of thought which characterizes well-being or "good life" through normative ideals based on religious, philosophical and other systems. This view is considered as the base for the social indicators tradition. Second view defines well-being over satisfaction of preferences. In this approach, well-being of an individual is related to whether she gets the things she desires. This tradition is the source of utilitarian theory. Third approach defines well-being though how individuals experience their lives. This view is mostly associated with the subjective well-being concept.

Utilitarian theory provides a base for dominant mainstream economic view, where utility is maximized by satisfaction of preferences through market consumption [63]. One of the main principles of mainstream welfare economics is that individuals are the best and only judges of their preferences or wants and therefore their level of well-beings and welfare (Consumer sovereignty). Consumers are rational actors and they decide what is good for them. The goods and services produced and consumed should be determined by the wants and preferences of the individuals [64]. This is assumed to maximize the well-being of each individual and therefore the total utility of the society. When we evaluate these different definitions of well-being through the window of resource consumption, this wellbeing approach can be criticized from many points. It is possible to say that a view that prioritize satisfaction of desires and preferences could serve as justifier of any consumption. When individuals lack information and knowledge, or have to decide under uncertainty, their decision of what is good for them would be unsound. Daniel Kahnemann [65], in contrast with the rational consumer assumption of welfare economic theory, reveals many cases where individuals behave irrationally and fail to judge what is good for them. Things or actions supposed to give pleasure not necessarily ends up promoting well-being. Another point is that people tend to alter their preferences and desires to the options available [64]. This “adaptive preferences” phenomenon is observable at both high and low income levels. At lower incomes, when people feel no hope to move upper classes, they tend to lower their desires and similarly people with higher income feels upward pressure in their desires [66] [67]. Furthermore, preferences and desires are not free of the impact of the market itself [68]. If markets and economic institutions shape the preferences and tastes of the consumers, then reliability of judgments of individuals on their well-being become suspicious and biased. According to neoclassical economic theory, desires are not satiable and individuals can increase their utility with a different bundle of goods, when they are satiated with consumption of one good. Although it seems to potentially be used to justify unsustainable consumption, some mainstream environmental economic studies use this to prove that it is possible to decouple consumption from well-being by just shifting individual's utility functions [69]. In other words, they claim that convincing people to change the bundle of goods and services they consume with the ones which have low environmental impact to increase their utility or well-being is a viable solution. However, this point of view still suffers from incautiously assuming that individual's choices are free from the impacts of institutional, technological and market factors which leave little space for people to change their lifestyles [70].

The other Hedonic originated approach associates well-being with the subjective experience of the individuals. In the subjective well-being concept, wellbeing is assessed through pleasant and unpleasant experiences and satisfaction from the life at all [62]. Although subjective interpretation of well-being provides a complementary insight to the well-being discussion, it is also subject to similar criticism to that of preference based theory. Adaptation curse follows also here. People tend to adjust their expectations to the reality and position which they are in [64]. Furthermore, the perception of wellbeing is highly influenced from culture, tradition, religion and other values. A Muslim person would hesitate to complain about his life as it is not perceived right for Islamic thought. This makes the individuals' judgment on their own satisfaction from life biased and inter-culturally incomparable. One other critic of hedonic understandings of well-being is that since it is a static evaluation of satisfaction or experience of the individuals, intergenerational concerns of resource consumption could not be addressed [69].

Eudaimonic school of well-being interprets the individuals in a broader context, within the society they flourish [70]. Eudamonia simply means human flourishing. While hedonic tradition conceptualizes well-being as an outcome like a positive feeling or an absence of pain, Eudaimonic tradition focuses on the content of one's life and the processes [71]. Fromm [72] points out that Euadamonic understanding of wellbeing requires distinguishing between desires whose satisfaction leads to purely subjective momentary pleasure and objectively valid needs whose realization leads to human flourishing and growth. Scholars following the Eudamonic school are typically interested in determining the elements indicative of good life [71]. There are different approaches to Eudamonic concept of well-being, each of which describes these elements differently. Some conceptualizes well being from needs perspective ([73], [74]) , some others from capabilities perspective ([66], [75]) and some others from social primary goods perspective [76]. In all approaches authors argue that there is objective, non-substitutable and universally valid dimensions of human well-being. Rawls [76] conceptualized these dimensions as social primary goods and defines individual well-being as possession of these social primary goods. In response to Rawls's perspective, Sen [66] puts out that individual's ability and opportunity to convert these primary goods in to valuable ends is more determinant in achieving wellbeing. He uses the term functioning to reflect various doing and beings that an individual value, ranging from basic (walking, eating) to complex (taking part in community). From Sen's perspective, what matters is not to achieve a functioning but being free to achieve it. [77]. Capabilities, then, can be defined as the full set of functionings that are feasible for a given person, or in other words, a person has freedom to achieve[78]. Some examples of capabilities are: the ability to live to old age, freedom to engage in economic transactions, or freedom to participate in political activities. Sen's capabilities approach is criticized as demanding to much information to operationalize [79]. The third approach in this tradition is the theory of human needs. The theory proposes that there are finite number of universally valid, incommensurable and non-hierarchical needs which are pre-requisites of human well-being [80].

Measurement of well-being is not less complicated than defining it. Several attempts have been made for functionalizing these different understandings in purpose of measuring well-being. Broadly, it could be said that there are two different approaches in measuring human well-being: Objective indicators (social indicators) and Subjective well-being measurement.

An objective indicator is a societal assessment made by an agent which quantitatively reflects people's objective situations in a given geographic unit [62]. Gross domestic product and national income, as representatives of monetary wealth or affluence have been the most popular objective indicators since the early 20th century as parallel with the fact that utilitarian theory of wellbeing is dominant in the mainstream economics.

British welfare economist Pigou was one of the first to take national income as the measure of well-being [81]. While he acknowledges that social welfare is a broader concept than economic welfare, he asserts that economic welfare and social welfare changes in the same direction [61]. Later, Kuznets [82] conceptualized the measurement of Gross National Income and since than it has been widely used as a tool for measuring economic and societal welfare all over the world. Affluence, and GDP as an indicator of it, remained popular also because it has the advantage of being easily available and measurable. On the other hand, it has long been a point of criticism to consider affluence as sole indicator of development. GDP alone fails to draw the picture of human development due to many reasons. GDP indicators aggregates the volume of all the measurable economic activities within a country or any geographic unit. Higher the numbers of GDP figures mean the higher amount of wealth available to the citizens of that country. That is expected to increase everyone's wealth and relatedly well-being. However, that is not always the case. One important defect of GDP is that both the wealth from production and consumption activities and defensive expenditures that we have to make in order to protect ourselves from harmful side effects of these production and consumption are summed together. For instance, both wealth from petroleum production activities and clean-up expenditures of an oil spill accident are assumed to add on human well-being [83]. While it includes these undesired expenditures (i.e. crime, pollution, war etc), it fails to include some important elements of well-being like freedom, happiness, affection, leisure time which are difficult to measure in monetary units [58]. Some informal goods and services that are not sold in the market like volunteering and housework are also neglected in the calculation of GDP, although they are important elements of societal well-being. GDP is also criticized to be overwhelmingly focused only on the quantity rather than quality [84]. GDP growth is often defended from the point as it enables to deal with poverty and unemployment assuming 'the rising tide will lift all boats'. However, it is not possible to say that all nations having high GDP, achieves high employment and fair distribution of wealth [85].

Human well-being is a complex concept and its measurement requires a more comprehensive approach than simply representing it with GDP. Since 1970's several social indicators have been proposed to measure different aspects of human well-being and social development, which has given way to emergence of a new discipline. Objective well-being indicators like life expectancy, literacy rates, access to water, food, sanitation, infant mortality rates etc. have the advantage that they have been regularly measured and recorded worldwide for nearly a half century. They are also used in combination to form indexes. The Human Development Index(HDI), which is proposed by Mahbub ul Haq in 1990 under the support of UNDP, could be seen as the most popular one among others. HDI is underpinned by Amartya Sen and Martha Nussbaum's "capabilities approach" on Well-being [66]. HDI focuses on ensuring three capabilities that is assumed to be essential prerequisites for human well-being: access to a long and healthy life, access to knowledge, access to a decent income. Life expectancy at birth, Adult literacy and GDP per capita was chosen to be used in the index as representative of health, education and income, respectively. Although it was appreciated as an important step towards defeating the GDP hegemony in well-being measurement, later in the following years, HDI has been subjected to many criticisms, which are also common for objective indicators in general. Objectivity is the important strength of social/objective indicators. On the other hand, selection of indicators requires a normative decision and always open to dispute. HDI is criticized of neglecting some important components of well-being like civil and political liberties and environmental impacts on wellbeing [78]. Weighting and aggregation methods used in an index with multiple indicators is also important and each decision has different impact on the outcome. HDI is found to be faulty to calculate the final index figure with an arithmetic averaging which violates the non-substitutability claim of objective well-being approach [86]. There is another question about an objective indicator that whether it represents what it aims to or not. Specifically, in the HDI case, adult literacy is questioned whether to be the right indicator to represent access to education. Similarly, the optimum value of an indicator and trade-offs between indicators should be taken in to account. For instance, in the case for life expectancy, whether longer life is always good or not is questionable, when a severely incapacitated patient is considered [62]. Another criticism to objective indicators, and also to HDI, is about the fact that there is high correlation between economic indicators and many social indicators [87], [88]. Diener and Suh [62] reveals examples of countries with similar economic levels but having different level of social achievements and assert that strong correlation does not suggest the social indicators are useless, rather they contain information beyond which the wealth indicators does not explain. HDI has been also criticized from missing distributional elements. On the other side, UNDP has been very receptive to the critics and modified the index significantly throughout the years. Just two years after the first proposal of the index, they responded to critiques on inequality and included an "Inequality-Adjusted HDI" in the 1992 report. Later they created a more comprehensive education index, changed income indices and modified the calculation method to improve the index in response to critiques [78]. Apart from the HDI, there has been several attempts to create better indexes of well-being.

In contrast with objective measurements of wellbeing, in subjective well-being measurement, only individual's judgment of her well-being is taken in to account, rather than what other agents consider important [62]. Subjective well-being consists of three main components: Pleasant moods and emotions, Unpleasant moods and emotions and life satisfaction [89]. Gross National Happiness Index and World Happiness Report are the most popular outcomes of this measurement approach. Subjective well-being data is obtained from surveys. Reliability of subjective well-being measurements are dependent on many factors like the method of the survey, the questions, the surveyor, temperament of the respondent, situational factors, personal relationships of the respondant and events experienced etc. [62].

Whereas neoclassical economics focuses on wants and preferences that are purely subjective; needs, capabilities and primary goods have the advantage to be objective [73]. Objective approach to wellbeing can provide a firmer base to employ in sustainable resource consumption policy perspective, since it allows for intertemporal, international and intergenerational comparison [90]. Not any index or indicator alone proves perfect in describing and measuring human well-being however despite deficiencies each can be useful when used in consistent context. In our study, we decided to handle the issue through the framework of objectivists' approach due to the fact that it is better-suited to sustainable resource use context as discussed through this part of the chapter.

3.2.3 How Much Energy Do We Need? : Fair Use

We examined the views over the relationship between energy and human well-being and we acknowledged that there exists a causal interaction in low levels of consumption however the direction and the extent of the relationship is indefinite especially in higher levels of consumption. Then, we elaborated on what we mean by well being and clarified our position over the context. Now let's resume to the discussion at the end of part 3.2.1. about how overconsumption could be determined. Overconsumption, as a term should be referring to a definition of normal consumption. It is better to rephrase them as defensible and indefensible level of energy consumption. There are cases which majority of people can define as overconsumption or indefensible consumption, like two person living in a house with 10 rooms or owning a hundred pair of shoes. On the other side, there are also many cases where overconsumption is not that obvious [91].

Defining defensible levels of consumption is mainly a subject of justice and requires an answer to the question "Who has the right to get what?". In this study, we are intending to determine fair levels of energy use as part of the efforts in keeping within the critical natural boundaries. At this point, how we conceptualize the concept "fair" is important.

As mentioned before, there are obvious inequalities among nations and also within nations. North-South conflict has been more apparent in the last few decades. Patterns of consumption has been driven largely by historical and recent high per capita demand in the North; but the burdens of increased consumption of resources is felt throughout the world in the form of climate change and loss of biodiversity [92]. Inequalities are not only at international level, it is also within nations and among different groups of people. There is a long literature extending the justice discussion to the environmental issues, starting from Bullard's works[93], which was one of the first highlighting the disproportionate exposure of oppressed communities to burdens of environmental degradation [94]. Environmental justice mainly deals with the fairness of the distribution of the environmental benefits and burdens among humans and also among nations. In particular, for our case, we are interested in the fair distribution of the benefits of energy consumption.

The term fair varies in different contexts. In documents of EPA (United States Environmental Protection Agency) on environmental justice, fairness means that no group of people should bear a disproportionate share of the negative environmental consequences resulting from industrial, governmental and commercial operations or policies [95]. For this study, fairness is considered to be a term related with the distributive justice. Different distributive justice theories vary in their answer to the questions what is distributed, among whom and with which principle [3]. In our case, the benefits of energy resources, in other words energy services, is to be distributed. The community of justice is present generations and future generations. Since this study considers the scale of the human economy for the ecological sustainability, future generations' access to nature and its resources is also of its concern. Distributive justice theories distinguish by the principle of distribution they use. There are different principles of distribution in which everyone is taken in to account according to either needs, deserts, entitlements etc. Our proposal is closer to a needs based distribution. According to the Needs Principle, a fair allocation is simply one that is sufficient to meet each individual's basic requirements for life [96]. Those, for example, who live in circumstances where they need to use more natural resources should profit more from the natural environment than others. Sachs [97] states, if Kantian justice could be adapted to international scale the freedom of a nation is constrained by the equal freedom of all other nations. Consumption of finite resources should be at such a level that the right of other nations to get their needs is not constrained. From this viewpoint, a fair distribution of global resources require each country organize its resource consumption in accordance with rules which, in principle, could be adapted by all other countries. Within a nation, similarly, over appropriation of natural resources, getting more than needed, by some group of individuals, at the expense of many others contradicts such rules [97]. This needs based perspective brings us to question how much energy do we need.

Determining a subsistence level energy consumption is relatively less contradictory. Basic needs like access to shelter, food, water are closer to be universal and widely recognized. However, when it comes to the boundary between needs and wants or basic needs and advanced needs, we step in to a more debated area. As discussed in the previous section, needs are considered relatively stable and universally less changing.

However, what is changing is need satisfiers [98]. Need for a shelter applies to all people however how this need is satisfied, the properties of houses, differs from culture to culture. Intercultural and intertemporal change in the understandings of what is needed and how needs are satisfied, makes it very complicated to assess the amount of energy. For instance, if we consider access to basic communication as a need to be satisfied or as a capability to be provided, what would be the energy required for meeting this component of well-being? It is used to be met by fixed telephones at homes 20 years ago. But now smart mobile phones have become the standard equipment for communication. Therefore, the need or capability to communicate was used to be satisfied through less energy consumption since we used the former telephones less. However, from today's perspective, smart phones and Internet in our pockets could be considered as need for many people. Maybe not accessing to games but access to Internet on mobile phones could be claimed/defended to be a need/norm, despite the fact that we did not need it 20 years ago. Another example of a temporal change in social norms can be observed in peoples shower habits. It is not a technology driven change. Only a few decades ago, taking a warm shower once a week was not unusual in Turkey. However, today one can defend taking daily shower as a need and claim the corresponding energy consumption as part of the right to have social respect. Intercultural differences in the level of energy services needed was also discussed in the Part 3.2.1. Further, interpersonal perception of needs (not basic needs) and wants may differ. As a result, we don't attempt searching for upper social threshold in the boundary between needs and wants. Obviously, upper social boundary should lie somewhere higher than the level where basic needs met, the lower threshold. Some scholars choose a level of well-being, based on a list where UN classifies countries from low developed to very high developed with respect to their well-being indicators scores. This sounds like choosing an optimum or upper boundary level for well-being. However, we refrain us from not only the ambiguity of defining needs and wants; but also from being determinant on what level of well-being is enough for human. Instead, our intention is to be able to determine a level of energy consumption that is not defendable.

Searching an answer to the question what level of energy is defendable, requires us to assess our current state of consumption in relation to our well-being. In other words, if we justify our energy consumption from the point that it increases our wellbeing, then any increase in our consumption that does not lead to a significant improvement in our well-being could be considered as indefensible. Through this aim, we need to analyze the relationship between energy consumption and wellbeing and try to detect some benchmarks where further energy consumption corresponds to relatively lower or no improvement in well-being. We prefer to name this upper benchmark as "fair use" level, for the reason that it refers also to justice.

Fair use indicates a consumption level which does not endanger others basic rights to access sufficient energy resources. It simultaneously serves for the purpose of stabilizing the resource consumption in order not to hit the critical natural boundaries. We aim to increase the average level of well-being in the society with less energy consumption per capita. This target could be achieved by reducing our energy use by technological efficiency. On the other hand, it could also be achieved partly by eliminating the injustice within society, in other words re-distributing the current total available energy resources. While a number of people enjoys large amounts of energy, there are also a large number of people that do not have access to energy resources for their basic needs. If the amount of consumption higher than the fair use level can be utilized for the ones that would get higher well-being improvements with the same amount of energy, it will serve for both limiting resource use and increasing the average wellbeing of the society. Therefore, we need to explore benchmarks which will warn us about excessive and unfair uses of energy resources.

CHAPTER 4

DETERMINING THE FAIR USE LEVEL

4.1 Literature Review

There have been studies which argue about a level energy consumption and greenhouse gas emissions, where access to basic well-being needs satisfied. Henry Shue was one of the first to declare a need for a moral minimum level for the greenhouse gas emissions. He distinguishes subsistence emission from luxury emission and argues this distinction to be taken into account when allocating mitigation burdens [99]. Rao and Baer [100], conceptualize "decent living emissions", which they propose to be used as a threshold to be exempted from the mitigation burdens. They determine decent living activities, which are necessary to achieve a list of basic goods and they suggest calculating corresponding direct and indirect energy consumption and emissions with bottom up methods like environmentally extended input-output analysis. Druckman and Jackson [101] attempt to determine a kind of decent living emissions for UK through bottom-up methods. They calculate the emissions produced in purchased goods and services that is required for achieving a minimum income standard. While they also end up with energy consumption figures as they have to use them in calculating emissions, they stay focused on emission rather than energy consumption. As mentioned before, focusing only on emissions may cause to ignore other environmental impacts of energy consumption and it may imply as if emissions are needed for development rather than energy consumption or energy services. The study of Goldemberg et al.in 1985 [102] was one of the earliest that uses bottom up methods to determine the energy requirements to reach a basic level of well being. They suggested that 1 KW/cap (32 GJ/cap) energy is sufficient to meet the basic needs at the year calculations were made. Zhu and Pan [103] similarly employ a activity based bottom up calculation and estimate an energy requirement of about 80 GJ/cap to meet decent living standards in China. These bottom up approaches rest on many assumptions regarding the type of energy consuming equipment (heaters, light bulbs, etc.), their sizes and intensity of consumption and production [104]. They also require defining a set of basic needs and determining an appropriate level of that which can be assumed as decent threshold. Even though, they are valuable efforts in understanding minimum energy requirements to achieve basic needs. For us, what as important is, to be able to quantify an upper benchmark which will guide us to enable the amount of energy required for raising people to subsistence level without increasing the total energy budget of the world.

Spreng, in his study at 2005 [104], proposes an upper limit to global average per capita energy consumption. His proposal is grounded on a climate model estimating an emission level of 8 Gt/year in order to stabilize climate change by the year 2050 . He translates this emission figure to per capita energy consumption using that year's average carbon content and suggests 2000 W/cap as an upper limit. He also proposed a basic needs limit of 600W based on the estimations on energy consumption of the poorest decile in 2050. Raworth [105] describes a safe and just space between a social boundary at the lower level and planetary boundaries at the ceiling. She argues that if only economy operates within this space, it could be sustainable and inclusive. On the other hand, Di Giulio and Fuchs [106], in their study which they conceptualize a similar space named "sustainable consumption corridors", argue that lower and upper limits have to be determined based on well-being concerns. However, they don't empirically analyze and determine these lower and upper boundaries.

Another group of previous studies prefer to adopt a top-down approach and examine the relationship between energy and well-being indicators through a macro-scale international perspective. Mazur and Rosa [107] were among the first to ask the question whether nations having relatively high energy consumption always have higher quality of life than those with lower energy consumption. In their study, they employ a cross-sectional correlation analysis between total primary energy consumption and 27 well-being indicators with a sample of 55 countries. They found strong correlation when all nations included but the correlation weakens when only industrialized countries are used. Buttel [108] makes a similar analysis by using energy intensity instead of energy consumption. On the basis of his findings, Buttel concludes that reduced energy intensities in industrialized countries need not deteriorate social well being. Rosa et al. [109] [110] use also longitudinal data for 25 years period (1950-1975) for 25 industrial countries. Of the 36 social indicators only 8 displayed significant correlation with energy consumption. Suarez [111] employed a cross-national analysis and he also compares energy and HDI relation in 1960–65 and in 1991–92, and found an improvement in average HDI at lower energy levels in the later data set. He observes that strong positive covariance of energy consumption with HDI starts to diminish after 1000 koe/cap. Pasternak [112] explores the same relation by correlating electricity consumption and HDI values of most populous 60 countries. He visually observes a plateau around 4000 kWh per capita electricity consumption which corresponds to an HDI value of 0.9. German Advisory Council on Global Change (WBGU) [113] proposed several "guard rails", which are defined as thresholds not to be transgressed for economic and social sustainability. 10 countries having relatively high HDI and low HPI (Human Poverty Index) value among 70 poorest countries are selected. Arithmetic mean of total primary energy consumption per capita values of these selected 10 countries is proposed to be the macroeconomic minimum energy requirement per person and year (7250 kWh/cap or 27 GJ/cap)). They also admit that climatic, geographic, cultural and historical differences make it difficult to determine a global minimum energy level. Smil [54] analyzed the relationship between average per capita energy use and some selected quality of life indicators by a cross-sectional correlation using a sample consisting of 55 most populous countries. Infant mortality, Life expectancy, Average per capita food availability, Literacy rate, Combined school enrollment ratios, HDI, Political freedom index are chosen as quality of life indicators. He detected a non-linear relationship between energy consumption and all indicators except political freedom index. He observed diminishing returns after 40-70 GJ/capita interval and almost no additional gains after 110 GJ/capita level. Dias et.al [114] carry out a similar cross-sectional regression analysis but they prefer to use Human Development Index (HDI) alone as an indicator of quality of life. The estimated regression curve is used to determine a level of energy consumption corresponding to the lowest HDI level among OECD countries which is assumed as a threshold point for being a developed country. Consequently, they utilize this threshold to estimate an average energy saving potential for OECD countries. Martinez and Ebenhack [115] employ a cross-sectional analysis between HDI and energy use as Dias et al., but they isolate some special case nations like OPEC countries and Former Soviet States and observed a stronger correlation for the rest. Steinberger and Roberts [116] carry out a cross-sectional analysis for the years 1975-1985-1995-2000-2005, derive threshold functions for energy consumption and carbon emission for each year. Through these functions, they determine saturation level for energy and carbon which correspond to UNDP's high human development benchmarks. This was one of the few attempts for observing the dynamic nature of the relationship between energy consumption and indicators of quality of life. They use HDI and also the components of HDI separately and for all indicators they observe that the energy threshold is decreasing over time. It means achieving human well being is becoming steadily more efficient. Mazur [117] repeats his previous cross-sectional correlation analysis and this time he also tested for a longitudinal data sample of 26 years. 11 of 13 quality of life indicators do not show any significant correlation with energy consumption in 21 industrialized countries. He admits that his analysis ignores specific circumstances of each nation like climate and geography which may affect the utility obtained from a unit of energy consumed. Steckel et al [118] correlates 144 countries final energy consumption with HDI and proposes 100 GJ/cap as threshold which corresponds to very high development benchmark of UNDP. Lambert et al. [119] investigates the impact of declining EROI (Energy return on energy invested) on the energy consumption and quality of life relationship. Study concludes that the contribution of both EROI and energy consumption saturates at certain levels. A selection of previous studies estimating a threshold level listed in Table 4.1 [120]. Our study differs in the energy indicator it used and the method it employed to detect the threshold from the previous studies.

4.2 Indicators

4.2.1 Energy Indicator

We need to decide which indicators would best represent the energy consumption and human well-being through our purpose. What supports the development of human well-being is not the energy consumption itself but the services it provides. These

Table 4.1: Selected studies from literature (TPED-Annual per capita total primary energy demand. EC-Annual per capita electricity consumption. FEC-Annual per capita final energy consumption)

Study	**Threshold**	**Well-being criteria**
(Pasternak, 2000)	EC: 4000 kWh (14.4 GJ)	HDI > 0.9
(Goldemberg, 2001)	TPED: 42 GJ	"acceptable standard of living"
(Smil, 2003)	TPED: 110 GJ	Saturation level in well-being
(WBGU, 2003)	Average TPED : 35.4 GJ	0.7 < HDI < 0.8
(Dias et al. 2006)	TPED: 120 GJ	Lowest HDI of OECD countries
(Martinez and Ebenhack, 2008)	16.7 GJ < TPED < 33.5 GJ TPED: 121.4 GJ	"extremely low" < HDI < 0.7 HDI > 0.9
(Steinberger and Roberts, 2010)	TPED dynamic function: 60 GJ (2005)	HDI > 0.8
(Steckel et al., 2013)	FEC: 100 GJ	HDI > 0.8
(Lambert et al. 2014)	TPED: 150 GJ	Saturation level in well-being
(Rao et al., 2014)	TPED: 30 GJ	90 percent of population living in "decent conditions"

services, such as thermal comfort, mobility, illumination, are called energy services and they constitute the very end point of the energy flow. Energy resource travel through different phases during this flow towards maintaining the energy services. The initial form of the energy resource is called the primary energy. It is the energy embodied in resources as they exist in the nature. It is then converted in to some secondary forms to make it ready for transport and transmission (i.e.refined oil, electricity). The energy converted is then distributed to the end users. The electricity at the socket, gasoline and diesel at the service station and natural gas at the cooker's pipe are named as final energy or delivered energy. This final energy is transformed in to useful energy such as heat or kinetic energy etc. through devices, machines and vehicles [121].

In most of the studies, primary energy consumption is used as an energy indicator.

Final energy consumption is used less frequently in the literature relating energy consumption with human well-being. Both energy indicators do not perform well through understanding the relationship. Instead we preferred to use disaggregated final energy, in particular residential energy consumption for several reasons. Firstly, primary energy consumption figures do not inform us well about the true amount of energy that is responsible for the achieved development in well-being. In other words, a country can enhance its citizens' well-being without increasing its primary energy consumption simply by importing energy-intense products instead of producing within the country. This is also valid for final energy consumption figures. This would bias our analysis since we are trying to determine what amount of energy is responsible of a certain level of well-being. The decrease in the amount of primary energy consumption in a country does not necessarily imply increasing energy efficiency, it may be the consequence of exporting responsibilities to some other countries. On the other side, residential energy and passenger transport energy consumption figures reflect the energy consumed only within the country. In this case, the responsibility can not be transfered to another country.

Secondly, total energy consumption figures includes components that could be related to well-being indirectly. Energy used in industry, for instance, leads to economic development and economic development leads to an increase in well-being. Relationship seems to be more indirect and prone to inefficiencies between economic growth and well-being. However, residential energy consumption can be more directly related to well-being of the household. Energy used for heating and cooling, cooking or similarly energy used for mobility has a direct impact on the quality of life of an household. Using disaggregated energy consumption as an indicator also enables us to observe how the nature of the relationship between human well-being and energy consumption differs in specific areas of use.

Last but not least, results of the analysis of disaggregated energy use will likely be more convenient for policy purposes. The energy consumption data that is used in this study is what we see in our utility bills. It is easier to picture in mind for consumers and easier to control for policy makers than total primary energy. Total primary and final energy figures present a general idea about a country's performance in achieving its human well-being level, however provide no clue of where the inefficiencies occur.

In the same manner, it would be better to further disaggregate residential energy to its subcomponents if the data were available. Our analysis will be mainly based on residential energy consumption per capita, however, final energy consumption per capita will also be included in the analysis for comparison purposes.

4.2.2 Well-being Indicator

As it is mentioned, this study does not attempt to propose a theory of defining and measuring well-being. Rather it discusses the existing understandings and utilizes those which serve best to our purpose. It is also mentioned in chapter 3, that this study follows the Eudaimonic tradition in defining well-being and argues in favor of using objective indicators in measuring well-being. Now the point is how to operationalize these concepts for our analysis.

Doyal and Gough[74] categorizes needs as basic needs and intermediate needs. They argue that the ultimate end of human activity is "minimally impaired social participation" and two universal basic needs are critical to achieving social participation. They conceptualize these needs as physical health and autonomy of agency. They also define a closed list of intermediate needs, which are essential preconditions to meet basic needs (Access to adequate nutritional food and water, housing, healthy work environment, healthy physical environment, health care as related with health; Security in childhood, relationships with others, physical security, economic security, safe birth control, education as related with autonomy). On the other side, although Sen has refrained from listing capabilities, he acknowledges that a sub-set of relatively important capabilities associated with basic needs may be identified [122]. Capabilities or needs can be categorized in to those not vary much among people and those may vary depending on the cultures. Needs such as access to nutrition, access to education, access to shelter and health and avoiding disease could be considered as examples of the first group of needs, which are relatively universal and unchanging. Needs such as avoiding shame, having self-respect are examples of the second group, culturally changeable [100].

We don't claim to take in to account all dimensions of well-being. Our intention is to choose well-being components that are relatively independent of culture and represent the important dimensions of well-being. We don't generate a long list of indicators in order to represent all intermediate needs, or capabilities but following the Doyal and Gough's [74] basic needs approach, life expectancy is chosen to represent physical health and access to education to represent autonomy. Life expectancy at birth is one of the most commonly-held indicators of human well-being. It captures the overall health conditions of society since it directly reflects longer lifespans and reductions in infant mortality, and indirectly reflects access to nutrition, life-long medical services, living conditions [123]. It is also possible to relate household energy services with life expectancy. Inadequate housing conditions (i.e. indoor pollution, lack of heat comfort, intensive housework due to lack of appliances) cause or contribute to many preventable diseases. For such reasons, life expectancy is a reasonable indicator that can represent the human need of health. In Doyal and Gough's concept, autonomy reflects the ability to learn, work, engage in and reflect on culture, and enjoy leisure. It requires mental health, cognitive skills and opportunities to engage in social participation. Access to education is an indicator that could at least partly represent the this described autonomy [74]. Adult literacy rate was used to be the common indicator. However, for our data group, consisting of mostly medium-to- high developed countries, adult literacy rates range mostly around 80-100 percent. Education index used in HDI could be a better in representing to the level of education from kindergarten to postgraduate education. Education Index is an indicator which combines expected years of schooling and mean years of schooling in a country. We use to use both Education Index and also its component expected years of schooling as separate indicators.

Certainly there are other dimensions of well being such as human dignity and psychological wellbeing. Rao [124] asserts that these are not very strictly dependent on material conditions. Once people have access to good health and education, other psychological components of well being depend less on resources, materials and energy, rather it depends on some other factors such as how people treat each other in the society. Life expectancy and Education indicators are also part of the Human Development Index, which is developed on the theoretical basis of capabilities approach. Besides health and education, HDI also includes living standards as a third component. However, living standards is represented by GDP per capita. Living standards could be a determinant in wellbeing, however, GDP is not a correct indicator of living standards and therefore human well-being, for the reasons which discussed in chapter 3. Instead of HDI, we included the Non-income HDI indicator in to our analysis. It is an index reported by UN and combines two non-income components of HDI. On the other hand, we don't exclude HDI totally from our analysis for comparison purposes

4.3 Data

Indicators have been determined and now the data for these indicators to be gathered now. In this study, we used nation states as a unit of analysis like other studies in the literature did. It is because the data is largely available in national level. Household energy data is taken from IEA World Energy Balances Report [125]. Well-being indicators data are available at UN Statistical Databases.

Before getting into analysis, we tried to eliminate and control as many factors as we can that could possibly bias our analysis of the relationship between human well-being and energy consumption.

Climate is one of them. Assume two identical countries with different climatic characteristics. They would end up with different energy consumption values for the same level of well-being. A true comparison requires climate normalization of countries' energy data as if they all have similar climatic conditions. Residential energy consumption consists of space heating, space cooling, water heating, appliances, lighting and cooking energy components. Among these, space heating and cooling are the most affected components by the differences in climate. The impact of climate on heating and cooling energy demand is generally quantified by using the indicators called Heating Degree Days(HDD) and Cooling Degree Days (CDD). Heating demand of a location is assumed to be linearly proportional to the number of HDD of that location. Heating degree days is simply the difference between the average temperature of a given day in a given location and the pre-determined base temperature. Base temperature is usually the temperature at which a building needs to be heated. Above this temperature, heating systems are expected to be off. Although base temperature and HDD are measures that may vary from region to region or building to building, most widely 18 C degrees is used as a base temperature. Choosing another base temperature would result in different HDD figures. Yearly HDD is simply the summation of daily HDD's. The value of HDD is the most reliable when it is measured in the smallest unit (i.e. a building). When it is to be calculated for a country, you have to deal with the inconvenience carried by the assumptions and generalizations. Degree day readings of regions of a country multiplied by the corresponding population weight for each region, then summed to determine population weighted degree day figure of the country.

Cooling Degree Days is similarly a measure for cooling demand referencing a cooling base temperature. Estimating the cooling energy demand is more complicated than estimating heating demand. It is because most of the time where theoretically a cooling energy demand is expected, no cooling energy consumption is observed. For instance, many people living in tropical climates are not able to afford the equipment and the energy needed for cooling. Cooling energy consumption still constitutes a very small part of the domestic energy consumption in most of the countries. On the other hand, cooling energy consumption has an increasing trend and will probably be important component of residential energy consumption with increasing wealth in developing countries in the recent future. However, since it brings more complication than benefits to our analysis, we decided not to normalize our data for cooling.

In order to obtain a climate corrected residential energy dataset, space heating energy consumption data of countries are required. We have reached the data of 40 countries out of 70 which has a significant heating demand (Out of 186 countries with available national HDD data, 80 countries have zero HDD). First we subtracted the space heating energy values from residential energy consumption. Then, using the space heating energy data and corresponding HDD figures of countries, energy consumption per HDD figures are obtained. These values roughly give an idea about the countries' space heating efficiencies. It is now possible to calculate an expected space heating energy consumption of countries for any HDD value. These re-calculated space heating energy figures are used to obtain the climate corrected residential energy consumption data for a chosen HDD ((Eq. 4.1)).

$$REC(Climatecorrected) = (REC - SHEC) + ((SHEC/HDD) * HDD_c) \tag{Eq. 4.1}$$

It is possible to observe from Table 4.2 how correcting for climate changes the energy consumption performance rankings of countries (Residential energy consumption figures are corrected as if all countries have 1000 HDD). We also tabulated residential energy consumption without space heating data. This dataset includes countries with available space heating data and the countries having zero or neglectable HDD. It can be said that this dataset is also almost free of climate impacts and it provides us to test the relationship with a larger group of country. Now we have prepared two datasets for our analysis each of which is expected to provide additional insights about the relation between energy and well-being.

The level of resource endowment in a country is another factor that could bias our analysis. In our preliminary analysis on the dataset, it is noticed that energy rich countries follow a different trend (Figure 4.1). Martinez and Ebenhack [115], in their study of the relationship between well-being and total primary energy consumption, also observe a distinct trend for heavy energy exporter countries such as OPEC members and Former Soviet Union (FSU) Countries. These countries tend to achieve the same well-being levels with higher amounts of energy compared with energy importer countries. States could subsidize or manipulate prices with taxes and policy measures. Nevertheless, a lower energy price and accordingly an overconsumption is observed in most of the energy (oil and gas) rich countries. After excluding these energy exporters, now our dataset consists of countries having similar conditions in terms of access to cheap energy. Furthermore, Former Soviet Union States are still special cases due to their inefficiency in the production sector and equipments. During the analysis, when one of the Former Soviet countries appeared as an outlier, we preferred to exclude those for a better model fit.

Table 4.2: Residential energy cons. per cap. before and after climate correction

Country	**HDD**	**REC**	**Country**	**REC Corrected**
Finland	5212	41.87	USA	25.52
Canada	4493	40.18	Canada	20.81
Norway	4535	34.59	Australia	19.01
USA	2159	33.65	Finland	18.19
Denmark	3621	32.81	Sweden	16.97
Sweden	4375	32.53	Greece	16.86
Austria	3446	32.44	Norway	16.73
Estonia	4605	30.69	Italy	16.25
Switzerland	3419	30.36	France	15.96
Germany	3252	29.60	UK	15.70
Latvia	4237	28.35	Estonia	15.66
France	2478	26.85	Austria	15.63
UK	2810	26.42	Germany	15.46
Netherlands	3035	25.72	Switzerland	15.32
Slovenia	3290	24.35	Cyprus	14.15
Italy	1838	24.19	Netherlands	13.82
Czech Republic	3569	24.11	Latvia	13.74
Ireland	2977	23.97	Japan	13.67
Poland	3719	22.06	Denmark	13.34
Hungary	3057	21.52	Ireland	13.14
Lithuania	4218	21.46	Slovenia	12.81
Greece	1269	19.18	Korea	12.65
Australia	828	17.73	Czech Republic	12.48
Croatia	2289	17.69	New Zealand	12.17
Korea	2480	17.01	Hungary	12.11
Japan	1901	15.51	Spain	11.71
New Zealand	1609	13.72	Portugal	11.27
Spain	1431	13.60	Poland	10.77
Cyprus	710	13.35	Lithuania	9.82
Portugal	1367	12.81	Croatia	8.18

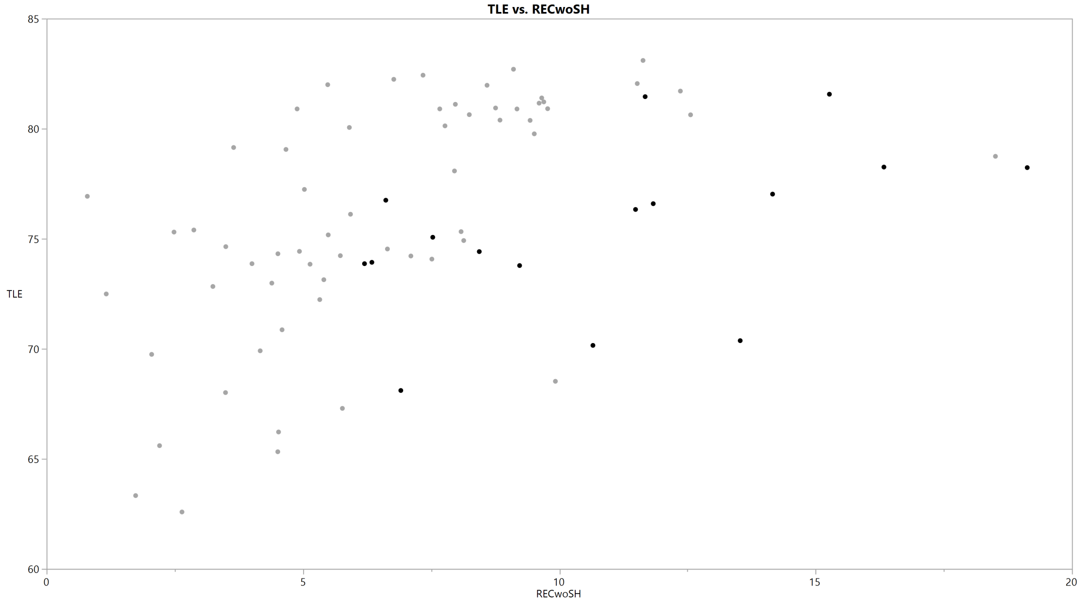


Figure 4.1: Energy rich countries and FSU countries' trend (Highlighted)- Residential Energy Consumption per cap. vs Total Life Expectancy

Similarly, countries not having enough access to modern energy sources and carriers show a distinct trend, as observed in the preliminary analysis (Figure 4.2, Figure 4.3). Martinez and Ebenhack [115] also analyzed the relationship between the fraction of biomass used to meet energy needs and Human Development Index values of countries and observed that countries dependent on traditional biomass consistently fail to achieve average development levels. This is mainly due to the inefficiency of traditional biomass and its direct negative impacts on quality of life. Putting countries supplied by electricity and countries dependent on traditional biomass together in the analysis would be like comparing apples and oranges. Therefore, countries that meet more than 60 % of its energy demand with traditional biomass are excluded from the analysis.

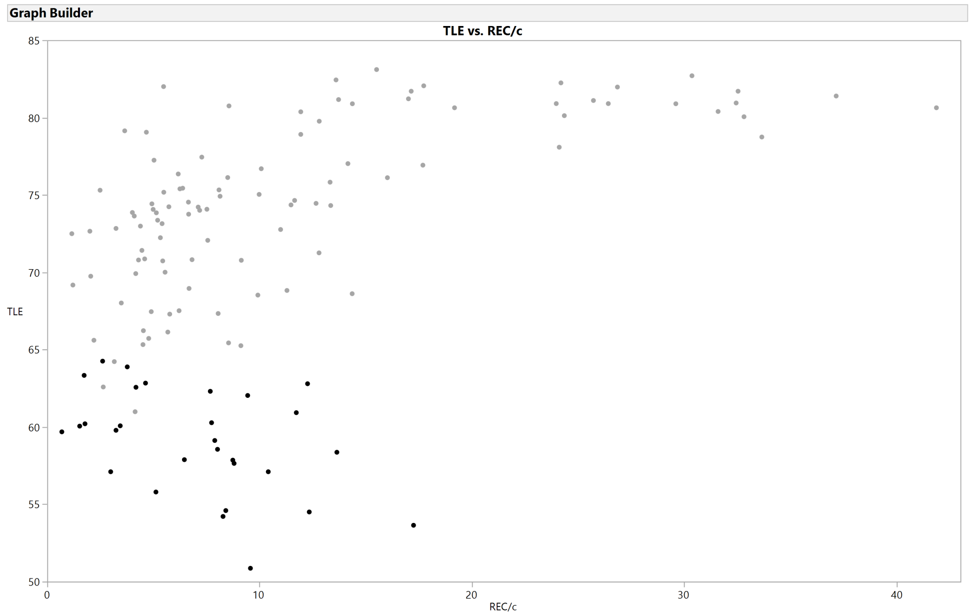


Figure 4.2: Traditional Biomass Dependent Countries- Residential Energy Consumption per cap. vs Total Life Expectancy

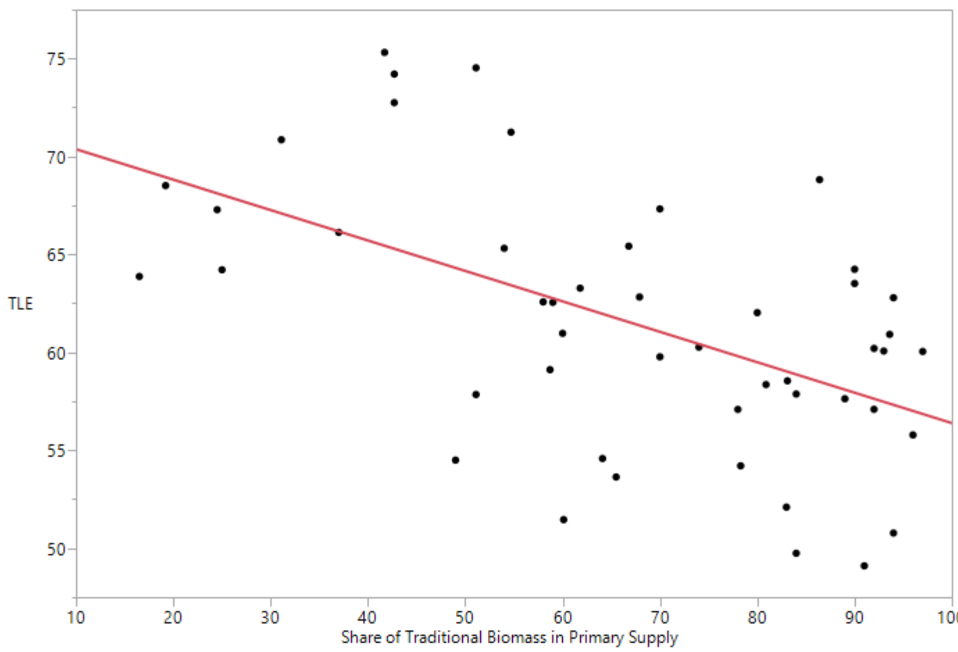


Figure 4.3: Share of traditional biomass in total primary supply vs Total Life Expectancy

At the end, for the empirical analysis, we left with a comparably homogeneous group

Table 4.3: Dataset - Residential Energy Consumption without space heating

Residential Energy Consumption without space heating				
Australia	Costa Rica	Guyana	Mauritius	Slovakia
Austria	Cuba	Hungary	Netherlands	Slovenia
Bahamas	Cyprus	India	New Zealand	Spain
Barbados	Czech Republic	Ireland	Nicaragua	Sri Lanka
Belgium	Denmark	Italy	Norway	Sweden
Belize	Dominican Republic	Jamaica	Panama	Switzerland
Brazil	El Salvador	Japan	Philippines	Thailand
Bulgaria	Estonia	Kiribati	Poland	Turkey
Cabo Verde	Fiji	Korea	Portugal	United Kingdom
Canada	Finland	Latvia	Romania	United States

of countries having similar energy availability, normalized climate and access to modern energy carriers (Table 4.3 and Table 4.4).

4.4 Methodology and Analysis

As indicated in section 4.3, two sets of energy data are tabulated: Climate corrected residential energy consumption at 1000 HDD (RECwSH) and Residential energy consumption without space heating (RECwoSH). Each energy dataset is regressed with the chosen well-being indicators data in order to model the relationship. Analysis with final energy consumption is also added to this section for the reason that it may provide additional insights.

4.4.1 Model Selection and Estimation

Scatter-plots are useful in order to get a general idea and see how the data points look like. Before all, it is important to recall that especially climate corrected residential energy dataset (RECwSH) consists of mostly developed countries. One reason is that the developed countries mostly lie in the colder regions, and have significant

Table 4.4: Dataset - Residential Energy Consumption corrected for 1000 HDD

Residential Energy Consumption corrected for 1000 HDD				
Norway	Sweden	France	Slovak Republic	Turkey
Switzerland	Ireland	Slovenia	Lithuania	China
Australia	United Kingdom	Italy	Chile	
Denmark	Japan	Spain	Portugal	
Netherlands	Luxembourg	Czech Republic	Hungary	
Germany	Korea, Rep.	Greece	Croatia	
United States	Belgium	Estonia	Latvia	
Canada	Austria	Cyprus	Romania	
New Zealand	Finland	Poland	Bulgaria	

space heating demand. Therefore, we won't be able to observe the trend in low development levels, but anyway our scope is for now higher levels of well-being where a saturation is expected. RECwoSH dataset includes more countries from medium development levels compared with RECwSH dataset. Among all data couples, only RECwSH-EDU plot (Figure 4.6) shows indications of a problem due to having not many countries from different development levels. Here most of the countries lie in the saturated region of the graph. In general, scatter-plots suggest that well-being continues to develop with the increase of energy consumption at medium and near high development levels, however after some level of energy use there is no significant development in well-being observed (Figures 4.4, 4.5, 4.6, 4.7,). This makes us to utilize some functional forms that follow a saturation behavior.

In the literature, a few different functional forms have been proposed and used in order for modeling the relationship between energy consumption and well-being. Semilogarithmic function is employed in studies by Pasternak [112] and Lambert et al. [119] (Eq. 4.2). Martinez and Ebenhack [115] suggest modeling the relationship in analogy with saturation phenomena that seen in some chemical or biological processes such as molecular adsorption, oxyhemoglobin dissociation, however they don't express which equation they choose and fit to data. Steinberger and Roberts [116] derive a hyperbolic function that can be transformed and solved by linear regression (Eq. 4.3).

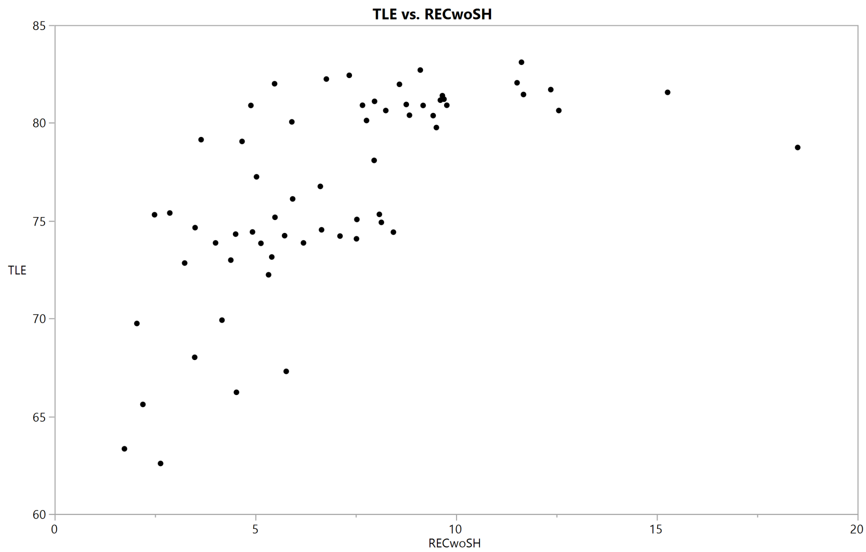


Figure 4.4: Scatterplot - Residential Energy Consumption per cap (without space heating) vs Total Life Expectancy

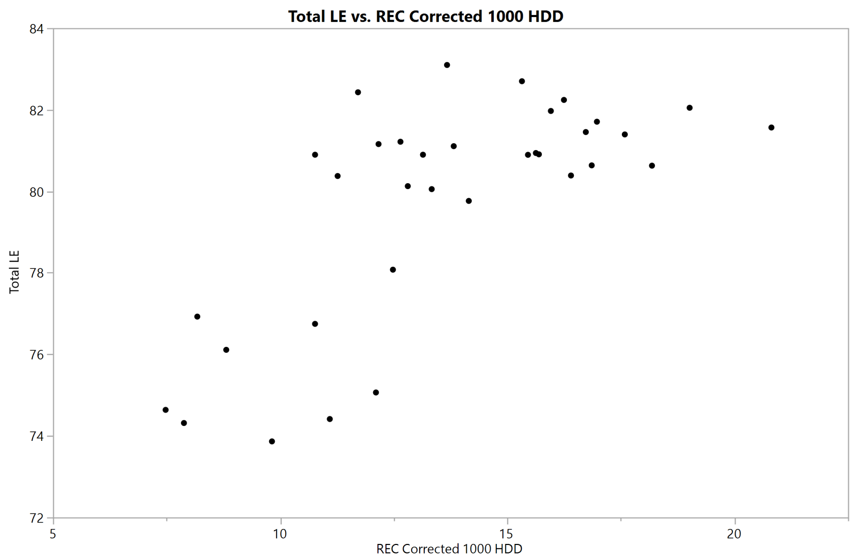


Figure 4.5: Scatterplot - Residential Energy Consumption per cap (climate normalized at 1000HDD) vs Total Life Expectancy

They found out that it fits the data slightly better than the semi logarithmic form and does not yield quadratic residuals. One negative thing with this model is that one should assume a maximum value for the human development variable chosen. All these previous studies employ either primary energy data or electricity consumption data, therefore we have to test these models also for our residential energy data. Be-

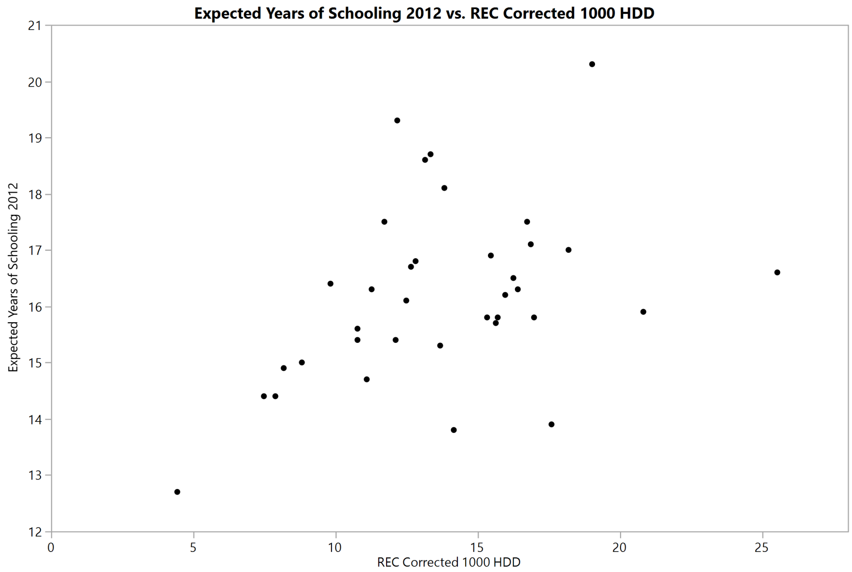


Figure 4.6: Scatterplot - Residential Energy Consumption per cap (climate normalized at 1000HDD) vs Expected Years of Schooling

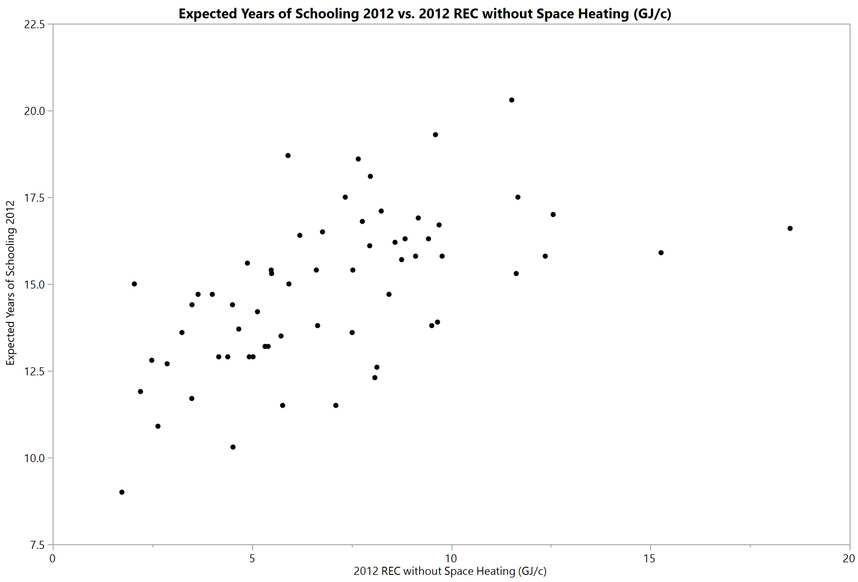


Figure 4.7: Scatterplot - Residential Energy Consumption per cap (without space heating) vs Expected Years of Schooling

yond these models, we also tested for different non-linear models which we think that could potentially approximate the saturation relationship. Non-linear regression has both advantages and disadvantages compared with linear regression. Main difficulty with it is that a good initial estimate is required for the numerical method chosen.

Lack of convergence is highly possible when starting values are not chosen close enough. Apart from the difficulties, when you decide using non-linear regression, a wide variety of functions become available for you to try and find a more robust model for explaining the relation. Another good point is the interpretability of the parameters. Usually, in a non-linear model each parameter could be associated with a property of the process behind the relationship. For instance, in a logistic function (Eq. 4.4), parameter A corresponds to the asymptote or the maximum possible value of the response variable and has the same units with the response variable. C is the inflection point where the growth rate achieves its maximum and has the same unit with the independent variable. B could be interpreted as the steepness of the curve, in other means the indicator of how fast the response reaches a saturation. In our study, in order to model the relationship between well-being indicators and energy consumption, we employed semi-logarithmic function, hyperbolic saturation function, logistic growth function, Brody function (Eq. 4.5) and Gompertz function (Eq. 4.6), using linear and non-linear regression platforms of JMP Statistical Software, R Statistical Environment, and SPSS Software where relevant.

$$HD = A + B * log(EC) \tag{Eq. 4.2}$$

$$HD = HD_{sat} - exp(A) * (EC)^B \tag{Eq. 4.3}$$

$$Y = \frac{A}{1 + exp(-B * (X - C))} \tag{Eq. 4.4}$$

$$Y = A * (1 - B * exp(-C * X)) \tag{Eq. 4.5}$$

$$Y = A * exp(-exp(B - C * X)) \tag{Eq. 4.6}$$

Table 4.5: Model Selection for RECwoSH vs Life Expectancy

Model	SSE	AICc	MSE	RMSE
Brody	635.2186	212.6431	10.95204	3.309387
Gompertz	635.535	212.6735	10.9575	3.310211
Logistic	635.8936	212.7079	10.96368	3.311145
Hyperbolic	639.0509	213.01	11.01812	3.319355
Semilog	661.5116	212.8239	11.21206	3.348442

4.4.1.1 Energy Consumption without Space Heating - Life Expectancy Dataset (RECwoSH-LE)

As stated recently, Steinberger and Roberts(2010) transformed the hyberbolic saturation function in to a linear expression. The response variable "HDI" took the form "Log(HDsat-HD)", and regressed linearly to the logarithm of energy consumption. However, the new response variable is hardly interpretable and not suitable for our purpose of visually inspecting the saturation behavior. Therefore, we didn't used linearized form of hyperbolic saturation function, in stead, we analyzed all models via nonlinear regression methods.

For the RECwoSH-LE dataset, Akakike Information Criteria (AIC) and other model fit measures don't provide enough evidence to favor one of these models to another. (Table 4.5) We inspected the model graphs and residuals for further clues. Semilogarithmic model curve is not saturating within our sample range, which is what we didn't expect from the scatterplot of the raw data (Figure 4.8). Hyperbolic model curve saturates also at high levels of life expectancy and high correlation between coefficient estimates is observed (Figure 4.9). It has also higher standard errors than other models. Model fit values of the other three models are very close and they show similar residual structure. Fitted curves are difficult to distinguish (Figure 4.10). Both Gompertz and Logistic models are S-shaped (sigmoid) growth models and include an inflection point parameter. Our dataset follows a concave downwards trend. It is possible that the whole relation may follow an S-shaped pattern if the data range could be extended to low development level region, however in our case inflection point add no insight to our analyze. Moreover, the coefficient representing inflection point in Gompertz and Logistic model estimates is usually a negative value, which is not possible in terms of energy consumption and life expectancy. This helps us to decide choosing one among very similar models. Brody model with 3 parameters representing asymptote, scale and growth rate is chosen to be the appropriate model for our analysis.

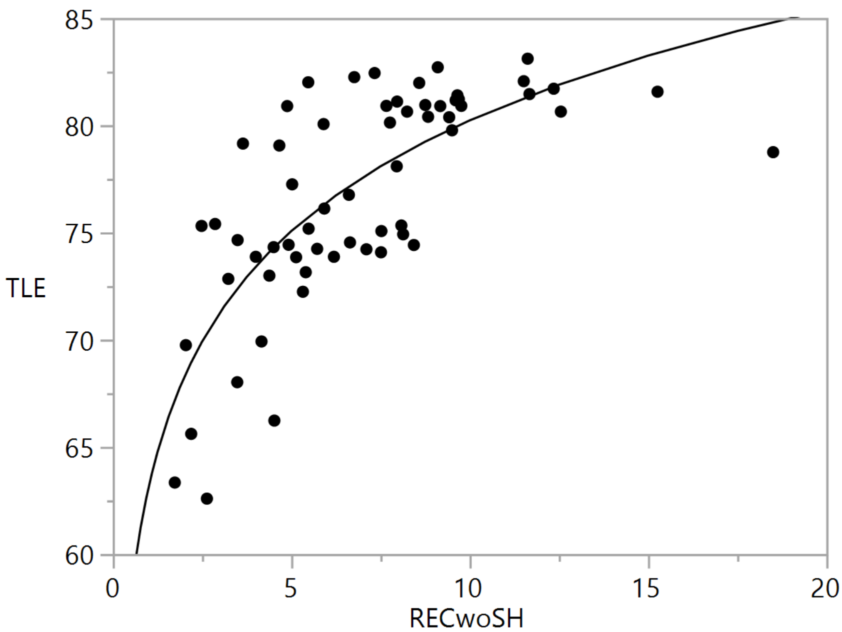


Figure 4.8: Model Fit - Semilogarithmic Growth Model - Residential Energy Consumption per cap (without space heating) vs Life Expectancy

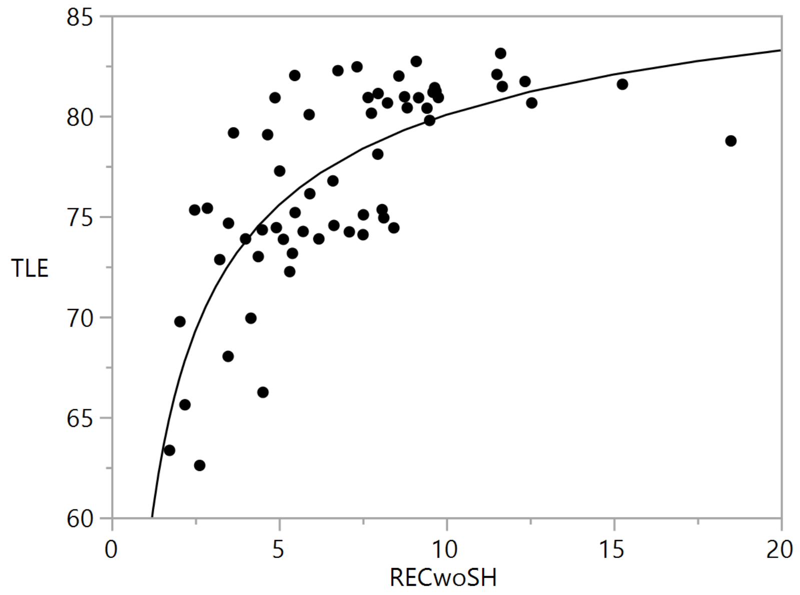


Figure 4.9: Model Fit - Hyperbolic Saturation Model - Residential Energy Consumption per cap (without space heating) vs Life Expectancy

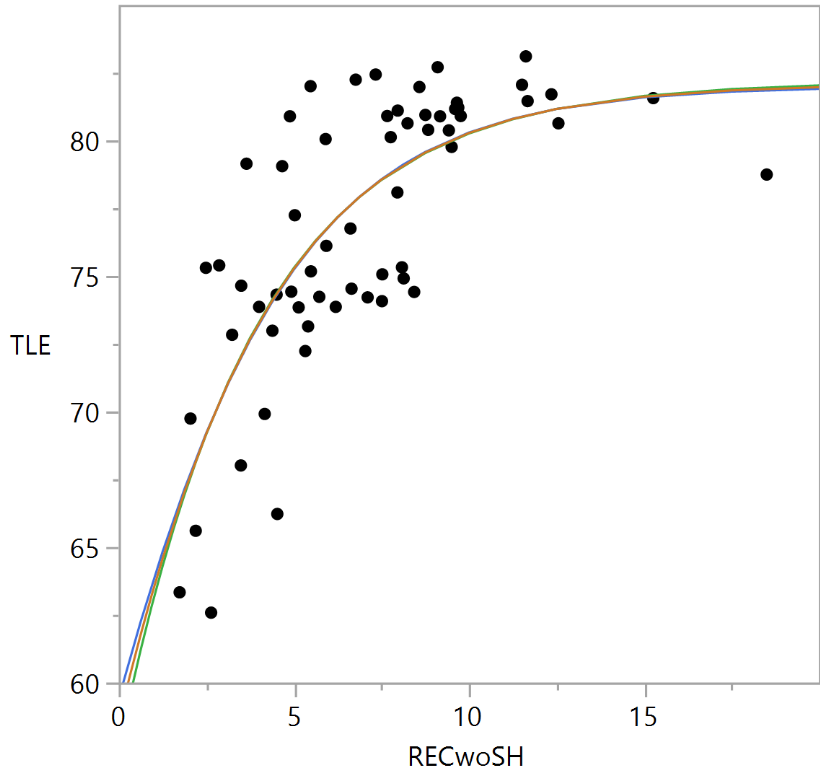


Figure 4.10: Model Fit - Brody,Logistic and Gompertz models - Residential Energy Consumption per cap (without space heating) vs Life Expectancy

Diagnostic analysis of the all three models shows that the residuals are normally distributed but suffer from heteroskedasticity (Figure 4.11). Both visual analysis of three residual plot and Levene Test indicates non constant variance in the residuals. Heteroskedasticity can be cured by variable transformation and variance modeling. As stated before, we are not favor of transformation of the variables, in order to keep the interpretability. In stead, we examined the residuals of the model fit to check whether they follow a certain pattern with respect to mean response or the predictor variable. A couple of different methods proposed in the literature in order for estimating the variance function. Bunke et al.[126] discusses the 6 most common models of variance and suggests estimating the main model and the appropriate variance function at the same time with cross validation method. Riazoshams and Midi [127] suggest graphical analysis of the empirical variances and mean responses to choose an appropriate model among these 6 most common models. For example, if a linear relation is observed between logarithm of empirical variance and logarithm of mean response in the graph, a power variance model can be assumed. For the exponential variance model, the logarithm of computed empirical variance is expected to be in proportion to the response average. We prefer to use this latter method. We regressed absolute residuals and fitted values of the Brody model fit. It exhibits linear relation which implies a linear variance model (Figure 4.12). We also regressed Brody model with power and exponential variance forms and compared the model fits and residual plots. Linear variance function has better AICc value (Table 4.6). Constant variance can be observed from residual plots (Figure 4.13). Also Cook's Distance test indicates that an outlier exists. It is the USA and we prefer not to exclude the USA from analysis. Therefore, a robust nonlinear regression is employed with a linear variance function in order to minimize the impact of the outliers and the heteroskedasticity to the model fit parameter estimates and corresponding prediction intervals (Figure 4.14). Robust Generalized Multistage Estimate algorithm of Riazoshams and Midi (2019) is used through this purpose [127]. Model fit results are shown in Table 4.7.

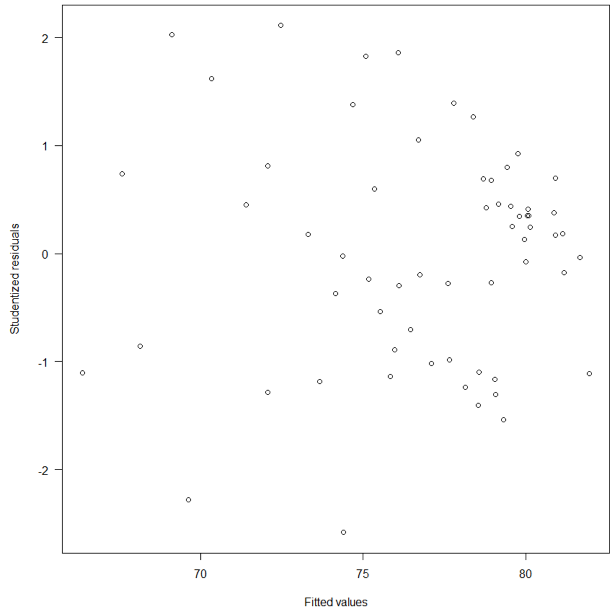


Figure 4.11: Residual Plot - Brody Model - Residential Energy Consumption per cap (without space heating) vs Life Expectancy

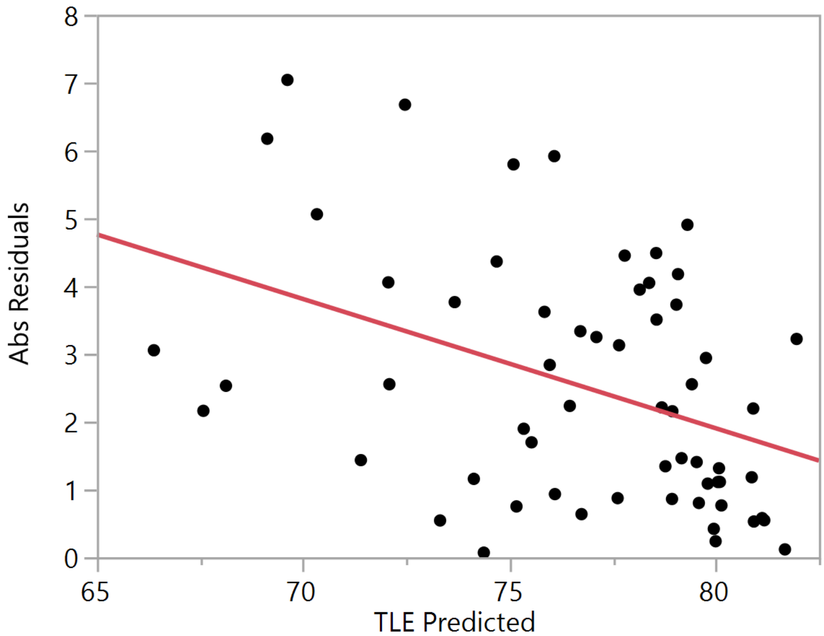


Figure 4.12: Variance Model Selection - Absolute Residuals vs Predicted Life Expectancy values from Brody Model Fit

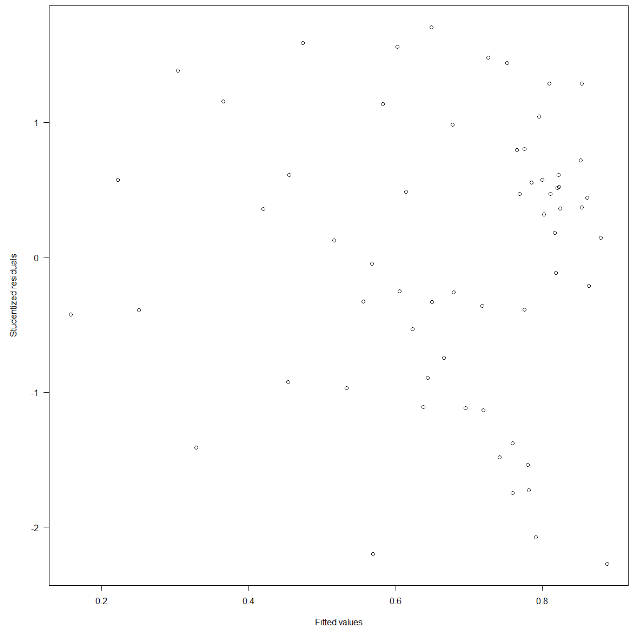


Figure 4.13: Residual Plot - Brody Model with Linear Variance Model - Residential Energy Consumption per cap (without space heating) vs Life Expectancy

Table 4.6: Variance Model Selection for RECwoSH vs Life Expectancy

MODEL	**AICc**
Linear	1636.3
Exponential	1638.2
Power	1639.8

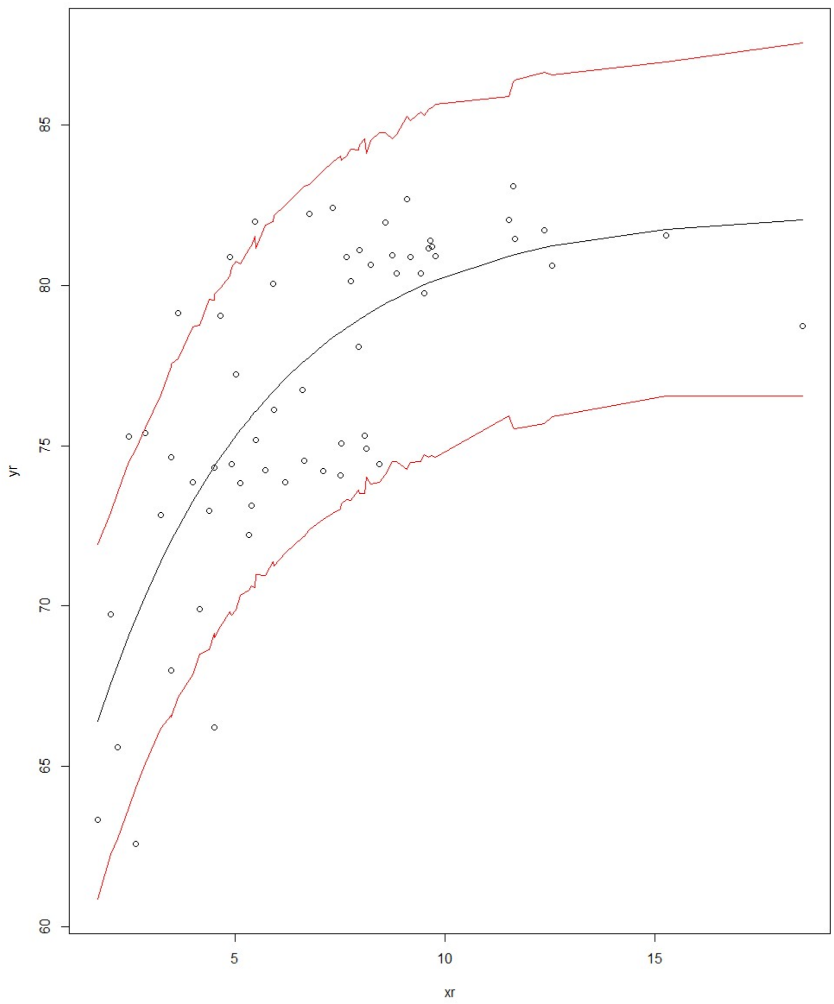


Figure 4.14: Robust Generalized Multistage Estimate - Brody Model with Linear variance model - TLE normalized vs RECwoSH normalized (with Prediction Intervals)

Table 4.7: Model Fit Results - RECwoSH vs TLE - Robust Generalized Multistage Estimate

Parameters	**Coefficients**	**CI low**	**CI upp**
p1	82.29517	82.2774	82.31296
p2	0.2979691	0.29747	0.298469
p3	0.249509	0.24871	0.250305

Table 4.8: Model Selection for RECwoSH vs Expected Years of Schooling

Model	**SSE**	**AICc**	**MSE**	**RMSE**
Logistic	149.6588	121.5666	2.672479	1.634772
Gompertz	149.6915	121.5794	2.673062	1.63495
Brody	149.7536	121.6039	2.674172	1.63529
Hyperbolic	150.81	122.0187	2.693022	1.641043

4.4.1.2 Energy Consumption without Space Heating - Education Dataset (RECwoSH-EDU)

Under the topic of education, we analyzed two indicators, Expected years of schooling and Education Index, with energy consumption in two separate regressions. For expected years of schooling, AICc values and other model fit measures are very close (Table 4.8). Asymptote parameter of the hyperbolic model is too large to be a reliable estimate of the maximum value of the response variable and correlation of the estimates are also very high (slightly less than 1). Therefore, hyperbolic model is eliminated. Using any of the three other models would bring the same results (Figure 4.15). Again Brody model is chosen to be fitted to the Expected Years of Schooling data. Residual diagnostics show that the normality and homoskedasticity assumptions are satisfied. Cooks distance test indicates possible outliers. Therefore, Robust MM estimator would give better results, narrower prediction intervals (Figure 4.16) (Table 4.9).

Similarly, Brody model is chosen to model the relation with education index. Residual diagnostics indicate error distribution is close to normal and variance is almost constant through the data range. Few outliers exist in the low energy consumption levels. However, we prefer not excluding those since we have not much information in that levels. Robust MM estimator is used to estimate model parameters (Table 4.10).

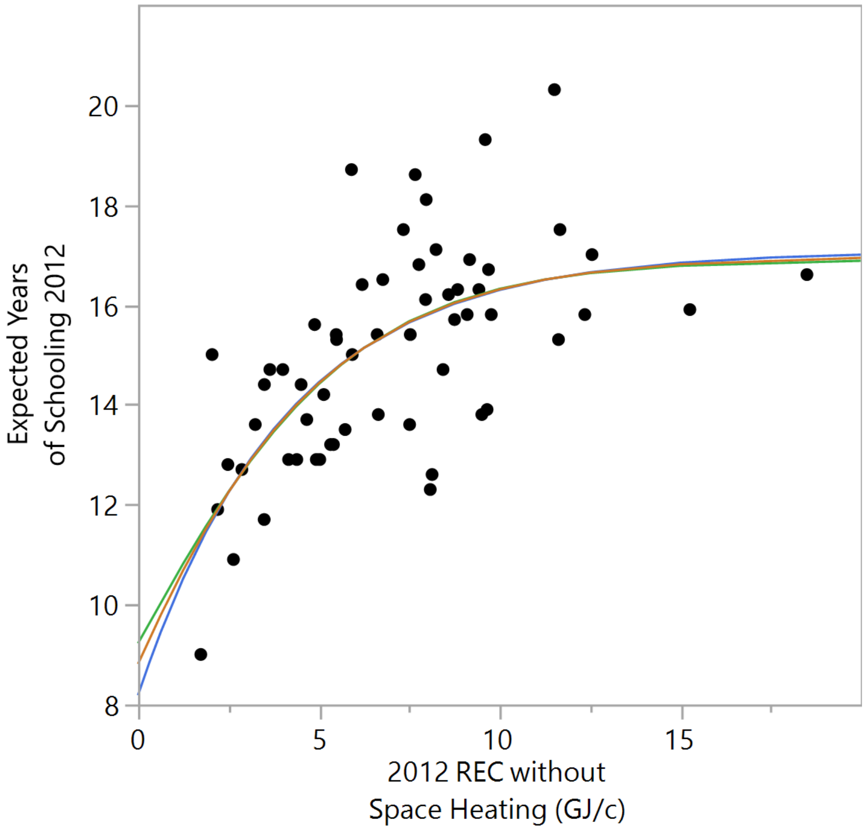


Figure 4.15: Model Selection - Residential Energy Consumption per cap (without space heating) vs Expected Years of Schooling

4.4.1.3 Energy Consumption without Space Heating - HDI Dataset (RECwoSH-HDI)

Similarly AICc values are close but slightly favors Brody model (Table 4.11). As seen in the model fit plot, all three models fit the data similarly (Figure 4.17). We decided to use Brody model as previously. Raw data indicates a few outliers which are very small island states. Excluding those will not effect our scores much but help our data to get closer to normal distribution. There are a few outliers again which we don't want to exclude. Therefore, Robust MM estimate is applied on the Brody model. Residual diagnostics indicate homoskedasticity and normal distribution. Model fit results are shown in Table 4.12.

Non-income HDI data are also fitted using Brody model after comparing with other models (Figure 4.18). Residuals are distributed normal and variance is almost con-

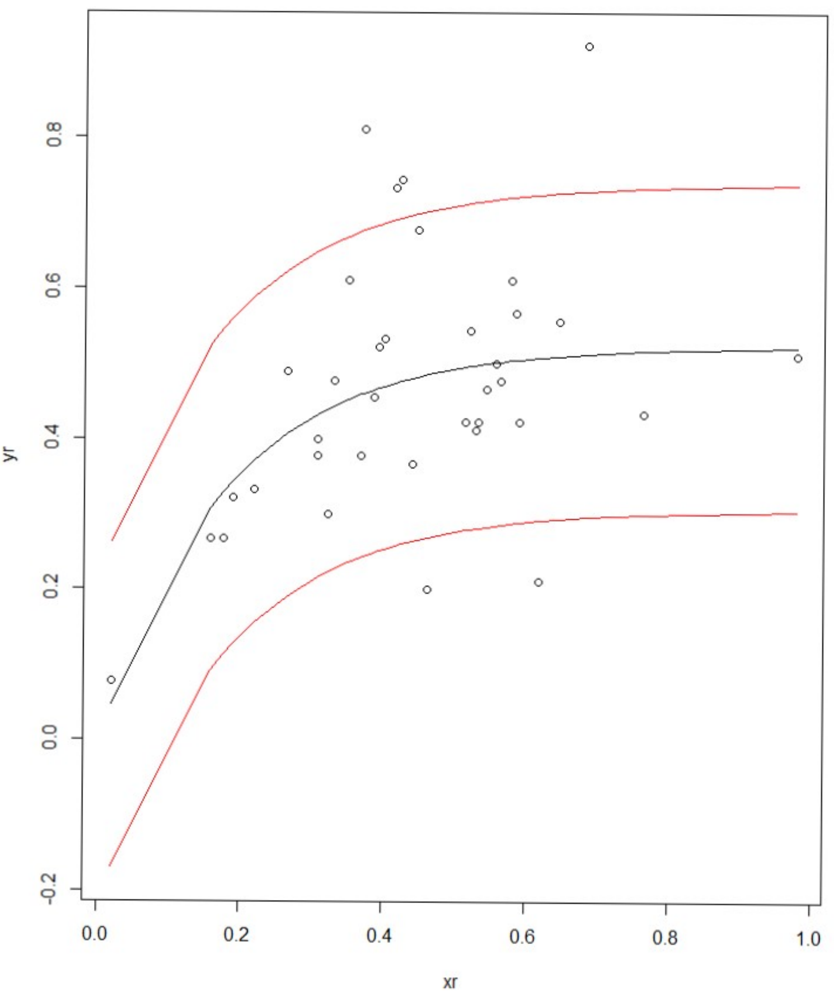


Figure 4.16: Model Fit with prediction intervals- Residential Energy Consumption per cap (without space heating) vs Expected Years of Schooling

stant. Vietnam and Thailand seemed to be strong outliers of this dataset. Especially Vietnam, having relatively low development figures with high energy consumption, was also observed to be standing considerably distinct from other data points in life expectancy, education and HDI analysis. This time we prefer to exclude, since they are stronger outliers in the HDINI analysis. Robust MM estimator results are shown in Table 4.13 and Figure 4.19.

Table 4.9: Model Fit Results for RECwoSH vs Expected Years of Schooling - Robust MM Estimate

Parameters	Coefficient	CI low	CI upp
p1	16.81783	16.81552	16.82014
p2	0.5710148	0.570578	0.571452
p3	0.2775198	0.277187	0.277853

Table 4.10: Model Fit Results for RECwoSH vs Education Index - Robust MM Estimate

	Parameters	St. dev	CI low	CI upp
p1	0.8937389	0.00027	0.89288	0.89459
p2	0.6561197	0.00073	0.6538	0.65844
p3	0.2464713	0.00049	0.24491	0.24803

Table 4.11: Model Selection - RECwoSH vs Human Development Index

Model	SSE	AICc	MSE	RMSE
Brody	0.194508	-157.117	0.003537	0.059469
Gompertz	0.195604	-156.791	0.003556	0.059636
Logistic	0.196691	-156.469	0.003576	0.059801

Table 4.12: Model Fit Results - RECwoSH vs Human Development Index - Robust MM Estimate

Parameter	Coefficient	CI low	CI upp
p1	0.9254999	0.925495	0.925505
p2	0.6452411	0.64522	0.645262
p3	0.2783398	0.278327	0.278353

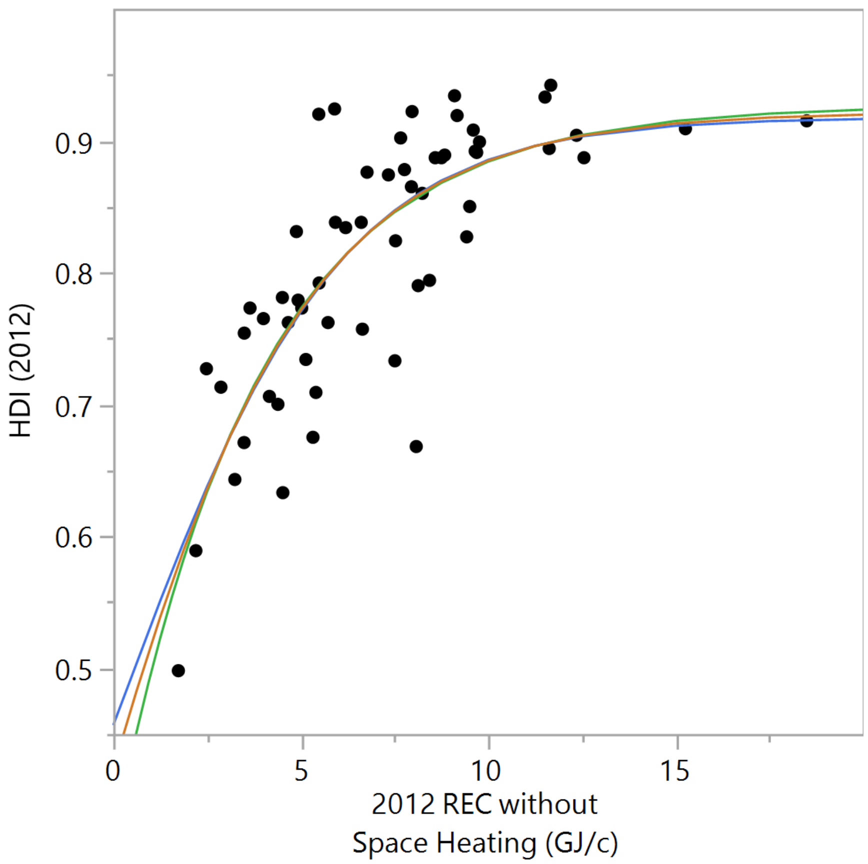


Figure 4.17: Model Selection - Residential Energy Consumption per cap (without space heating) vs Human Development Index

4.4.1.4 Energy consumption corrected for Climate (1000HDD) - Life Expectancy (RECwSH-LE)

As previously, Brody model is chosen to explain the Energy consumption - life expectancy relationship (Table 4.14). 3 FSU countries are excluded as detected to be outliers. In the previous datasets, USA was not a very strong outlier. Also because it is an important country with high population, we prefered to keep it in the analysis anyway. However when space heating energy added in to analysis, it became a very high leverage point and a strong outlier that may change the model fit alone (Figure 4.20). Therefore, the USA is excluded from the analysis. Residual distribution is close to normal when 3 FSU countries and the USA are excluded. Residual diagnostics imply that there is non-constant variance. This time variance is not a function of the mean response. Logarithm of both axis are also graphed but no relation is observed. Instead

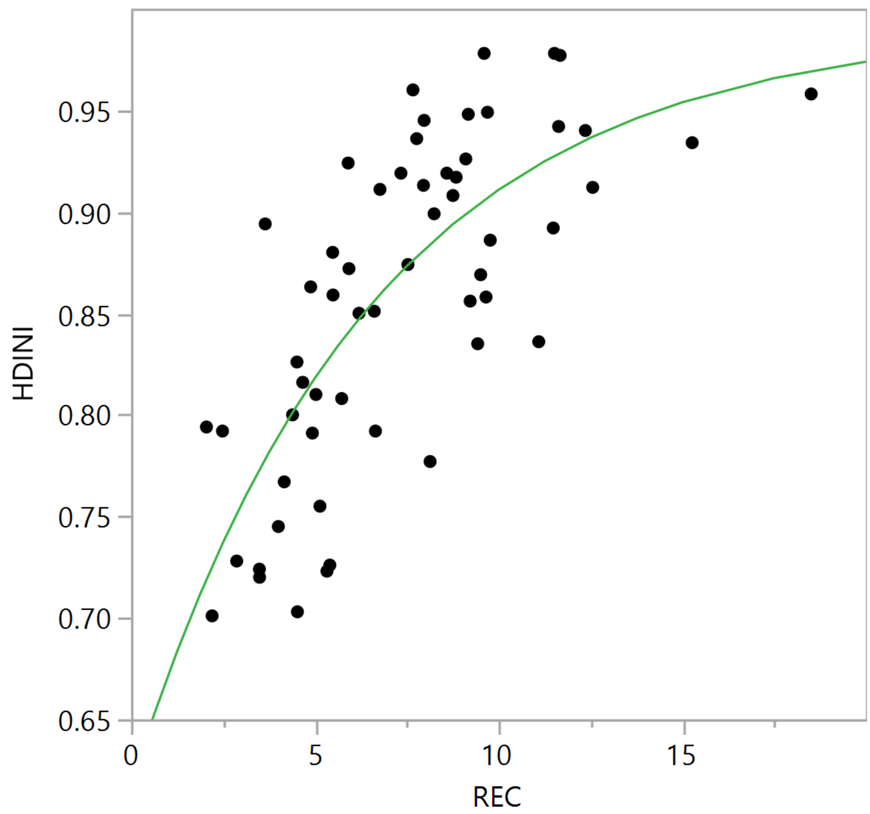


Figure 4.18: Model Selection - Residential Energy Consumption per cap (without space heating) vs Non-Income HDI

absolute residuals seem to be linearly related with the predictor (Figure 4.21). An R package called NLREG is used to estimate the model parameters and prediction intervals since it allows employing different custom variance models in maximum likelihood estimation.

4.4.1.5 Energy consumption corrected for Climate (1000HDD) - Education Dataset (RECwSH-EDU)

In these datasets, most of our data lies in the saturated region. There is not enough data point to be able to model the region where the curve bends through developing countries level. Therefore, not much importance will be attached to the results of these analysis. To be consistent, we assumed a Brody model after comparing model fit measures (Figure 4.22). For expected years of schooling data, errors seem to be homoskedastic but normality is violated because of the outliers like Australia and

Table 4.13: Model Fit Results - RECwoSH vs Non-Income HDI - Robust MM Estimate

	Parameters	St. Dev.	CI low	CI upp
p1	0.9861	0.00013	0.98573	0.98656
p2	0.38299	0.00012	0.3826	0.38338
p3	0.16382	0.00018	0.16326	0.16438

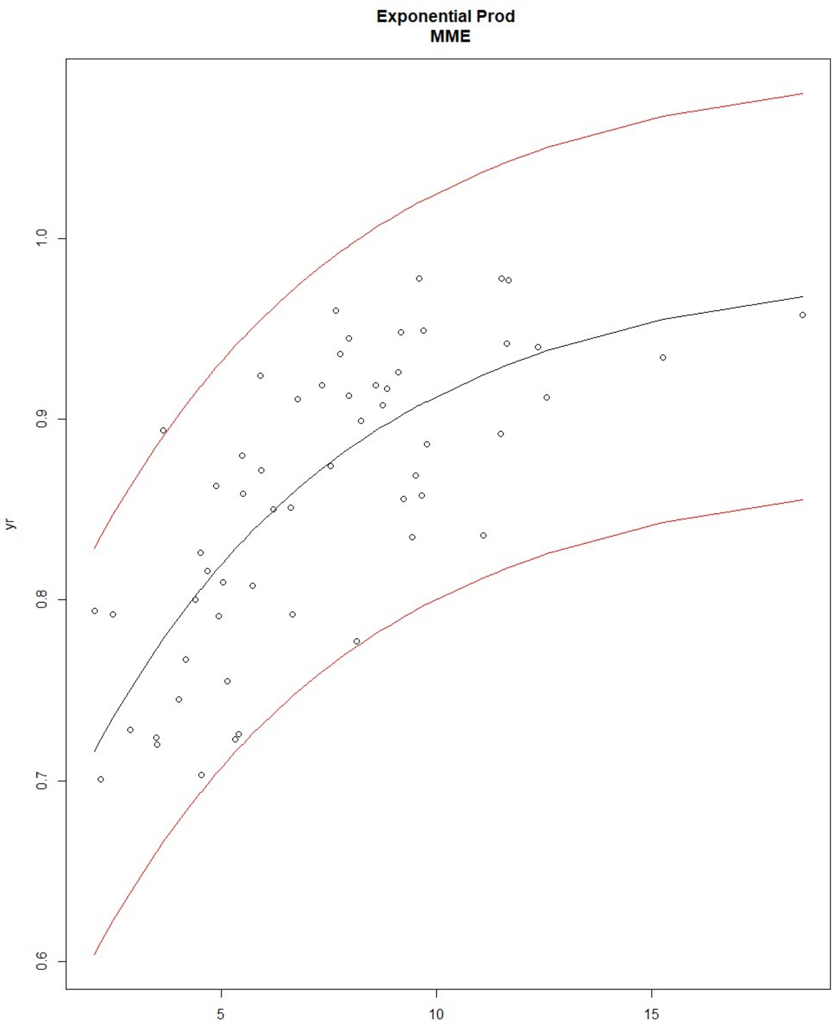


Figure 4.19: Model Fit with Prediction Intervals - Residential Energy Consumption per cap (without space heating) vs Non-Income HDI - Robust MM Estimate

New Zealand. When these two excluded, normality can be assumed. There are still a few weak outliers, therefore, a robust MM-estimator is employed to estimate model

Table 4.14: Model Selection - Residential Energy Consumption per cap (corrected for Climate-1000HDD) vs Life Expectancy

Model	AICc	SSE	MSE	RMSE
Logistic	104.38133	38.689088	1.3817531	1.17548
Gompertz	104.42011	38.737513	1.3834826	1.1762154
Brody	104.46122	38.788924	1.3853187	1.1769956

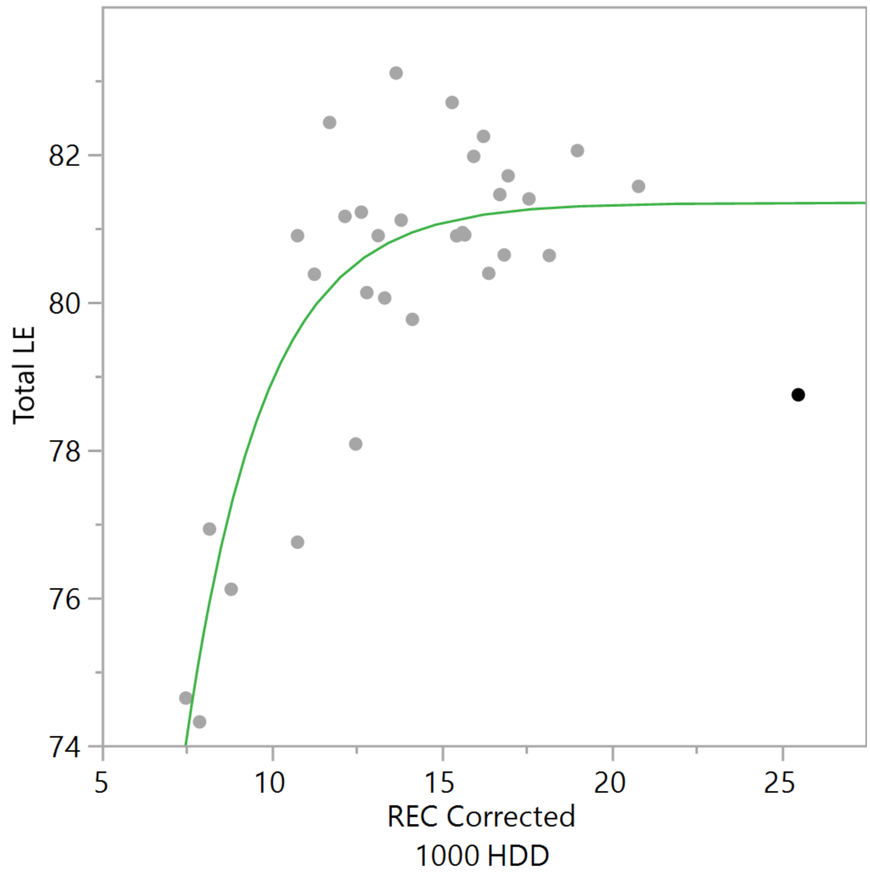
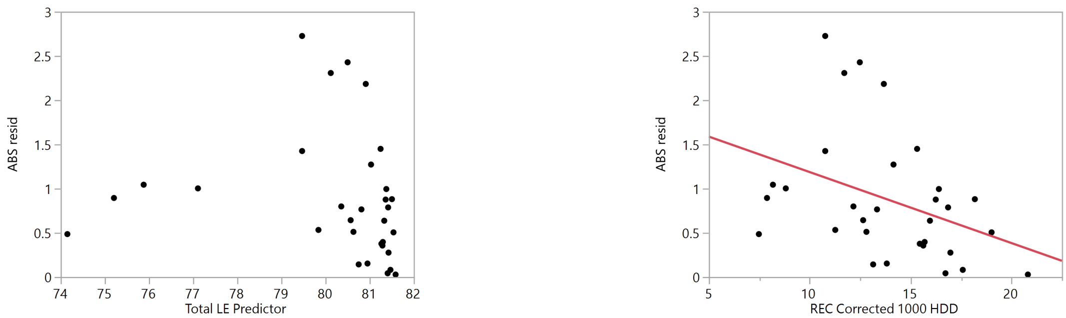


Figure 4.20: Graph shows USA as outlier - Residential Energy Consumption per cap (corrected for Climate-1000HDD)vs Life Expectancy

parameters (Figure 4.23) (Table 4.15).

Residuals diagnostics for the Education Index data do not show considerable deviations from normality and homoskedasticity. Robust MM Estimate results are shown in Table 4.16.



(a) Abs Residuals vs Predicted response

(b) Abs Residuals vs Predictor

Figure 4.21: Variance Model Selection

Table 4.15: Model Fit Results - Residential Energy Consumption per cap (corrected for Climate-1000HDD) vs Expected Years of Schooling

Parameters	Coefficients	CI low	CI upp
p1	16.58366	16.58364	16.58367
p2	0.8009791	0.800959	0.800999
p3	0.2637392	0.263735	0.263744

Table 4.16: Model Fit Results - Residential Energy Consumption per cap (corrected for Climate-1000HDD) vs Education Index - Robust MM Estimate

	Parameters	St. dev	CI low	CI upp
p1	0.870327	4.33E-06	0.870313	0.870341
p2	0.996142	9.23E-05	0.99584	0.996444
p3	0.254649	1.68E-05	0.254594	0.254704

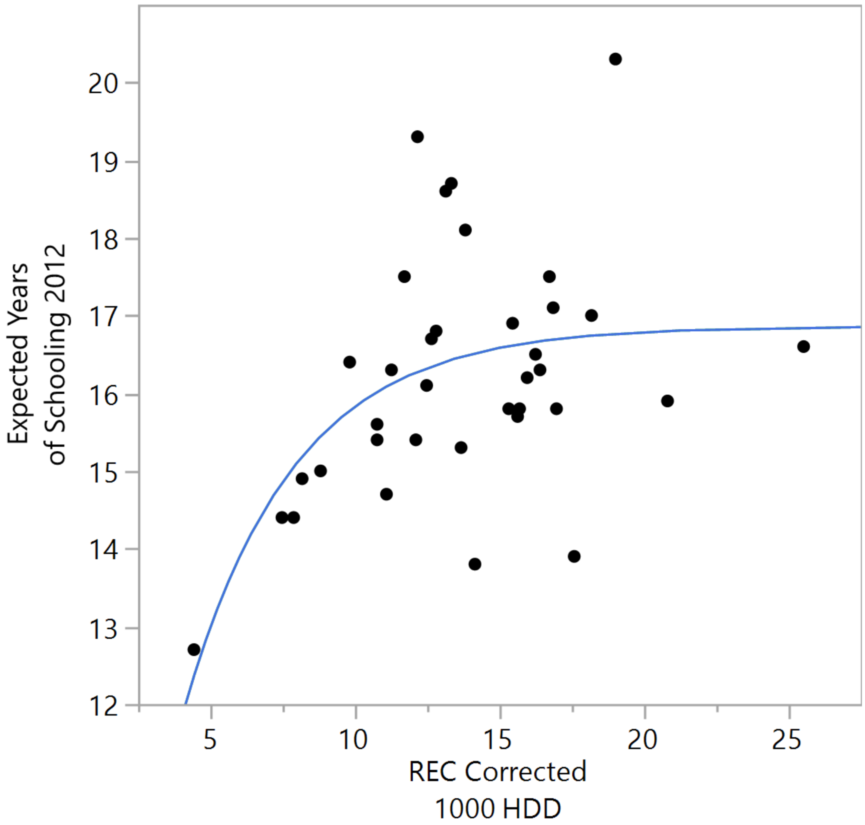


Figure 4.22: Brody Model Fit - Residential Energy Consumption per cap (corrected for Climate-1000HDD)vs Expected Years of Schooling

4.4.1.6 Energy consumption corrected for Climate (1000HDD) - Human Development Index (RECwSH-HDI)

Brody model is chosen after model comparison (Table 4.17) (Figure 4.24). Residual diagnostics indicate homoskedastic error variance and normal distribution. Model parameters are estimated with maximum likelihood estimator via NLREG R package and JMP software (Table 4.18) .

Non-Income HDI data is also fitted with Brody model (Figure 4.25). Residual plots and test show that normality and homoskedasticity assumtions are hold. Robust MM estimate results are shown in Table 4.19 and Figure 4.26.

Table 4.17: Model Selection - Residential Energy Consumption per cap (corrected for Climate-1000HDD) vs Human Development Index

Model	**AICc**	**SSE**	**MSE**	**RMSE**
Logistic	-147.15	0.023436	0.000732	0.027063
Gompertz	-147.107	0.023465	0.000733	0.027079
Brody	-147.063	0.023494	0.000734	0.027096

Table 4.18: Model Fit Results - Residential Energy Consumption per cap (corrected for Climate-1000HDD) vs Human Development Index

Parameter	**Coefficient**	**Std Error**	**CI low**	**CI upp**
p1	0.920236	0.017097	0.886727	0.953745
p2	0.900975	0.509506	-0.09764	1.899589
p3	0.228322	0.076144	0.079083	0.377561

Table 4.19: Model Fit Results - Residential Energy Consumption per cap (corrected for Climate-1000HDD) vs Non-Income HDI - Robust MM Estimate

	Parameters	**St.Dev.**	**CI low**	**CI upp**
p1	0.9356705	1.28E-05	0.935629	0.935712
p2	2.439074	0.002151	2.432035	2.446113
p3	0.3514016	0.000113	0.351032	0.351771

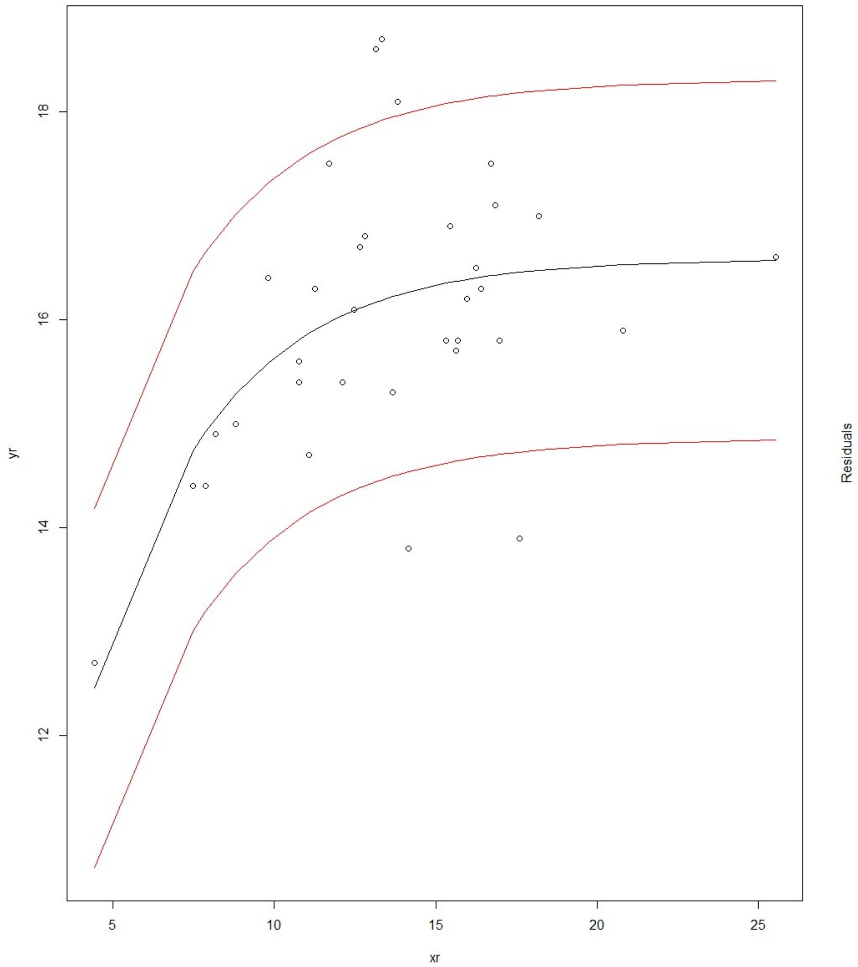


Figure 4.23: Robust MM Estimate - Residential Energy Consumption per cap (corrected for Climate-1000HDD)vs Expected Years of Schooling

4.4.1.7 Final Energy Consumption vs Well-being Indicators

In Section 4.2.1, why we put residential energy consumption in to the center of our analysis is explained, however, total final energy consumption still may hold some valuable information. We regressed total final energy consumption per capita with life expectancy. As seen in Figure 4.27, there are countries lying far apart from the main trend, majority of which are energy rich countries and FSU countries. At lower levels, the distinct trend of biomass dependent countries could again be observed. Therefore, as it was done previously in the residential energy analysis, energy rich, FSU and biomass dependent countries are excluded. Climate correction would reduce the number of countries in the analysis since space heating data is not available for

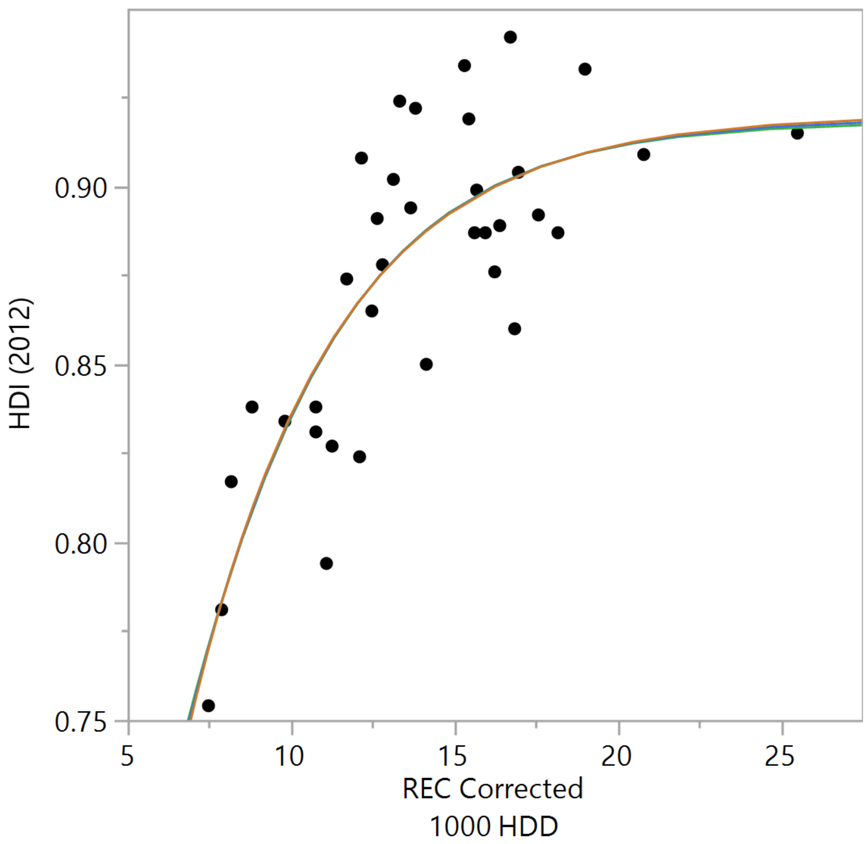


Figure 4.24: Model Fit - Residential Energy Consumption per cap (corrected for Climate-1000HDD)vs HUman Development Index

all countries. Logistic, Gompertz and Brody Models fit the data very closely. Brody model is chosen for the same reasons explained in the previous sections.

4.4.2 Detection of Fair Use Level

We have now chosen the model but what this model says us about the level of fair use is still a question to be answered. It is possible visually to point an approximate level after where the curve starts to level off. However, it is better to detect the level with a certain methodology rather than visually choosing an arbitrary point. Through this purpose, "knee" of a curve could be a good reference point. Although the term "elbow" is also used interchangeably in the literature, most of the time both terms imply the similar region or a point where the curve bends sharply. We prefer to use "knee" since it makes more sense in a concave downward curve. Despite being

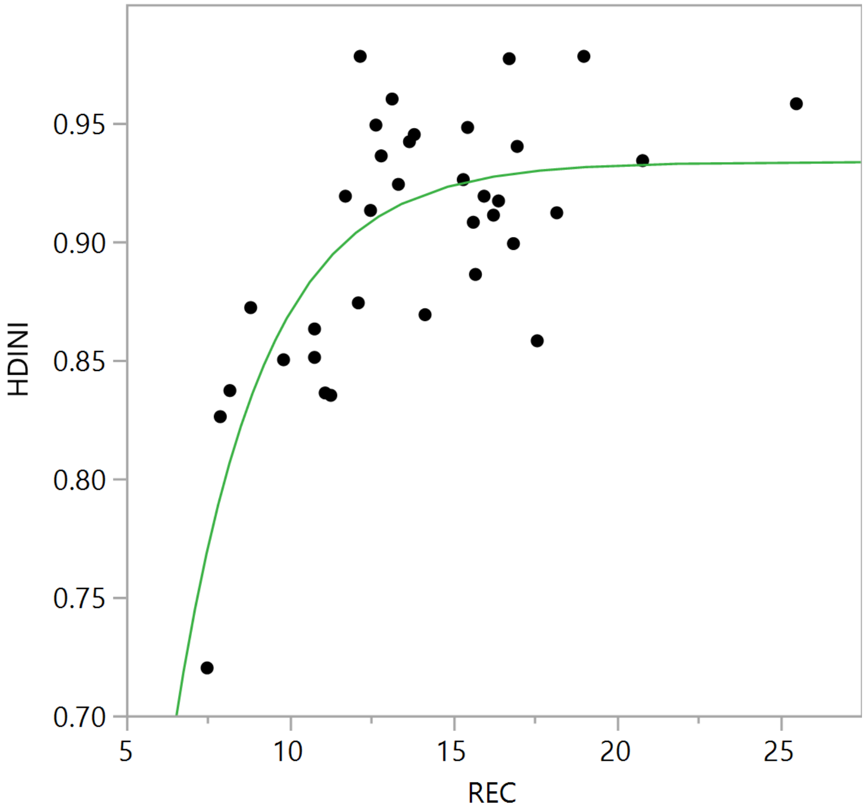


Figure 4.25: Model Fit - Residential Energy Consumption per cap (corrected for Climate-1000HDD)vs Non-Income HDI

used in various fields (cluster detection algorithms, fatigue damage theories, system behaviour, optimization etc), there is yet no formal definition. However, it is widely acknowledged that what most consistently describes the knee is the mathematical concept, "maximum curvature". Curvature is a mathematical measure of how much a function differs from a straight line. For any continuous function $F(x)$, curvature $K_f(x)$ is defined as following:

$$K_f(x) = \frac{\mid F'' \mid}{(1 + (F'(x))^2)^{1.5}} \qquad \text{(Eq. 4.7)}$$

$$K_f'(x) = 0 \qquad \text{(Eq. 4.8)}$$

Maximum curvature is the unique extreme point of the function $K_f(x)$. It can analytically be solved by equating its first derivative to zero and finding its roots (Eq. 4.8).

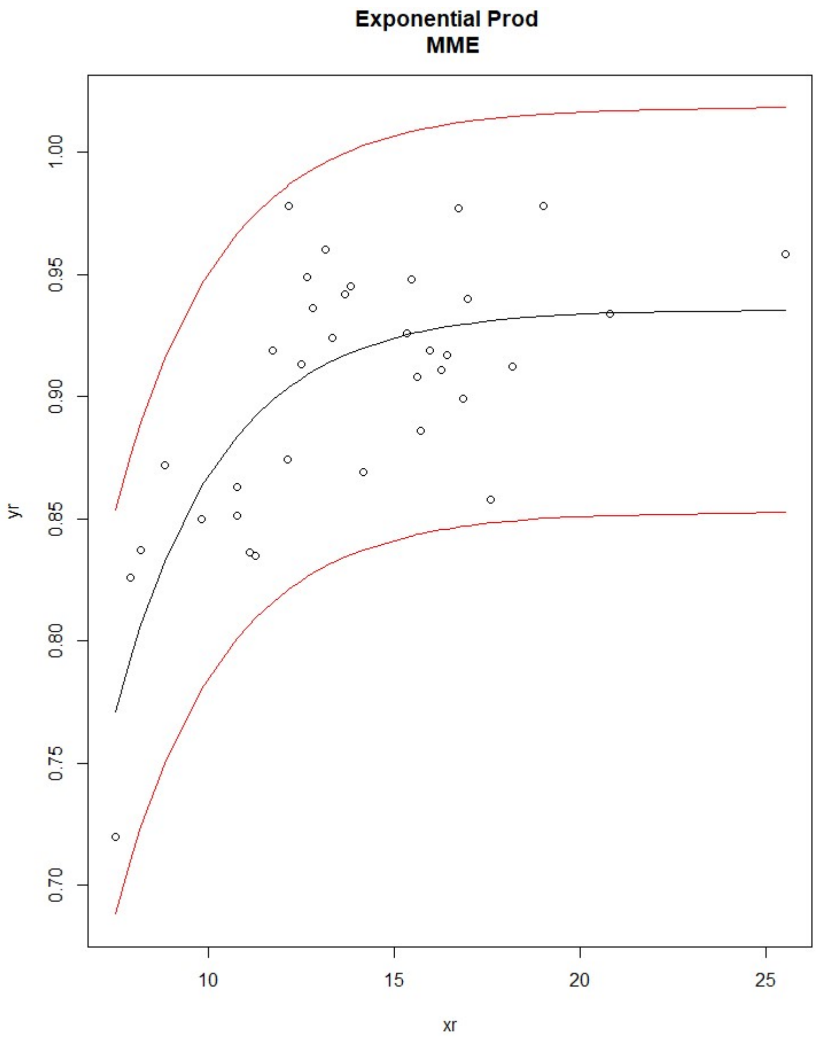


Figure 4.26: Model Fit - Residential Energy Consumption per cap (corrected for Climate-1000HDD)vs Non-Income HDI - Robust MM Estimate

We are not interested in the value of the maximum curvature instead we need to know the corresponding x and y values. This maximum curvature point,or knee point has nothing to do with the inflection point where diminishing return begins, and the curvature is zero. Knee point could simply be interpreted as a transition from high gain to low gain region. In other words, a small improvement in well being corresponds to a considerably large increase in energy consumption after this knee point. Therefore, this concept highly satisfies our description of the fair use level.

Maximum curvature formula is applicable, by definition, if only we have a continuous function. However, we have a discrete dataset. There is two option for calculating the

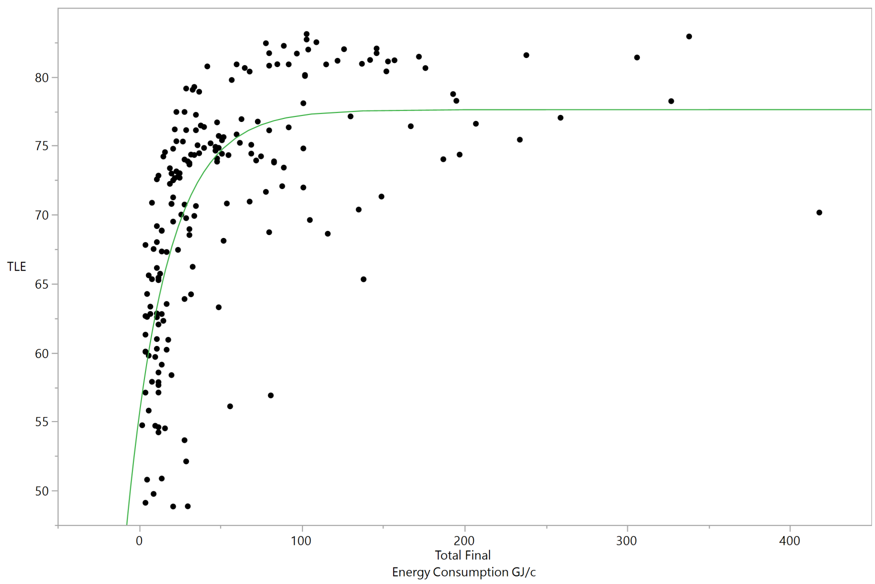


Figure 4.27: Total Final Energy Consumption per cap vs Life Expectancy

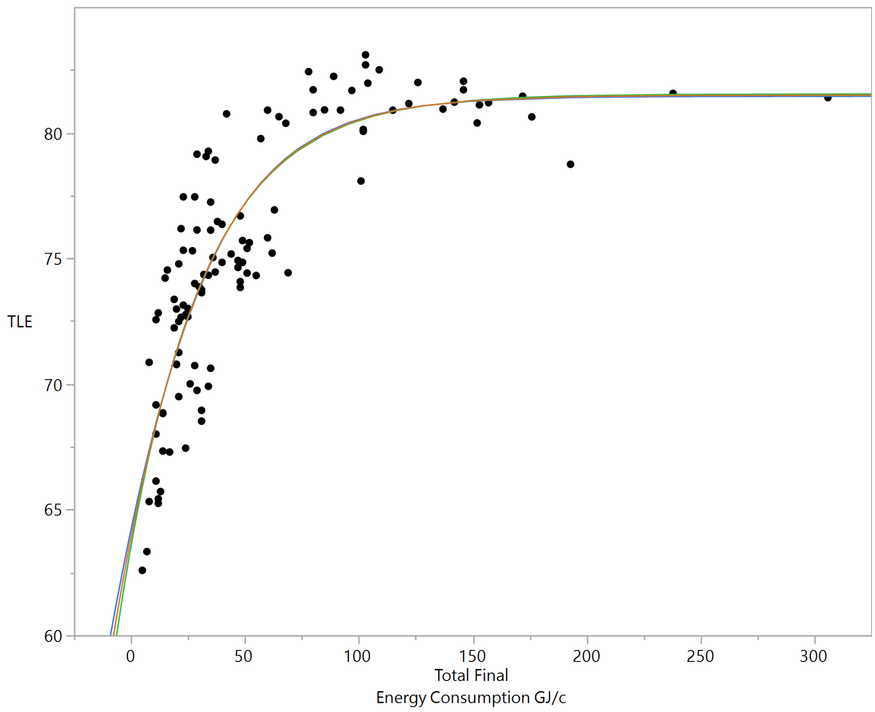


Figure 4.28: Total Final Energy Consumption per cap vs Life Expectancy - Energy rich, FSU and Biomass dependent countries excluded

knee point. One is to fit a continuous model to the data;this is what we already have done. Second way is to use the estimation methods developed for discrete datasets. After a review in the knee detection literature, we found out that most common methods are Angle-based Method [128], Menger Curvature Method[129], Kneedle Algorithm [130], L-method [131], Extremum Distance Estimator [132]. Each has some drawbacks and none of them proves perfect in estimating knee points. However, we are not looking for a precise estimate at this point. Our intention here is to apply at least one different method to get some rough estimates in order to be able to compare our results from the Maximum Curvature formula. Therefore, we have chosen the Kneedle Algorithm since it performs better than Menger Curvature and Angle-based methods and its code is readily available [130].

After initial calculations, we noticed that knee values obtained from the maximum curvature formula are sensitive to the magnitude of the data values of each variable. Therefore, we decided to normalize our datasets in order our analysis to be independent of units (Eq. 4.9).

$$X_n = \frac{X - X_{min}}{X_{max} - X_{min}}$$
$$Y_n = \frac{Y - Y_{min}}{Y_{max} - Y_{min}} \qquad \text{(Eq. 4.9)}$$

A second possible way to determine a fair use level for energy consumption could be the UNDP's country classification benchmarks. In Human Development Report[133] released at 2013 (which reports the figures of 2012), UNDP ranks 187 countries according to their HDI values and groups them in to four based on fixed HDI cut-off points:

- First quartile - Very high development (HDI > 0.800)
- Second quartile - High development (HDI between 0.700-0.799)
- Third quartile - Medium development (HDI between 0.550-0.699)
- Fourth quartile - Low development (HDI < 0.550)

For each quartile, average values of HDI, Life Expectancy, Mean and Expected Years of Schooling and GDP/c are reported in the UNDP report. Besides averages of quartiles, the lowest value of very high development quartile is also candidate of being a reference point for our analysis. These values are reported for HDI but not for other

Table 4.20: Fair Use levels and other possible benchmarks

	Knee Formula	Kneedle	UNDP low	UNDP average	Best performer	Best perf. quartile
RECwSH- LE	12.23	11.2	9.47	13.24	10.77	11.97
RECwSH- EDUindex	11.26	10.7	8.55	12.87	8.17	
RECwSH-EDUyears	9.28	10.5	7.78	12.32	8.81	10.75
RECwSH - HDI	13.65	10.9	9	13.7	8.17	10.4
RECwSH-HDINI	12.13	11.5	8.46	16	8.17	
RECwoSH-LE	7.8	7.1	6.32	9.85	5.48	5.47
RECwoSH-EDUindex	7.12	7.6	7	10.22	5.48	
RECwoSH-EDUyears	6.1	7.5	6.56	10.47	4.89	6.1
RECwoSH-HDI	7.63	7.4	6.69	10.32	4.89	6.4
RECwoSH-HDINI	8.27	8.2	6.32	10.47	5.48	

well-being indicators that we'd like to use in our analysis. We could have used the life expectancy or education value of the country which stands at the lowest of the very high development quartile determined by HDI based ranking. Instead we re-ranked countries with respect to their Life expectancy and Expected years of schooling, Education Index, HDI and Non-income HDI scores and grouped them similarly in to quartiles. Then we took the lowest of the first quartile as a benchmark for very high development and also noted the average of the first quartiles (Table 4.21). This benchmarks are used in our fitted model and corresponding energy consumption values are calculated and noted as possible fair use levels. Furthermore, we identified the best performers, in other words, countries that achieve the quality of life benchmarks with less energy consumption than others. That informs us about what is practically possible under given conditions. Taking into consideration that the best performer may have a special advantage, we also noted the average of the best performing quintile. We mentioned in the previous sections that determining a threshold based on a level of well-being indicator is not what we intended to do since we refrain us from the controversy of defining an appropriate level for well-being. Even though, we included UNDP benchmarks in our analysis mainly for comparison purposes.

Table 4.21: UNDP Benchmarks

	HDI	TLE (years)	Exp. Years of Schooling (Years)	Mean Years of Schooling (Years)	Non Income HDI
Average of First Quartile	0.884	80.1	16.3	11.5	0.927
Lowest of First Quartile	0.814	76.92	15	10.9	0.835

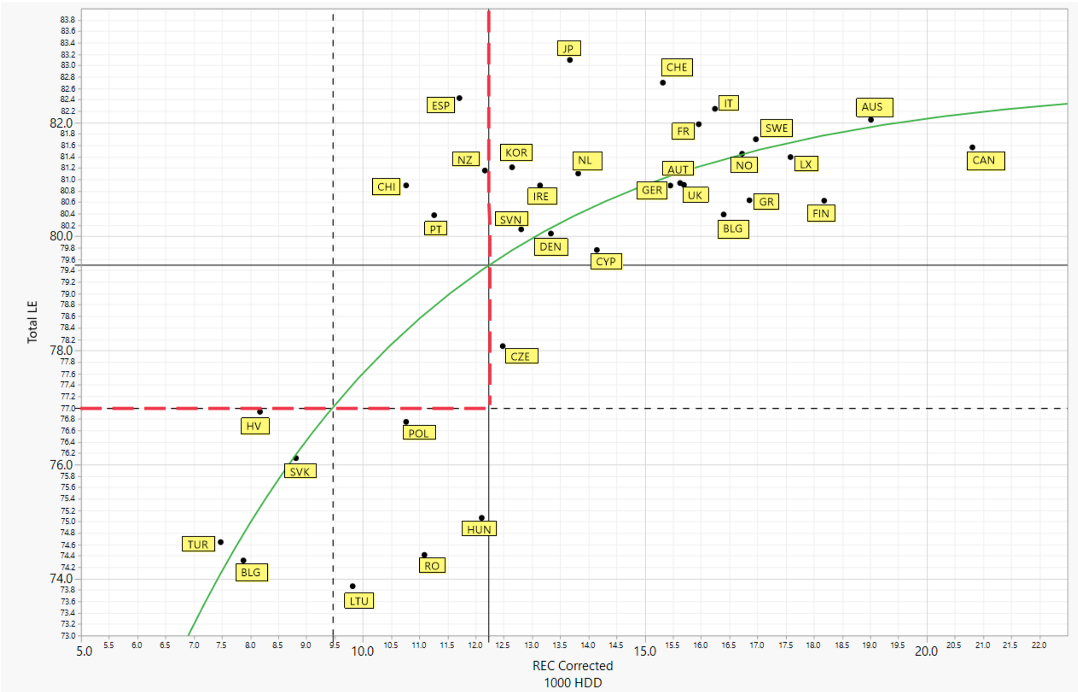


Figure 4.29: Fair use level- Residential Energy Consumption per cap. (climate normalized at 1000HDD) vs Total Life Expectancy

4.4.3 Results and Discussion

Knee values calculated by maximum curvature formula and Kneedle algorithm and other possible benchmarks based on UNDP reports are all tabulated together in Table 4.20. When we consider the knee values resulted from the analysis of RECwoSH with well-being indicators, it is possible to observe that the figures are close to each other and ranges between 7-8.2 GJ/c. Kneedle calculations are also consistent with the values calculated by maximum curvature formula. This level of energy use indicates the fair use level under available technology, at the year 2012, for a country with majority of its population having access to modern energy carriers and also for a

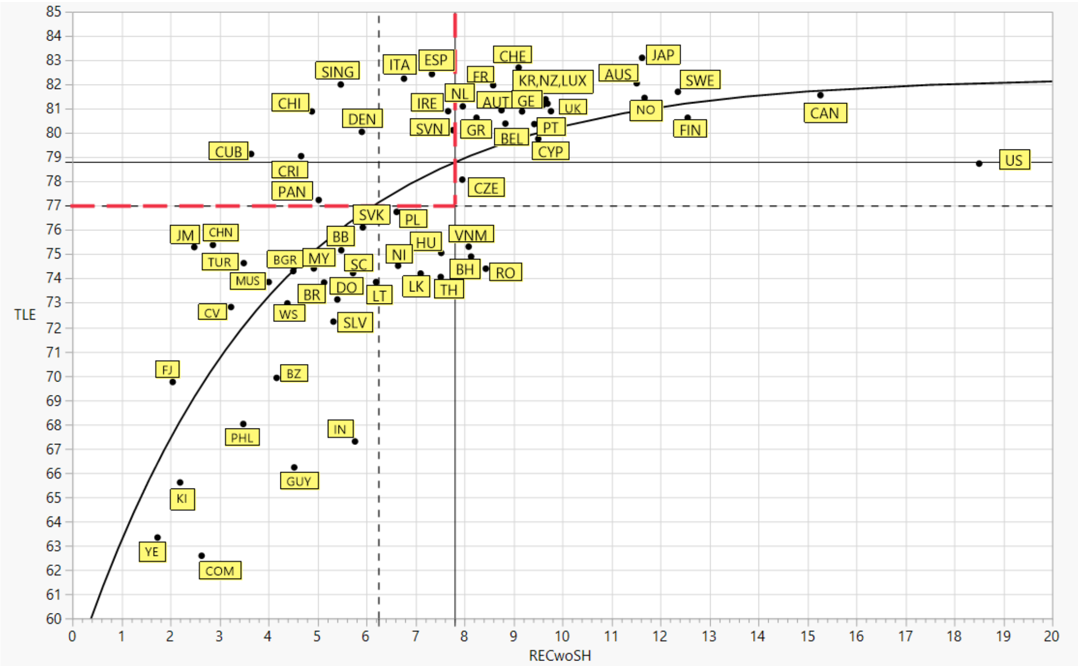


Figure 4.30: Fair use level- Residential Energy Consumption per cap. (without space heating) vs Total Life Expectancy

country that is not an energy exporter. The third column in Table 4.20 shows the energy use figures that corresponds to the values in Lowest of the First Quartile row of Table 4.21. These UNDP benchmarks are consistently lower than our knee values in the first two columns. Putting these benchmarks together in the same graph, we observed that they point at a region framed with red dashed lines in Figures 4.29, 4.30, 4.31, 4.32, 4.33, 4.34, 4.35, 4.36, 4.37, 4.38, 4.39. This region is bounded from right by knee point calculated by maximum curvature formula and from below by UNDP very high development cut-off point. We name this region as fair use region and assume that within this region, countries' energy consumption is fair. But when we move to the right of the fair use line, we find countries in overconsumption. Lower bound can be considered to be chosen somehow arbitrary. UNDP decides to name the first quartile as very high development. One other may decide to call the first "quintile" as very high development. In other words, this is not a strict line, and can be shifted a little below or upper. It is not possible to say that countries lying just below this level suffer from low quality of life. However, we can say that countries beyond this level enjoy a comparatively good quality of life. Therefore, countries below this line have to aim this level without exceeding the corresponding

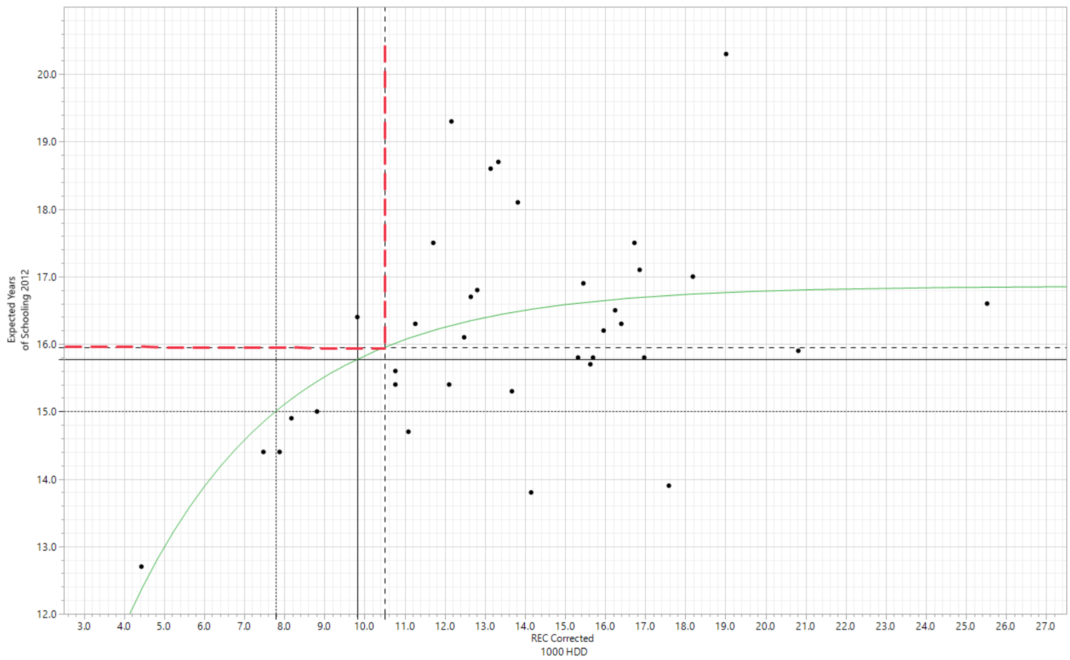


Figure 4.31: Fair use level- Residential Energy Consumption per cap. (normalized at 1000HDD) vs Expected Years of Schooling

energy consumption line on the graph. Similarly, this vertical boundary, although derived from a methodology, is not proposed to be a strict border, from where a small shift would make a country fair and unfair. Rather, it is a reasonable and justifiable approximation of the boundaries for energy consumption. Countries passing beyond the vertical line, have to aim reducing energy consumption to fair levels.

For the RECwSH analysis, it is possible to say the similar things. We can observe from the graph which countries perform well and how far or close to fair use benchmarks. However, this time numbers are only valid for countries having average HDD level of 1000. In order to get informative figures for a certain HDD, fair use levels have to be recalculated. For instance, if we want to compare a countries' real residential energy consumption with respect to the fair use level, we have to repeat all the analysis by using the HDD of that country. This would end up with an updated fair use level specific for that HDD. This updated fair use could be used in national energy policies. The RECwSH dataset, as mentioned before, consists of 35 countries, most of which are very high development countries. In the analysis with education indicators, lack of data for medium development countries made it difficult to fit the

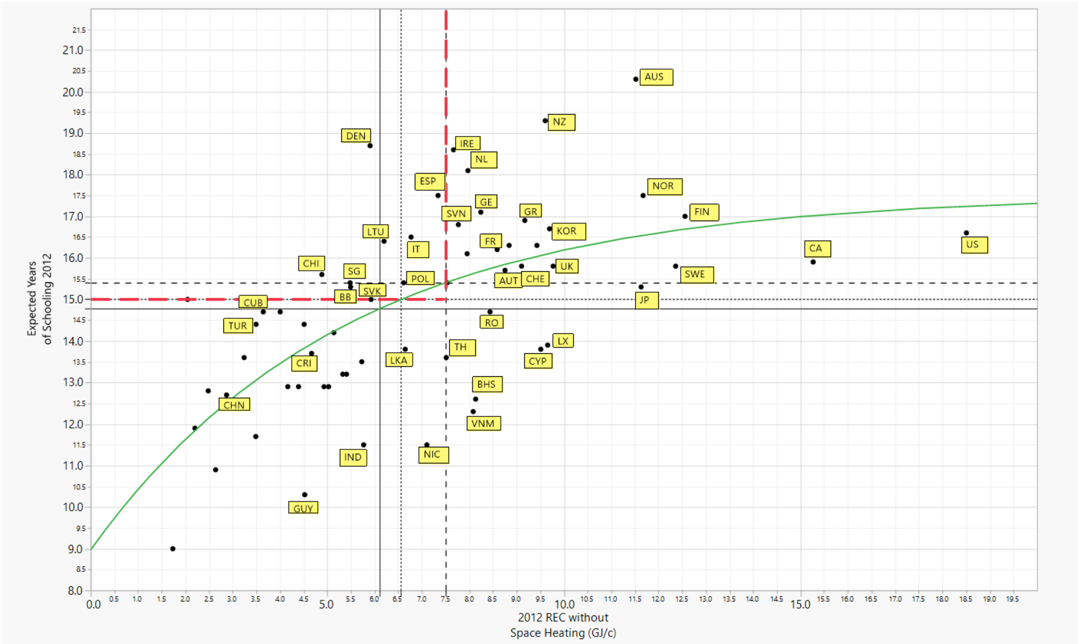


Figure 4.32: Fair use level- Residential Energy Consumption per cap. (without space heating) vs Expected Years of Schooling

model conveniently. Since our knee methodology tries to detect a sharp bending from high development to very high development region on the curve, it can be influenced much from this lack of data at lower levels. For this reason, we prefer not to lean on the result of these analysis (RECwSH vs Education Index and RECwSH vs Expected years of schooling) in our comments. Apart from this, it observed from the first column of Table 4.20 that results from the knee formula is ranging around 12-13,65 GJ/c for the 1000HDD case.

When we zoom in to the graphs of energy consumption with different wellbeing indicators for more detail, it is possible to observe how countries perform in terms of utilizing residential energy for well-being. For instance, at RECwoSH-TLE graph (Figure 4.30), it is seen that on average, the life expectancy benefits slow down but continues to grow up to around 8 GJ/c. After 8.5 GJ/c level, there is no country having life expectancy less than 78, which is greater than UNDP very high development cluster boundary. Thinking reversely, we can infer that moving from 20 GJ/c to 8.5 GJ/c, a country not necessarily degrade its life expectancy score. In other words, one can infer that it is possible to reach same development levels, on average with

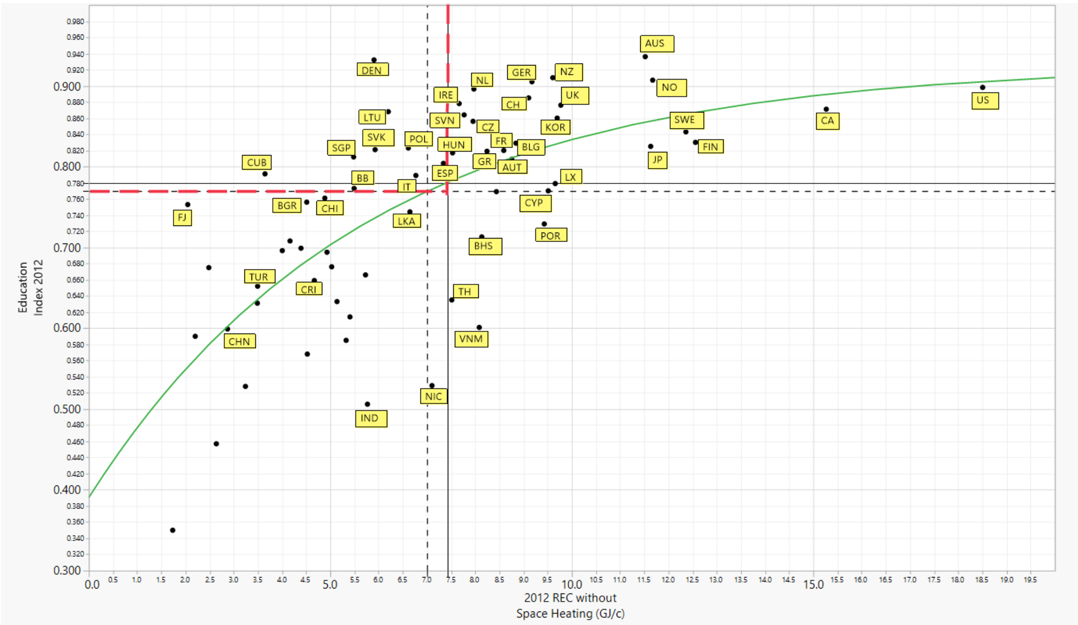


Figure 4.33: Fair use level- Residential Energy Consumption per cap. (without space heating) vs Education Index

less energy consumption than for example US. Some group of countries, for instance, stand far out of the fair use region consistently in all graphs. These countries, United States, Canada, Australia, Norway, Finland, Sweden, are, not surprisingly, highly industrialized countries and standing at the top in terms of per capita GDP in the world. They have relatively high life expectancy and education scores. However, the problem here is, when we look at RECwoSH-TLE graph (Figure 4.30) for instance, it is easily observed that Cuba, a country consuming four times less energy than US, has higher life expectancy. Similarly, life expectancy at Canada is only slightly higher than Chile. On the other side, energy consumption in Canada is more than triple of the consumption in Chile. The question is how these huge differences can occur between countries in the fair use region and the far right of that. In the vertical axis, between the fair use region and the area under it, the per capita energy consumed could still make difference. The difference in life expectancy, for instance, between China and Denmark or Turkey and Ireland can be partly attributed to their energy consumption levels. However, like in the case for US and Cuba, factors other than energy consumption, should be determinant. Certainly, it requires further detailed studies to understand the underlying reasons behind these distinct performances, but we can

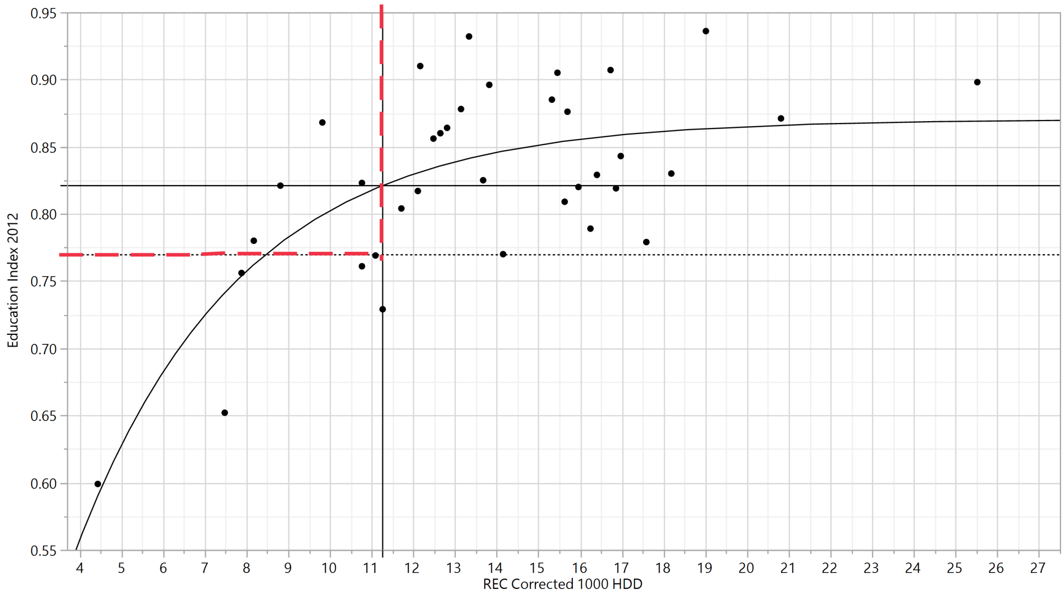


Figure 4.34: Fair use level- Residential Energy Consumption per cap. (without space heating) vs Education Index

still elaborate about possible factors. In the Cuba-US case, the difference could be mainly attributed to Cuba's special success in public health care system. Cuba, as a socialist state, provides free access to all health services. Therefore, all vulnerable and low income groups, which are exposed to worse health conditions even in many developed countries, have equal access to services. Cuba also achieved one of the highest statistics in doctors per 10000 people indicator(based on WHO database). On the other side, US healthcare system has long been criticized to be unaffordable for many of its citizens [134].

As mentioned before, the culture in US also determinant in their overconsumption of energy. On the other hand, Denmark and Finland, two Northern European countries, having relatively similar cultural backgrounds also differ much in their energy consumption. Denmark achieves a high life expectancy level with only half of the energy consumed in Finland. Possible reasons for that could be Denmark's dedicated energy conservation and clean energy policies for decades. Since 1990's, high taxes on residential electricity and fossil fuel consumption have been in effect [135]. In US, on the other side, energy prices have been highly subsidized for long decades [136]. This is similar to the case of energy exporter countries. They also achieve the

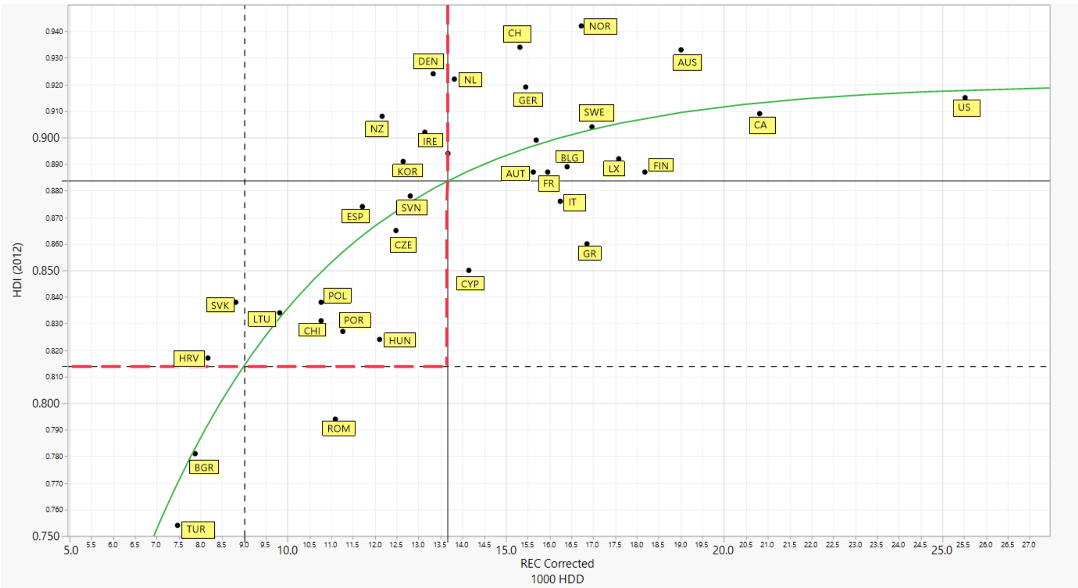


Figure 4.35: Fair use level- Residential Energy Consumption per cap. (normalized at 1000HDD) vs Human Development Index

same wellbeing levels with consistently higher energy consumption than non-energy exporter countries as we observed in previous analysis.

The countries lying in the leftmost of the fair use region, like Cuba, Denmark, Costa Rica, Singapore and Chile are important countries for us to be informed about what is possible under certain conditions. Their energy efficiency (efficiency not refers only technical) in reaching high well-being cannot be attributed to their special inherent advantages, for example lying in milder climate region or being rich in resources, since in the analysis we controlled for them. There may be many reasons ranging from structural to cultural.

Another point to mention from the graphs, when it is the HDI on the well-being side, Cuba and Costa Rica drops down to the underdeveloped region. Non-income HDI analysis brings them again back to their best performer position. This is a good case to show the implications of including GDP to the well-being. HDI seems to be influenced by GDP per capita. Our point here is not to claim to ignore the importance of income in wellbeing. It is the GDP that we reject as an indicator of material wealth of a household.

This fair use level is a benchmark. It could be utilized for many purposes. Coun-

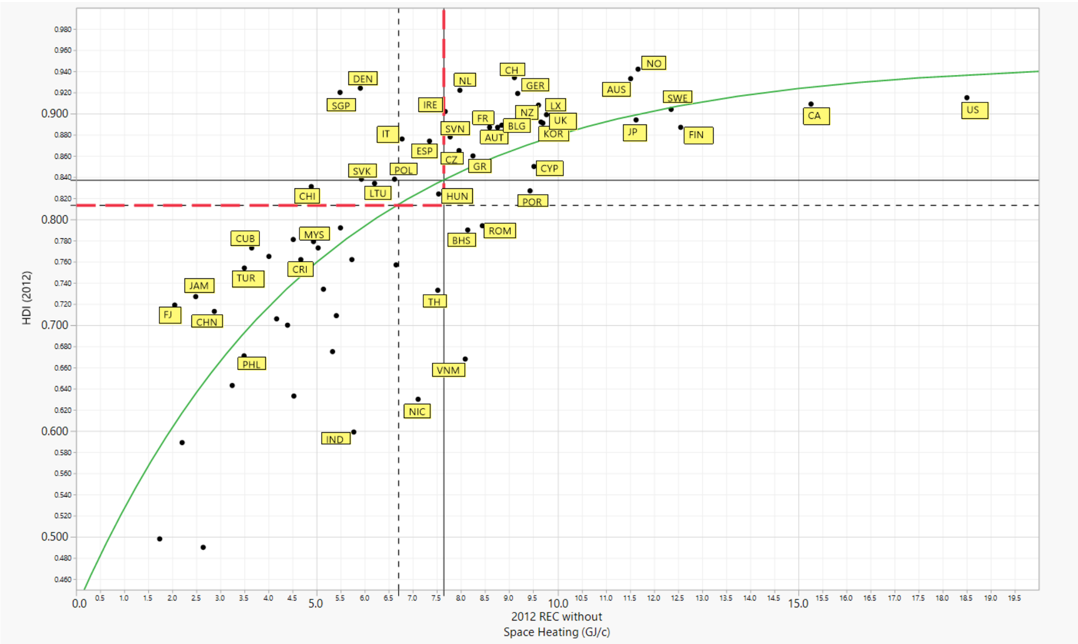


Figure 4.36: Fair use level- Residential Energy Consumption per cap. (without space heating) vs Human Development Index

tries may compare their position with respect to that fair use level. Besides being an international benchmark, it is also a meaningful within a country across its citizens. Countries are not homogeneous units. We use here countries' average energy consumption figures and it does not reflect the distribution within the country. Since our analysis employed residential energy consumption, it allows for being utilized within a national energy conservation policy. There is also another important point that should be mentioned. In this study, we reveal that there is a huge gap between what is achievable and what is consumed. This gap could be partly closed by energy conservation by residential users, individual frugality efforts. However, the responsibility of overconsumption could not be burdened to end users alone. Energy consumption amounts of the individuals are resultant of also the governmental policies, cultural and traditional factors, economic system, family structures, energy affordability, existing infrastructures, housing stock etc. It is not fair and realistic to expect people reduce their energy consumption with leaving everything unchanged. Reducing energy consumption to fair levels would certainly require a comprehensive change at a whole, yet more, a cultural transformation, a systemic change.

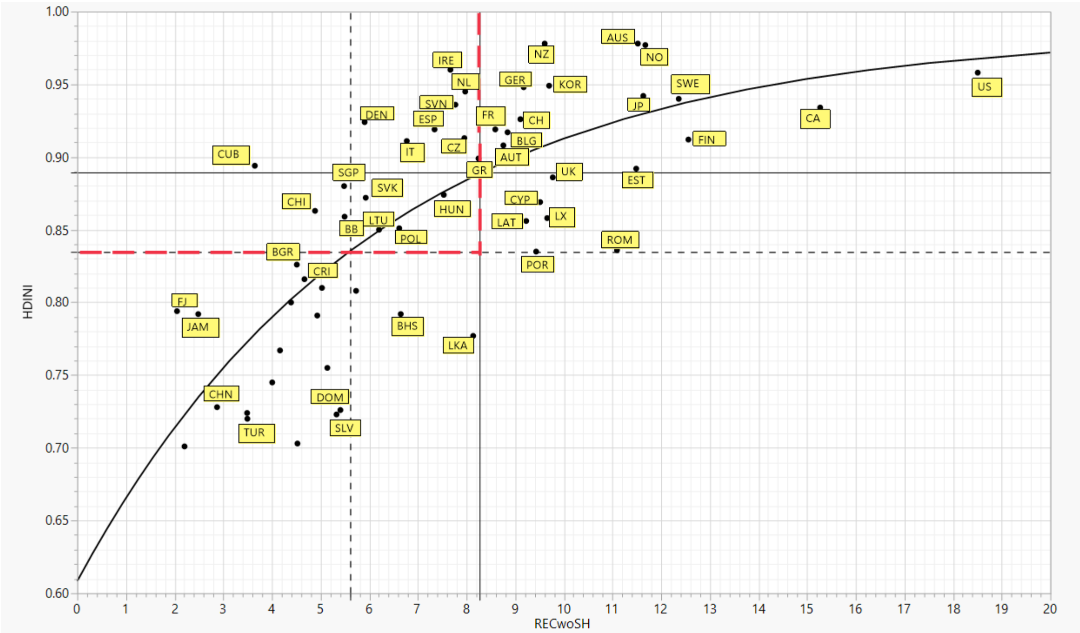


Figure 4.37: Fair use level- Residential Energy Consumption per cap. (without space heating) vs Non-Income Human Development Index

What we observed after analysis is, reducing energy consumption would not necessarily mean losing well-being benefits it brings. Each nation has different dynamics in utilizing their energy consumption to achieving well-being and therefore energy reducing action in each country will be different according to its special circumstances.

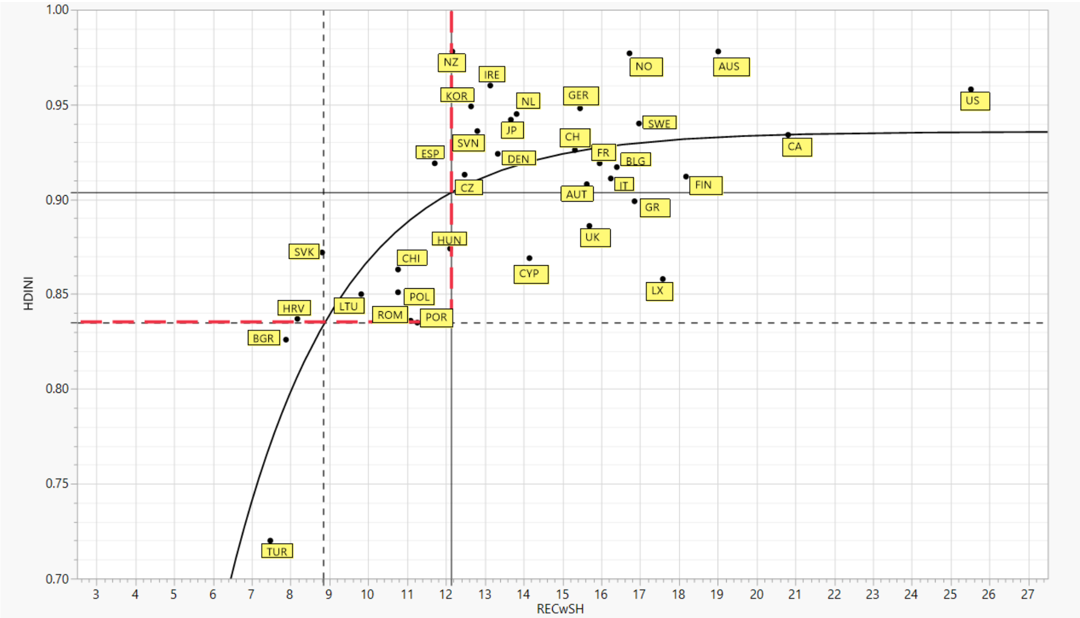


Figure 4.38: Fair use level- Residential Energy Consumption per cap. (without space heating) vs Non-Income Human Development Index

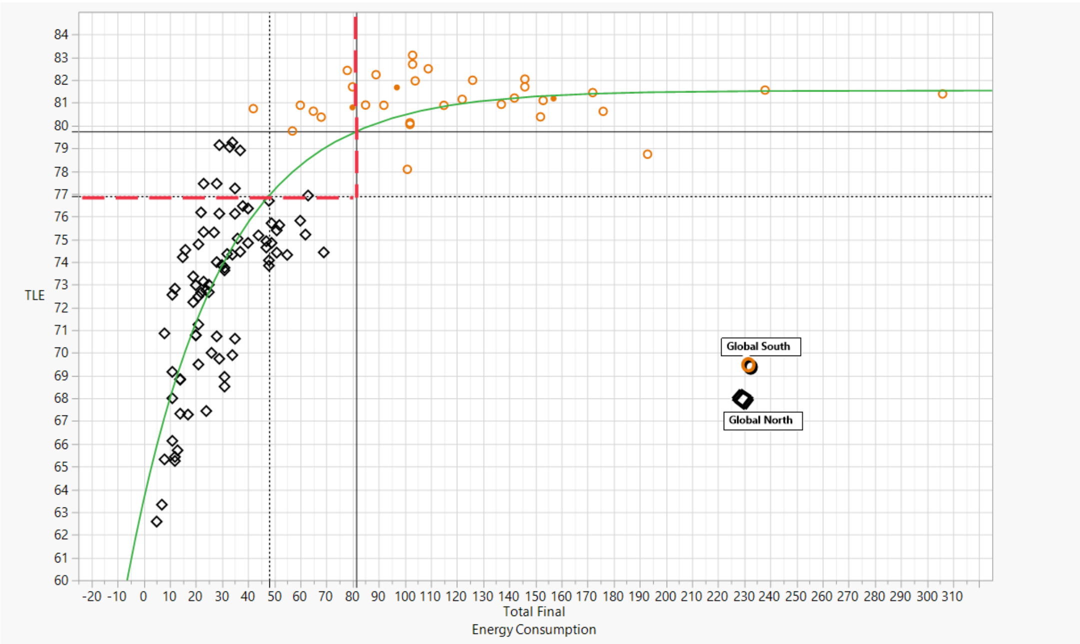


Figure 4.39: Fair use level- Total Final Energy Consumption per cap. vs Life Expectancy

CHAPTER 5

CONCLUSIONS

For decades, reducing the environmental impact driven by energy consumption has been on the agenda. Each year, renewed energy efficiency targets promise more reduction in the amount of energy used to achieve the same level output. However, desired output is in terms of Gross Domestic Product, in most of the cases. Therefore, what we have at the end is decreasing per dollar energy consumption but increased total energy consumption, due to the fact that economies and populations continue to grow. Efficiency indicators are usually in the form of a ratio, input per output. This study is grounded on the critics of the both components of this ratio. In the analysis, not only the output is changed from GDP to health and education based wellbeing indicators, but also primary energy input is replaced by residential energy consumption. This enabled us to compare the true performances of countries in utilizing energy to achieve wellbeing.

The argument consuming less, on the other hand, has not been enough to mobilize societies to take an effective action. The questions “who will reduce the consumption” and “to what level” have to be set in order to be informed about the responsibilities. The answers for these questions are also part of a larger discussion about justice. Political North of the world is responsible for the ecological costs caused by historical energy consumption. While the South has been catching up fast in the last 20 years, 45 percent of total energy consumption is occurring in 8 wealthiest countries (G8 countries). On the other side, according to International Energy Agency, by the year 2015, 1.2 billion people live without access to electricity. Distributional equity is often ignored by conventional economics. It also fails to consider ecological boundaries in the analysis. Ecological economics diverges from this conventional view in its emphasis on both. Our proposed fair use level has the potential to serve for both purposes.

In purpose of progressing within ecological boundaries, fair use level could be reference for high energy consuming countries as a reduction target. Less developed countries' increasing consumption could be counterbalanced by the reduction of the high developed countries. Fair use level provides a justifiable benchmark that can be useful both in international context and also within a country. Fair use level will be a reference point for nations to see their position and share responsibilities fairly. The distance from fair use level will imply the inefficiency of a nation in achieving wellbeing (efficiency gap). Fair use can be considered as a global average energy consumption target which will be achieved as similar to the emission reduction mechanism "contraction and convergence". This target would require high consuming countries to curb their excessive use (contract) and allow developing countries some space to meet their developmental needs by stabilizing the global average energy consumption (convergence to fair use level). Certainly, achieving this target requires a global involvement. On the other side, fair use level also can be utilized similarly within a country. This prevents high consumers of developing countries from benefiting exemption from reduction targets, and also prevents low consumers of developed countries being effected from costs of reduction efforts. Not to mention, decarbonization efforts should follow these energy consumption reduction targets in order to achieve the ecological targets in essence.

One important feature of our study is that it aims to produce figures that can be used in a policy design. Primary energy consumption needed to achieve an acceptable human development has been proposed in several previous studies. However, per capita primary energy consumption is a cumulative figure which accounts for data from many different areas of use. Consumption characteristics and dynamics of households and industry are non-identical. Each area is regulated with different type of policies. Therefore, primary energy consumption figures may be useful for a country to see its position among others however it does not inform us about countries' specific performance in different areas. Furthermore, primary energy figures can possibly be manipulated by transferring high energy consuming production to other countries. Household energy consumption figures provides information about one specific sector and it cannot be exported. We have to mention that our findings are first proposals for a possible fair use level. How people can curb their consumption to that fair level is another question but that is out of scope of this study. Residential Energy tariffs could be implemented based on fair use level. Inclined block rates tariff is an example of conservation oriented energy tariff in which increasing energy consumption is punished through higher prices. Consumers exceeding fair level could be charged significantly higher prices. There are many other behavioral ways suggested for reducing energy consumption; from voluntary acts to new lifestyles, new forms of prosperity to sufficiency and frugality. These are not unimportant, but we have to admit that there is not much way out there to go with only individual acts, demand side personal solutions. Underlying political, social and economic factors determining an individual's demand for resources should not be ignored. It is a subject of another discussion. Further research could better provide a complementary insight and investigate the ways how this concept can be employed in a well-designed energy policy.

As Raworth [105] states "the focus of the scientists is mainly setting objective boundaries based on critical ecological limits of the earth, however, eventually the question of where to set the boundaries of natural resource use is normative". What we proposed here is also conceptual and the empirical analysis is exploratory. We do not aim to propose a new ethical perspective or developing new understandings of wellbeing. In the analysis also there are certain limitations. Although some factors are controlled for better comparison, there may be other that can possibly influence energy-wellbeing performances of countries. Residential energy consumption data is corrected using space heating data. Available data is limited and we had to work with a small number of countries. It also made us to work with 2012 data for the reason that more space heating data was available for that year. Cooling energy consumption has also been increasing with the increasing income in countries lying in hot climates. For instance, including cooling energy may help us understand Thailand and Vietnam's relative inefficiency which is observed in resultant graphs.

Urbanization rates of the countries could be another determinant. Further research could be focused on urban areas which are responsible of most of the growing energy consumption. Comparing urban data will prevent us from ignoring the heterogeneities in consumption of energy between rural and urban areas and also between different geographical and climatic regions within a country. In our study, we analyzed only residential energy consumption. Urban passenger transport energy consumption has similar characteristics with residential energy consumption as both have direct impact on well-being and both figures reflect the true responsibility of the final user. Energy needed for mobility is an important and growing component of total energy consumption and still highly dependent on fossil fuels. Combining residential energy use with passenger energy transport and creating a household energy consumption indicator would provide us a comprehensive understanding on the relationship between household energy consumption with wellbeing. Further research would use this methodology to test whether a fair use level could be detected with different well-being indicators or other energy consumption areas. Fair use level contributes to both intragenerational and intergenerational justice. Stabilizing our average consumption is an attempt to keep the choices for the next generations and a step forward to maintain a fair distribution today.

Our proposed fair use level is valid for a specific time period where technological efficiency could be considered unchanging or slightly changing. Fair use level would be required to be updated in order to represent the current technology of that year.

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APPENDIX A

DESCRIPTIVE STATISTICS

Statistics

RECwoSH

N	Valid	62
	Missing	0
Mean		7.0147
Median		6.7100
Std. Deviation		3.26103
Variance		10.634
Skewness		.914
Std. Error of Skewness		.304
Kurtosis		1.582
Std. Error of Kurtosis		.599
Range		16.77
Minimum		1.74
Maximum		18.51

Figure A.1: Descriptive Statistics- RECwoSH

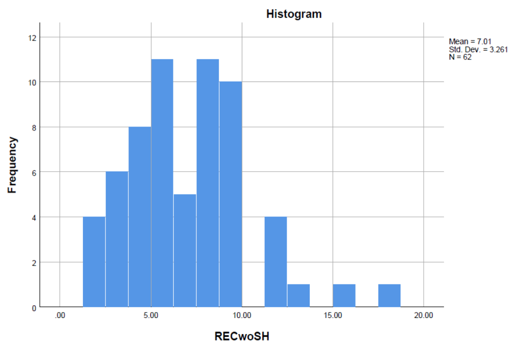

Figure A.2: Histogram - RECwoSH

Statistics

TLE

N	Valid	62
	Missing	0
Mean		76.5973
Median		76.9950
Std. Deviation		5.10159
Variance		26.026
Skewness		-.903
Std. Error of Skewness		.304
Kurtosis		.291
Std. Error of Kurtosis		.599
Range		20.52
Minimum		62.58
Maximum		83.10

Figure A.3: Desc.Stats-TLE(RECwoSH)

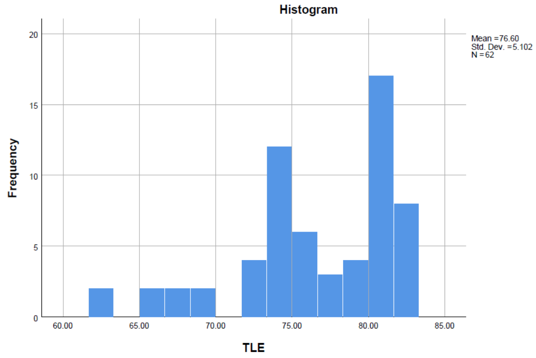

Figure A.4: Histogram-TLE(RECwoSH)

Statistics

EDUIndex

N	Valid	62
	Missing	0
Mean		.74632
Median		.77150
Std. Deviation		.128629
Variance		.017
Skewness		-.776
Std. Error of Skewness		.304
Kurtosis		.259
Std. Error of Kurtosis		.599
Range		.586
Minimum		.350
Maximum		.936

Figure A.5: D.Stats - EDUIndex (REC-woSH)

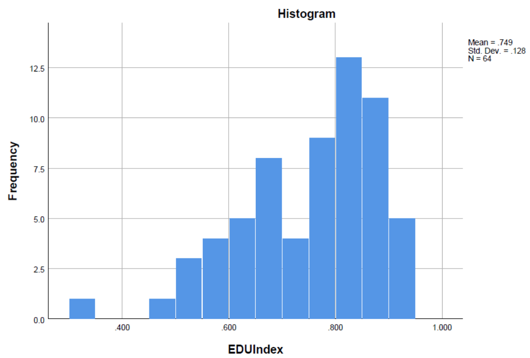

Figure A.6: Hist.- EDUIndex (RECwoSH)

Statistics

EDUYears

N	Valid	62
	Missing	0
Mean		14.815
Median		15.000
Std. Deviation		2.2513
Variance		5.068
Skewness		-.070
Std. Error of Skewness		.304
Kurtosis		.007
Std. Error of Kurtosis		.599
Range		11.3
Minimum		9.0
Maximum		20.3

Figure A.7: D.Stats- EDUYears (RECwoSH)

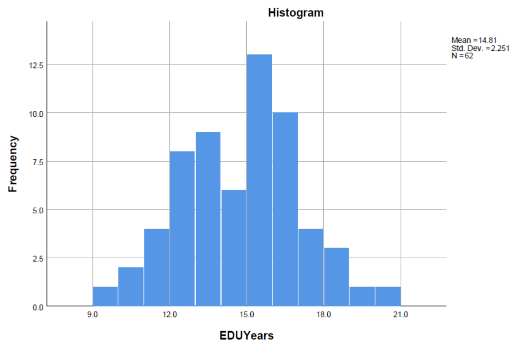

Figure A.8: Hist.- EDUYears (RECwoSH)

Statistics

HDI

N	Valid	64
	Missing	0
Mean		.79909
Median		.82550
Std. Deviation		.108759
Variance		.012
Skewness		-.872
Std. Error of Skewness		.299
Kurtosis		.306
Std. Error of Kurtosis		.590
Range		.452
Minimum		.490
Maximum		.942

Figure A.9: Desc.Stats-HDI(RECwoSH)

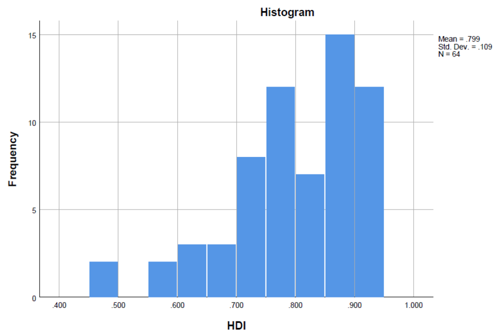

Figure A.10: Histogram-HDI(RECwoSH)

Statistics

HDINI

N	Valid	61
	Missing	3
Mean		.84516
Median		.85900
Std. Deviation		.090274
Variance		.008
Skewness		-.498
Std. Error of Skewness		.306
Kurtosis		-.689
Std. Error of Kurtosis		.604
Range		.361
Minimum		.617
Maximum		.978

Figure A.11: D.Stats- HDINI (RECwoSH)

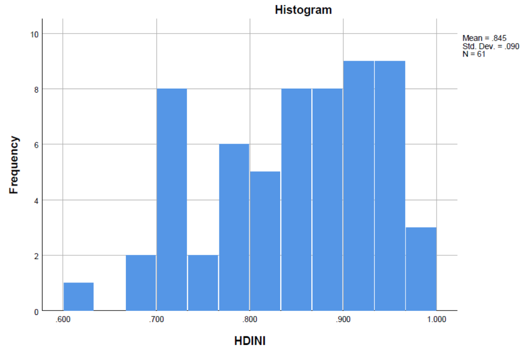

Figure A.12: Hist.- HDINI (RECwoSH)

Statistics

RECwSH

N	Valid	38
	Missing	26
Mean		13.7987
Median		13.7068
Std. Deviation		3.99335
Variance		15.947
Skewness		.283
Std. Error of Skewness		.383
Kurtosis		1.205
Std. Error of Kurtosis		.750
Range		21.09
Minimum		4.44
Maximum		25.52

Figure A.13: Desc.Stats-RECwSH

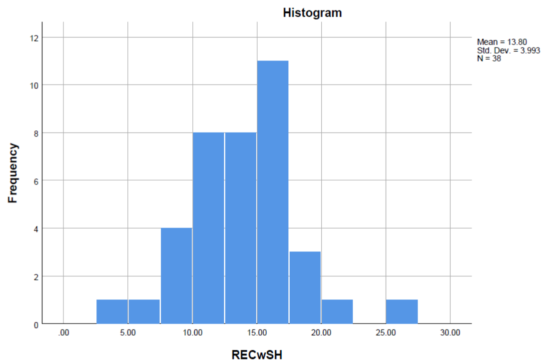

Figure A.14: Histogram-RECwSH

Statistics

TLE

N	Valid	38
	Missing	0
Mean		79.3402
Median		80.6305
Std. Deviation		2.87672
Variance		8.276
Skewness		-.781
Std. Error of Skewness		.383
Kurtosis		-.856
Std. Error of Kurtosis		.750
Range		9.32
Minimum		73.78
Maximum		83.10

Figure A.15: Desc.Stats-TLE(RECwSH)

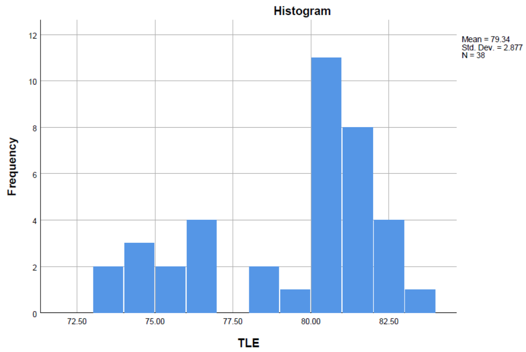

Figure A.16: Histogram-TLE(RECwSH)

Statistics

HDI

N	Valid	36
	Missing	0
Mean		.86922
Median		.88700
Std. Deviation		.052391
Variance		.003
Skewness		-1.093
Std. Error of Skewness		.393
Kurtosis		1.154
Std. Error of Kurtosis		.768
Range		.229
Minimum		.713
Maximum		.942

Figure A.17: Desc.Stats-HDI(RECwSH)

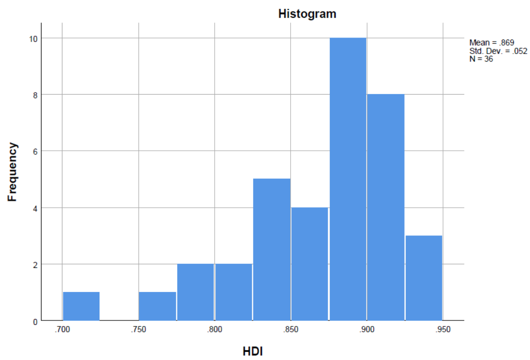

Figure A.18: Histogram-HDI(RECwSH)

Statistics

HDINI

N	Valid	35
	Missing	0
Mean		.90200
Median		.91300
Std. Deviation		.054516
Variance		.003
Skewness		-1.089
Std. Error of Skewness		.398
Kurtosis		2.082
Std. Error of Kurtosis		.778
Range		.258
Minimum		.720
Maximum		.978

Figure A.19: D.Stats- HDINI (RECwSH)

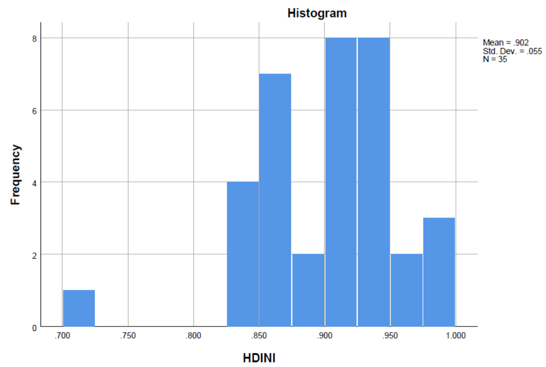

Figure A.20: Hist.- HDINI (RECwSH)

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M.S.	METU Petroleum and Nat. Gas. Eng.	2010
B.S.	METU Petroleum and Nat. Gas. Eng.	2007

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2008-present	ODTÜ GİSAM	Research Assistant
2007-2008	Energy Operations Turkey	Engineer

PUBLICATIONS AND CONFERENCES

M. O. Aydemir and U. Soytaş, “Quality of life and energy use: Is there a fair use energy level?”. Routledge Handbook of Energy Economics, pp. 289–306, Sep. 2019.

M. O. Aydemir and U. Soytaş, 2018, "From ecological to social boundaries: Fair use of energy," Global Conference-International Forum for Economists, May 25-28, Amsterdam.