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“TACKLING CLIMATE CHANGE AND POVERTY FOR SUSTAINABLE DEVELOPMENT: AN APPROACH FOR THE ENERGY SECTOR.”

TESIS
QUE PARA OPTAR POR EL GRADO DE
MAESTRO EN ECONOMÍA

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R·A
Bioenergía

Acknowledgments

To my mother, Sonia.

Abstract

Energy Security (ES), the fight against climate change (CC) and poverty are mayor challenges humanity will face in this century. Energy technologies on renewable energy (RET), energy technologies on Fossil fuels equipped with CCS or Nuclear Energy (Clean Energy) and Energy Efficiency (EE), are presented as economically viable alternatives to ensure energy security while achieving international goals for CC and poverty abatement. Both technologies face a number of market failures that need to be corrected to optimize their implementations. The competition between these technologies is likely to continue stimulating energy innovations and their abilities to reduce tradeoffs between environmental and poverty abatement policies. This is reflected partially in the lowering of Clean Energy and RET implementation costs over the years. In an optimistic scenario, availability of physical and technological resources will be key determinants for the energy mix choice of economies, but these will be subject to the provision of two international public goods: mitigating climate change and fighting poverty; the first related to intergenerational and the second to intragenerational justice. At a global scale, thanks to technological progress and refereed market mechanisms, natural resources and technology are interchangeable between nations (and generations). Different countries have different capacities and priorities to implement RET or Clean Energies. Developing countries with growing populations and energy demand need investment in their energy sector and free international energy trade and integration can help regions that include developed, developing and least developed countries allocate natural, technology and monetary resources to create cheaper cleaner and more reliable energy while helping provide CC and poverty abatement international public goods.

KEY WORDS: *SUSTAINABLE DEVELOPMENT, POVERTY, ENERGY SECURITY, RENEWABLE ENERGY, CARBON CAPTURE AND STORAGE, CLIMATE CHANGE, ENERGY MIX.*

Resumen

La Seguridad Energética (ES), *el combate al Cambio Climático* (CC) *y la pobreza, serán de los retos más importantes que enfrentará la humanidad en el presente siglo. Las tecnologías energéticas de energías renovables (RET*, por sus siglas en inglés) *y tecnologías energéticas de combustibles fósiles equipados con Captura y Almacenamiento de Carbono* (CCS), *Cogeneración Eficiente o la Energía Nuclear (Energías Limpias) se presentan como alternativas económicamente viables para garantizar la seguridad energética, al tiempo que facilitan alcanzar objetivos internacionales de CC y reducción de la pobreza. Ambas tecnologías enfrentan una serie de fallas del mercado que necesitan ser corregidas para optimizar sus ritmos de implementación. Es probable que la competencia entre estas tecnologías continúe estimulando las innovaciones energéticas que incrementan sus capacidades para reducir las compensaciones o costos de oportunidad conocidos (tradeoffs) entre las políticas ambientales y de reducción de la pobreza. Esto se refleja en la reducción de los costos de implementación de Energía Limpia y RET a lo largo de los últimos años. En un escenario optimista, la disponibilidad de recursos físicos y tecnológicos serán determinante clave para la elección de la combinación energética de las economías, pero éstas estarán sujetas a la provisión de dos "bienes públicos internacionales": la mitigación del cambio climático y lucha contra la pobreza; la primera relacionada con la justicia intergeneracional y la segunda con la justicia intrageneracional. A escala mundial, gracias al progreso tecnológico y a los mecanismos de mercado arbitrados, los recursos naturales y la tecnología son intercambiables entre naciones (y generaciones). Diferentes países tienen diferentes capacidades y prioridades para implementar RET o Energías Limpias. Los países en desarrollo con poblaciones y demanda de energía en crecimiento necesitan inversiones en su sector energético las cuales pueden mermar sus acciones para combatir a la pobreza. Fortalecer el libre comercio internacional y la integración energética puede ayudar a las regiones que incluyen países desarrollados, en desarrollo y menos desarrollados a asignar recursos naturales, tecnológicos y monetarios para generar energía más barata, al mismo tiempo que proveen bienes públicos internacionales para el combate a la pobreza y al CC.*

Prologue

The present work aims, on its own way, to continue the previous degree's dissertation. The earlier dissertation, published in February of 2011, is written in Spanish and its title can be translated as: "The evolution of economic theories of natural resources and technology: Towards a Theory of Sustainable Technology". The former work established this now continuing research on technology and the environment pointing at energy technologies, especially renewable energy ones, as possibly the main economic drivers towards sustainable development. In the same sense, the convergence of natural resource theories and technological change economics, specially neoclassical and evolutionary theories; will probably shape a theory of technological change and sustainable development. Even though this dissertation continues the line of study of the later one, it's designed to be self-contained. The topic in this study will continue to raise awareness and call for research. It is recognized that the shape of the world's energy mix will likely suffer a drastically change in the following decades. It would seem necessary to change energy systems to renewable energy as soon as possible, nevertheless this energy transition designed to avoid future generations being worst-off can be costly, and can use scarce economic recourses that could be used to alleviate poverty in poor and developing countries for generations alive, barely, today. This can be a case of intergenerational versus intragenerational justice in the distribution of resources. Policy makers must be aware that tradeoffs between carbon emission reductions and unbearable economic development costs exist, especially in the poorest economies who struggle to fight extreme poverty and attract foreign direct investment to cover their growing energy needs. These tradeoffs can be a treat to the fair distribution of intragenerational wealth, which must never be left out of the table when discussing intergenerational justice. This view is especially important after the Paris agreement, which is groundbreaking and brought to the table an unprecedented number of parties, but is not legally binding and does not consider formally the historical emissions debt of developed countries. This renewed political will is a clear sign of the increasing awareness surrounding climate change, but still most economic agents worldwide don't take properly into account costs and externalities related to this treat and leave the problem in just politics more than recognizing the global welfare that can come from international cooperation. This work pretends to do some relatively clear suggestions of not the policies *per se* but on some basic tenets to be addressed when formulating renewable and clean energy implementation policies for the global energy transition in developed and developing countries.

Chapter 1: ***Introduction***

"Energy is the golden thread that connects economic growth, increased social equity, and an environment that allows the world to thrive"
Ban Ki-moon, Special Message, 5 Clean Energy Ministerial, Seoul, 12 May 2014

Environmental degradation and global warming, or anthropogenic driven climate change (CC) by Green House Gas Emissions (GHGE), affect natural good stocks and natural service provision, minimizing human welfare, human security and economic development. Impacts of anthropogenic pollution are due primarily to agriculture and energy systems including transport and power generation based primarily on fossil fuels. Various adverse effects of these energy systems and the central role of technology, to drive economic development away from them, are recognized by many economic agents (from individuals to international organizations). The adverse effects can be found in Our Common Future, also known as the Bruntland Report (WECD, 1987), The Stern Review (Stern, 2006) the fifth report of the Intergovernmental Panel on Climate Change (IPCC, 2014) and many other publications (see chapter 2).

One of the core arguments spurred from ecological economics is around the assumption that CC mitigation costs are lower in the present; so if rapid action is taken, future (high) costs can be minimized. Nevertheless high transitions costs and market barriers in a society were fossil fuels are locked in to the system force the transition to be moderate due to the high costs to overcome this path dependency. One of the basic ways to address these problems is by technological change. The role of technological change is recognized by economic agents as a basic tenet for the mitigation and adaptation to CC, both in renewable and fossil sources. From the Stern Review (Stern, 2006), to the Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) (IPCC, 2012); these publications provide information to economic agents (aiming at decision makers) on the advantages, capabilities and costs of Renewable Energy Technologies (RET) and Clean Energies (CE) to replace Fossil Energy Technologies (FET).The information provided allows economic agents to recalculate their utility, making societies maximize their welfare in time, thus becoming key element to mitigate the negative effects of GHGE, climate change and environmental degradation in the present. This way, new information around future CC costs has changed the allocation of resources worldwide; this alongside with induced technological change has caused, in part, a series of technological innovations around both RET and FET.

Specific literature on energy security, economic development (including poverty abatement) and renewable energy technology implementation is still relatively scarce. This dissertation will try to give insights, on the combination of the three subjects focusing on scarcity and, therefore, on the tradeoffs that generate when governments chose between the provisions of different public goods. Especially between two international pubic goods; CC mitigation and poverty abatement (translated into basic development of under developed countries). The first international public good is related to intergenerational justice in distribution, the second with intergenerational one. This will aim at considering some basis for the distribution of energy technologies in an Economy´s specific energy mix aiming at achieving a sustainable development[1] path.

In the last years RET implementation has increased dramatically. Greater availability of information concerning the advantages of renewables over fossil energy, along with unstable fossil fuel markets, have caused two mayor effects enhancing technological progress in the last years. On one hand relative high fossil fuel prices in the 2008 -2014 period caused an Induced Technological Change (ITC) around FET, RET, CE and energy efficiency worldwide. More information, public awareness on CC and the recognition of existing market failures have incentivized governments to deploy policies, that level the field of play between RET and FET. Within national boundaries, especially policies regarding Energy Security and industrial competitive strategies on the RET sector; and within international political economics, policies attached to regimes such as the Kyoto Protocol and its superseding Paris Agreement. This has placed RET on competing terms with FET which has spurred innovation on both sets of energy technologies; on the renewable’s side around price and on the fossil’s on environment, having an overall positive impact on the energy sector. The advantages of RET, CE (especially FET equipped with Carbon Capture and Storage systems) in decreasing CO_2 emissions are evident.

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[1] The term “Sustainable Development” is commonly defined as the development that “meets the needs of the present without compromising the ability of future generations to meet their own needs” (UNDP, 1987;p.15).

Besides Energy Efficiency, RET and CE are recognized as the two technological breakthroughs from the energy sector for climate change mitigation[2]; nevertheless their implementation will be diverse due to a series of constrains. These limits usually are not taken into account in revised literature and infer deeply on technological choice, the present dissertation aims to contribute to the state of knowledge by providing a better understanding concerning RET and Clean Energies versus conventional FET and their implications for economic development. The present work does not intend to point out clear suggestions on RET or Clean Energy enhancement policies *per se*, but on the basic tenets to be addressed when formulating energy implementation policies. Providing Energy Security while mitigating CC and tackling poverty, as the common saying goes, are opposite sides of the same coin and addressing these jointly can booster economic development by reducing trade-offs. In spite of the technological lock in and different barriers for the deployment of renewables, including market failures; government intervention is necessary for the deployment of RET. The 2014 – 2015 decade was proclaimed by the United Nations as the "Decade of Sustainable Energy for All". The initiative called Sustainable Energy for All (SE4All) is based on achieving greater energy security with three objectives for 2030, ensuring universal access to modern energy services, doubling the amount of renewable energy and doubling energy efficiency, all by 2030. Nevertheless can countries afford to implement RET, or are RET optimal in their energy mix? Does doing so affect their already scarce resources for abating poverty? This question's answer varies very much from one economy to another, specially separating the global North and South.

This thesis is divided in 6 chapters that guide the dissertation. After this introductory chapter the second one addresses the literature review for the research. In the present dissertation CC is considered has a fact and its costs, along with different others are calculated according to different scenarios; following the line of tree main international publications the 2015 World Energy Outlook (WEO) by the International Energy Agency (IEA), the 2016 International Energy Outlook (IEO) by the Energy Information Administration and the 2015 Energy Revolution (E[R]) by Green Peace International (GPI); and naturally the Fifth Assessment Report (AR5) of the IPCC. Most of the facts used come from these publications and their respective databases, but due to the scarcity of information some is calculated or referenced from

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[2] Also Bioenergy with CCS could play an important role (IPCC, 2014;p. 22).

other publications. The higher amount of literature on the subject is recent (2006 on) and is continuously changing as the state of the world's energy suppliers adjusts. A new theoretical approach would seem necessary due to the importance RET will have in the following decades.

The third chapter concerns the background. It is the foundation of the tree main issues for a sustainable economic development, finding the convergences of Energy Security, Environmental degradation (especially trough Climate Change) and Poverty. These issues lag behind and threaten present and future economic development. Poverty abatement must not be seen only as a moral duty, it is proven to be better for the economy; nevertheless, it can be expensive to guarantee energy security and environmental security wile combating poverty. No country in the world without universal energy access can have an inclusive development. Creating a comprehensive policy that jointly addresses energy security, climate change and poverty can prevent inefficient tradeoffs and help achieve climate and poverty abatement goals faster.

The general purpose of the fourth chapter is to provide a brief overview of the effect of technological change to drive energy and the environment to a sustainable inclusive development. After defining the role of technological change the issue of inter an intergenerational justice is valuated alongside some basic concepts in which development economist rely, from an interdisciplinary point of view, to explain development. Induced technological, change and path dependency are described. The world's energy system shifted at the star of the last century and in hand with the second industrial revolution to fossil energy, an energy carrier that is now virtually locked-in the system. Environmental awareness has risen in the past years and along with induced technological change have created a positive setting for technological evolution around RET and FCCS. Full cost pricing along with higher oil prices (due in part to decreasing marginal utilities in oil extraction) have caused a major shift in the use of energy technologies over the past years. Finally five theoretical technological stages are set for energy technologies that can guide interdisciplinary policy makers step by step on choosing one over the other. This chapter sets the basic theory for the analysis in the dissertation. Prices, technological lock-in and sunken costs make highly inefficient to immediately switch the power system from FET to RET.

The fifth chapter, core for this dissertation, underlines the importance of the factors that sum up for a country to choose its energy mix concerning energy security but environmental degradation and poverty abatement in a global scale. For this, a first part describes based on the previous chapter how climate change and poverty abatement can be considered international public goods. On a second part a simple methodology for determining the energy mix, considering the provision of public goods for climate change (intergenerational justice) and poverty abatement (intragenerational justice). The international CC and Poverty abatement system is described were countries face the prisoner's dilemma on international cooperation on CC and Poverty Abatement. Different countries have different tradeoffs depending on their natural resources, technological endowments and stage of technological locked-in energy systems. There are also taken into account the prices of over emissions of an economy, its natural resources stock, and its technological lock-in, its learning by doing and technology absorption capabilities.

Finally, on the sixth chapter, the hypothesis and research questions are reevaluated and the conclusions are outlined. In the Epilogue future discussion and research in the area is suggested. Under this framework, in the last section, some command and control policies are proposed.

1.1 Research Questions

The basic research questions of this work are divided by chapters, each chapter having a specific role in answering the main question in Chapter 6. These are:

- Chapter 3. What is the contemporary relation between energy security, poverty abatement and the environment?
- Chapter 4. What is the role of technology addressing Sustainable Development? What is the context that makes RET and Clean Energies so important for development and poverty alleviation?
- Chapter 5. What could be the best approach to analyze energy security, sustainable development and energy technologies as a whole? How do we find the right mix and how does global trade and Technology come in account considering the Paris agreement and Kioto Protocols?
- **Research Question** - Chapter 6. Could there be an energy mix that maximizes global welfare? What are some of the options countries and the international community

have to enhance the provision of CC and poverty abatement international public goods for sustainable development from the energy sector?

1.2 Hypotheses

The hypotheses of this dissertation can also be divided by chapters that add up to the final general one of Chapter 6. These are:

- Chapter 3. "Environmental security, energy security and poverty abatement are deeply interrelated and could be distinguished as the 3 main challenges to achieve a sustainable a development path."
- Chapter 4. "Technological change and choice are the main drivers for sustainable development from the energy sector; nevertheless, they rely on prices and on policies that have sustainability as a goal."
- Chapter 5. "The Environmental Kuznets Curve shows that poor and developed countries would go through a highly contaminating phase as they pass from agricultural to industrial economies, to avoid this catastrophe two recommendations are broadly laid out: i) Available technology and best practices must be transferred internationally North-South, South-South to promote leapfrogging processes, and ii) Free Trade and DFI must be facilitated internationally to help promote RET in developing countries who are increasing their energy demand."

i) **General Hypothesis** - Chapter 6. "There are two main approaches to enhance a sustainable development for the energy sector: i) **Intergenerational** approach. Technological lock-ins, natural resources and technology endowments make it cheaper to strengthen the implementation of Renewable Energies in developing and least developed countries; and ii) **Intra-generational** approach. On the other hand, combating poverty is also a global public good, developing countries allocate more efficiently resources for ending poverty and the integrations of energy regions across the world, taking advantage of new technologies for energy transmission, including developed and developing counties with lower cost of labor, greater natural resources and growing energy needs promotes FDI and technology for leapfrogging to be brought to places in need of poverty elimination."

Chapter 2: Literature Review.

"It is obvious that we cannot achieve the Millennium Development Goals or Sustainable Development without access to reliable - affordable energy"
Dr. KandehYumkella,UN SE4ALL, IEF, 2014.

Although there has been a heavy increase in the literature surrounding Energy, Sustainable development, technological change and poverty, and the specific subjects in this dissertation; as a whole, there is still a lack of a comprehensive literature stock. As a disclaimer, some very important publications on the subject are not included, not because of their relevance on the subject but rater due to the narrowing of this dissertation. As the common saying in the matter goes, so the trees won't obstruct our view of the forest.

2.1 Introduction

Energy and its relationship with technological change (specifically with technological choice) the environment and economic development (specifically trough poverty abatement), is a topic that was probably not specifically, and rigorously, addressed until the end of the past century. It's even possible to say, that a strong theoretical framework on the matter is not built yet. The relationship between the topics can be ambiguously found in some classical economists but was "forgotten" for a long time; as, some would argue, economics turned more into chrematistics (Naredo, 2003). The formal gathering between endogenous technological change and the economic system was made until the works of Schumpeter (1942), and later Romer (1990). The reconciliation between economics, natural resources and energy was properly made until the works of Georgescu-Roegen (1971, 1977). For the pioneer works of Energy Economics and RET the work of Slesser is to mention: Energy in the Economy (1978). The first publications that address the three topics together come from international organizations concerned, more or less, with sustainable development. Probably the most groundbreaking is Our Common Future (UNDP, 1987), also known as the Bruntland report, which underlines the basic principles to achieve sustainable development. The next high impact publication on the matter was in 2006; the Stern Review (Stern, 2006) is probably the first reference to emphasize that technology will be a crucial factor in driving the economic system to a sustainable development path. In more recent years the fourth and fifth reports of the Intergovernmental Panel on Climate Change (IPCC, 2007, 2014) recognize the importance of Renewable Energy Technologies (RET) and FET, more or less, to help achieve sustainable development and avoid CC catastrophe. This view has been shared by the International Energy Agency (IEA) who since 2008, with its World Energy Outlook (WEO), has specifically addressed the matter of RET and climate change scenarios (IEA, 2008). The IEA continues each year to update the scenarios and forecasts for RET in the global energy mix (IEA, 2013-2016) and has been building technology roadmaps for different fuels and energy technologies. The first publication from the IEA regarding RETs as development drivers is from 2001, named Towards a Sustainable Energy Future (IEA, 2001). Also the United Nations Development Program in its Human Development Reports (UDR) addresses each year the technological factors that can reduce poverty while fighting and mitigating climate change (UNDP, 2011 - 2016). As it is reviewed later, it was the first of these reports the UDR 1994, based on the thought of Amartya Sen of human development (1999), were the basic human securities from threats are outlined (UNDP, 1994). The 2016 World Energy Outlook by the IEA describes what are the main challenges and goals if countries abide by their pledges to the 2016 Paris Agreement (EIA, 2016).

2.2 Energy Security, Environmental Degradation and Poverty.

On the next chapter tree basic goals are considered to achieve a sustainable development path: Energy Security, Environmental Security (especially from CC mitigation) and extreme poverty abatement. Energy Security in this dissertation is based on the publication “A Quest for Energy Security” by APERC (2007), nevertheless the changing stages of Energy due to price volatility and technological breakthroughs could call for a new approach that could take into account resilience of energy systems (WEC, 2013). On poverty there is a focus on the Millennium Development Goals (MDG) and their superseding Sustainable Development Goals publications (UNDEP, 2013, 2014, 2016). On the Global challenge two are the main publications surrounding the correlation between energy, development and the environment; one is the Global Energy Architecture publication of the World Economic Forum (2017) and the other is the Energy Trilemma set of publications from the World Energy Council (2013, 2016). On the last point of the chapter the concept of Inclusive Green Growth of the OECD (2012) is outlined and used to build a connection with the Trilemma of the WEC.

2.3 Energy Technologies and Sustainable Development.

Recently there have been several studies that show the capabilities of Renewable Energy Technologies (RET) *versus* Fossil Energy Technologies (FET) thus becoming key elements to mitigate the negative effects of Green House Gases (GHG) emissions and environmental degradation. These works include the Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) from the IPCC (IPCC, 2012) -the bedside book for most of the technical capabilities review of this thesis-, the Energy Report, 100% Renewable Energy by 2050 from the World Wildlife Fund (WWF, 2011), Deploying Renewables report of the International Energy Agency (IEA, 2011), Achieving Energy Security in Developing Countries of the United Nations Environmental Program (GNESD, 2010). All these publications tend to draw 2 similar conclusions about RET. One is that the more implementation or RET will lead to lower levels of CO2 emissions, mitigating climate change. The second is around that a lack of policy to properly internalize the negative externalities of FET leads to higher relative prices of RET, causing a burden on the implementation of these technologies. This second conclusion is a part of a series of barriers (including market failures), that undermine the implementation of RET.

Publications concerning theory of technological change, energy and the environment come from different disciplines and times, some vestiges of these relations can be traced back to the Physiocrats, some could argue that they passed through Marx in the Grundrisse or through Schumpeter (Xhemalce, 2011), but the first theorist to recapitulate these was likely Georgescu Roegen and in a very lax, but interesting way Kennet Boulding (1965). From there the works of authors like Daly, Constanza, Stagl, Yergin, and others is of great importance; nevertheless more accordingly to the narrowing of this dissertation, specific publications start in the mid-eighties. Energy for a Sustainable World (Goldemberg et al., 1987) focuses on energy efficiency for sustainability. In a specific country comparison, the book Energy Policies and the Greenhouse Effect: Country Studies and Technical Options (Grubb, 1991) gives a perspective of very different, countries and their implementation capabilities of different energy technologies. The publication, Environment, Energy and the Environment (Kaya and Yokobori, 1997[3]) (from where the Kaya identity is derived), is a great advancement in RET and SD. Energy after Rio (Reddy, 1997) gives some energy diverse energy scenarios with the implementation of RET. Towards a sustainable Energy Future is the first energy and sustainable publication by the IEA (IEA, 2001). Energy for Sustainable Development: A policy agenda; addresses some of the basic barriers in international RET implementation. A worthy to mention publication that addresses renewable energy, technology and development from 2002 is: The Hydrogen Economy (Rifkin, 2002). Technological change and the Environment by Grübler, Nakicenovic and Nordhaus (RFF, 2002) is of vital importance; along with, the article Technological change and the Environment by Jaffe, Newell and Stavins (2003). Innovations and the Environment by Yoram Krozer (Krozer, 2010) collects in a synthetic way the theories of technological chance and its implications for the environment.

Recently there has been plenty of academic work around the relationship of the tree elements: technological change, economic development and the environment. But these approaches have been specifically regarding some problems. A theory is not properly outlined on the matter, as Ruttan describes "A mayor challenge for the future is to integrate the insights about endogenous growth gained from the theoretical and empirical research conducted within the induced technological change, the evolutionary and the path dependence theories(…)with insights into the relationships between human capital, scale and trade" (Grübler, Nakicenovic and Nordhaus, 2002; p.29) were scale refers to the scale of the economic system over the ecological system. These theoretical issues have not been properly addressed to generate a new theoretical framework. As it is reviewed on the fourth chapter, continuing the line of research of the previous dissertation, the identification of theoretical convergences between the theories can help build a baseline for a future discussion on the matter (Xhemalce, 2011). Some other basic publications that collect the state of the art in theory of technological change and RET, that are mentioned latter include; Technology, Growth, and development by Vernon Ruttan (Ruttan, 2001), the International Handbook on the Economics of Energy by Joanne Evans and Lester

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[3] Based on the 1993 Conference in Tokyo; "Global Environment, Energy and Economic Development".

Hunt (Evans and Hunt 2009), and the handbook in Economics of Innovation by Hall and Rosenberg (Hall and Rosenberg, 2010 Vol. 1 and 2).

2.2 Technology Publications

The IEA and the International Renewable Energy Agency have offered technological roadmaps for the deployment of energy carriers and their respective technologies outlining the specific effects these have on the environment and, in some cases, poverty abatement.

On FET and their importance in the energy mix, the book of Marck Jaccard, Sustainable Fossil Fuels is to mention (Jaccard, 2005).

2.3 Valuation and Modeling.

For this dissertations especial attention lies on some quantitative models concerning economic, technological and environment variables. From the simple IPAT identity published in the early 70's (Ehrlich and Holdren, 1972) base of the Kaya Identity, to the stochastic dynamic general equilibrium models used today; all have faced different natural resource valuation constraints due to the changing information. One of the preferred publications for natural resource valuation is the work by Panaïotov, Instruments of change: motivating and financing sustainable development from (Panaïotov, 1998). Beaudreau in Energy and the Rise and Fall of Political Economy (Beaudreau, 1999) makes an attempt to input energy in the traditional production function. The publication Energy Indicator for Sustainable Development (IAEA, 2005), provides some basic insights on how to measure and compare energy and sustainable development.

The first series of models to address climate change and emissions come from the DICE model by Nordhaus (1994). Model which did not include technological change, until 2005 when endogenous technological change was introduced in the ENTICE model by Popp (Popp, 2005). Other, former briefly, described models include the DEMETER-1CCS model (Gerlag, 2006) which focuses on leaning by doing and induced technological change (ITC). The WorldScan CGE focuses on international spillover effects created by following the Kyoto protocol (Bollen, *et al;* 2003). The MIND model presents the benefits of learning by doing in backstop technologies including FCCS (Edenhofer et al., 2005). The AIM/Dynamic Global focuses on

Research and Development (R&D) around energy efficiency (Masui et al., 2006). The E3MG model focuses on the long term stabilization costs (Barker et al. 2006). All these models focus generally on the importance of endogenous technological change, induced technological change and energy in sustainable development. The models converge around the positive effect of policy to generate technological change leading to a reduction in abatement costs generating cheaper and better technology (Edenhofer et al. 2006). For an optimum energy technology mix the MARKAL, model from the IEA (Loulou et al., 2007), provides relevant conclusions[4]. There are some models that place especial emphasis on technology, including backstop[5] technologies for GHG emissions and welfare loss (Box 2.1).

Box 2.1 Energy, Technology and Development Related Models (backstop technology).

Year	Model	Reference
1992	GREEN	Burniaux et.al.
1999	G&S CGE	Goulder and Schneider
2000	G&M CPPCM	Goulder and Mathai
2001	WIAGEM	Kemfert
2003	DERMETER	Gerlagh and Van der Zwaan
2004	K CGE	Kverndokk et al.
2006	FEEM-RICE	Bossetti et al.
2006	ENTICE	Popp, 2004, 2006
2006	MESSAGE	Rao et al.
2006	MIND	Edenhofer et al.
2007	Markal-Times-TIAM	Loulou and Labriet
2008	WITCH.2	Bosetti et al.
2009	IGEM	Goettle et al.*
2010	GCAM	Zhang et al.**

*The model has evolved since its Jorgenson and Wilcoxen version of 1993.
** Based on Edmonds, J. and J. Reilly. 1983; and previously known as MiniCAM (Brenkert A, S Smith, S Kim, and H Pitcher. 2003)

2.3 Other

On energy security there has been a great shift in the way of conceiving it. From a national point of view of realism to neoliberal views more focused on the individual, and back again to

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[4] as the MOSES for short term energy security (Jewell, 2011)

[5] That substitutes others in a specific context. E.g. scarcity, overprice, depletion, regulation, etc.

household securities more recently with the fuel poverty concept in developing and developed countries (were households spend more than 10% of their income for the provision of energy services, especially heating). A great key publication on this aspect is “A quest for Energy Security in the XXI Century” were the principle of the 4 A’s is essential in any modern energy security analysis (APERC, 2007). Were Energy Security is the baseline; the literature widens from the previously mentioned HDR of 1994 to works concerning the tradeoff between securities for human development. The scope on tradeoffs of human securities is very big, as the cost of opportunity in economics. The first work to address the tradeoffs between human security, and development can even come from Malthus; however the publication by Meadows, The limits to growth better describes the (relatively) contemporary tradeoff between development and natural resource degradation. More recent works used in this dissertation to examine tradeoffs include quotes on health security and the environment the work of Ross H. Hall (1990).

Specific country literature is available in different tones for the selected countries. For every country in the case studies, energy profiles are used from the EIA (2013,c,m), IRENA-REMAP (2013, s,u,c,m), ABB (2012 s,u,c,m) and the IEA’s Energy Profiles data base (EIAEP).

Chapter 3: Background**. Energy Security, Poverty and Environmental Degradation; Global Challenges for a Sustainable Development.**

> "We do not wish to impoverish the environment any further and yet we cannot for a moment forget the grim poverty of large numbers of people (…) are not poverty and need the greatest polluters?"
> (Indira Gandhi, Conference on the Human Environment, 1972)

Probably the three basic lags to achieve a sustainable development path are Environmental Degradation (including Climate Change driven by the agricultural an energy sectors), Extreme Poverty and Energy Security. These three can be seen as the loss or scarcity in human security[6] (based on UNDP,1994; p.22-25). Today, the international community recognizes the broad relationship between SE, poverty and the fight against climate change as critical factors for sustainable development. From the energy perspective, the study of these has been contemporarily brought together by the "Energy Trilemma" and the "Energy Triangle".

The concept of Energy Security has change alongside the different techno-economic paradigms since the industrial revolution[7]. The conceptual analysis of 'security' begins at the end of World War II focused on national security at the macro level within the neorealist school of tough. Historically as part of national security, the state must seek the "productive security" of its agents to satisfy, by any means, its priorities over others. In this thinking, the State must guarantee the provision of energy through electricity grids that form a natural monopoly by providing a public good such as lighting (which is non-rival and non-exclusive) and facilitating access to electricity consumption that *per se*, Is a private good (rival and exclusive); So access to energy must be public to be bought by citizens (this does not mean that companies are state owned).

Following the end of the cold war, the concept of Energy Security evolves towards neoliberalism; human security is viewed at an individual level, based on the concept of human development of Amartya Sen. Different human securities are clearly interdependent to each

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[6] Environmental and Income Security

[7] Techno-economic paradigms are the ones that relate technological change and economic development. The 4th parading is generated from the radical technological innovation of the internal combustion engine and develops an economy and world system around oil and oil products (Pérez, 2003).

other, in this interdependence surges a key concept in the search for human security taking into account a sustainable economic development: the "tradeoff", or known opportunity costs, that surge when moving from one objective to another that can be subject to decision making or policy development. These reflect opportunity costs between different securities and their outcomes can be predicted (Scully, 2008). Security tradeoffs are often not advisable or desirable; however, sometimes they can be optimal due to scarcity of resources or market failures[8,9].

Environmental, Income and Energy Security can be seen as necessary for a sustainable development; nevertheless, technological 'lock-in' and other systematic failures cause higher trade-offs between policy options, and make these interdependent objectives seem less dependent. The joint enhancement of energy security (3.1), environmental security (3.2) and poverty abatement (3.3) is required to reach any of the eight basic Millennium Development Goals (MDG), proposed by the United Nations (based on IPCC, 2012; p.710), and a sustainable development path. A brief introduction to these three and their interdependency is made on this chapter.

3.1 Energy Security

Energy is probably the most important commodity in our world, it allows biological and physical systems to interact and create life[10]. Energy Security, refers to the harvesting of Energy to create goods, it is essential for economic development, as it allows for a degree of confidence in the supply and demand of energy which keeps markets functioning properly (being energy their

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[8] For example there are communities in developing countries that have to make tradeoffs between their environmental security and their income security (or environmental services) to cut down forests to increase their income, which is controversial because it is not possible to fully determine the exact fairness in resource allocation or if these good can be substituted when gone. We will get back to this problem in the next chapter concerning inter and intra generational justice valuation.

[9] There are other situations where governments deliberately and wrongly sacrificed some securities with the supposed aim of increasing others, in the case of the former USSR where to ensure income security in one region, environmental and income security was severely damaged in the Aral Sea region. An example for energy, is the Libyan or the Syrian conflict who sacrificed human security, to allegedly ensure public safety of the majority (because a "terrorist" threat); it is necessary to point out that due to countries striving to guarantee their energy security or their political assets they agree to support these tradeoffs.

[10] From the way plants transforms sunlight into Oxygen to the way we create electricity from nuclear fusion, energy is the base of our way of life.

primary product). The lack of Energy Security translates almost immediately into poor economic performance and social unrest together with a series of chain reaction calamities[11].

Energy Security is defined in various ways that, as other human securities, circle around certainty and uncertainty. The IEA states there is security in the supply of energy services when these are "adequate, affordable and reliable" (IEA, 2007a, p.13), which in turn defines energy insecurity as "the welfare loss that can be caused by a change in the price or availability of energy" (Bohi and Toman, 1996 cited in: IEA, 2007b). There are several definitions but all focus on the risk and uncertainty caused by changes in the prices and availability of energy, capacity and infrastructure to obey strong changes in demand. A definition, closer to a more national energy security sense, can be: "the ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy (…) these can come from physical (sources) or economical elements (affordability)" (APERC, 2007; p.6). Other definition more related to international relations and geopolitics can be: "Energy security is also about the relations among nations and how they interact with each other" (Yergin, 2011; p. 298).

Energy security has faced great changes in the past years due to the unconventional fuels revolution (Yergin, 2011; p.273, 370) which has been an international game changer and along with technological changes in EOR techniques, has pushed the peak oil[12] talks and concerns away from the debate (IEF, 2013; p. 7-8). Energy security is shifting in its form an including more market coordination, environmental and other non-traditional variables. Energy Security, also changes deeply in each level of analysis in time and in markets; in the following boxes this is described briefly.

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[11] See Yergin, 2011.

[12] Based on the Hubbert peak theory, a bell-shaped curve describes the lifecycle of the production of oil peaking when oil fields age, reduce and finish producing oil. The technological break troughs and lack of market competitive options have created a plateau in the bell curve.

Box 3.1 Energy Security in the Short, Medium and Long Runs.

In the Short Term resides in overcoming energy shortage problems, wherever these arise from physical or economical forms.

In the Medium Term, configuring energy rules and regulations for the sectors governability that can guarantee the resilience of physical and economic elements. Like having adequate power lines, to avoid power failures; or transparent energy markets, to reduce uncertainty in investment and better decision making.

In the Long Run, will rely on the way policy is structured so energy architecture can deal with natural degradation and climate change problems. This is likely to include includes research and development policies on energy efficiency and oil decoupling, but with oil still as a mayor player.

Source: Elaborated in part based on Dirmoser (2007; p. 6) and Chichilinsky (2009).

Box 3.2 Energy Security of Supply and Demand.

-Supply-

Along with fostering "Technology Push" trough R+D+i in energy technologies, there are 5 essential factors in ES from the supply side: the availability of fuel reserves; the ability of an economy to meet projected energy demand; the level of an economy's energy resource diversification; in terms of the availability of related energy infrastructure and energy transportation infrastructure; and geopolitical concerns surrounding resource acquisition.

⇔

-Demand-

Provide consumers with information regarding the advantages of energy efficiency promoting a "Technology Pull". By providing an easier access to these goods for consumers. "In terms of energy demand elasticity, an economy that is able to decouple economic growth with energy use –through energy efficiency and conservation– will have an advantage in terms of its energy security".

Source: Elaborated partially based on APERC 2007; p.7

One of the most accepted contributions on the factors that determine Energy Security is the 4 A's theory of APERC. These are: Availability, Accessibility, Affordability and Acceptability (APERC, 2007). Nevertheless Energy Security will eventually be highly influenced by the technology used in specific scenarios whereas it is RET, FET, or even appropriate technology.

3.2 Changing Energy Security

Energy security has been highly affected due to a series of changes in oil prices, driven in great part by the OPEC, geopolitical downturns, policies and armed conflicts (Graph 3.3)[13] . Oil prices due to the low elasticity of demand face higher volatility with changes and from 2004 to 2014 there was a period of especially high oil prices that help consolidate induced technological changes. . The decision of OPEC, led by Saudi Arabia, to maintain production levels at the end of 2014 despite the oversupply of the markets thanks to the shale revolution and lower oil demand estimates made oil prices drop by 50% in the beginning of 2015, compared to the prices in June of the previous year (EIA 2015; p.1) (3.X). This cartel decision generated a price war to dump the shale and other higher cost producing fields, nevertheless innovativeness and flexibility with medium and smaller shale oil producers allow them to survive and OPEC alongside Russian and other non-members made a production cut to increase oil prices in December 2016.

By the year 2035 more than half of international oil will still come from OPEC members, especially from the MENA region (IEA, 2011; p.4), which many agents consider a politically unstable region. These changes will likely continue to occur in the next years and, despite some downward pressures and price volatility, relative prices of oil are expected to slowly increase (driving a continued induced technological change and thus making the prices of alternative technologies lower) (IEA, 2017; p. 7).

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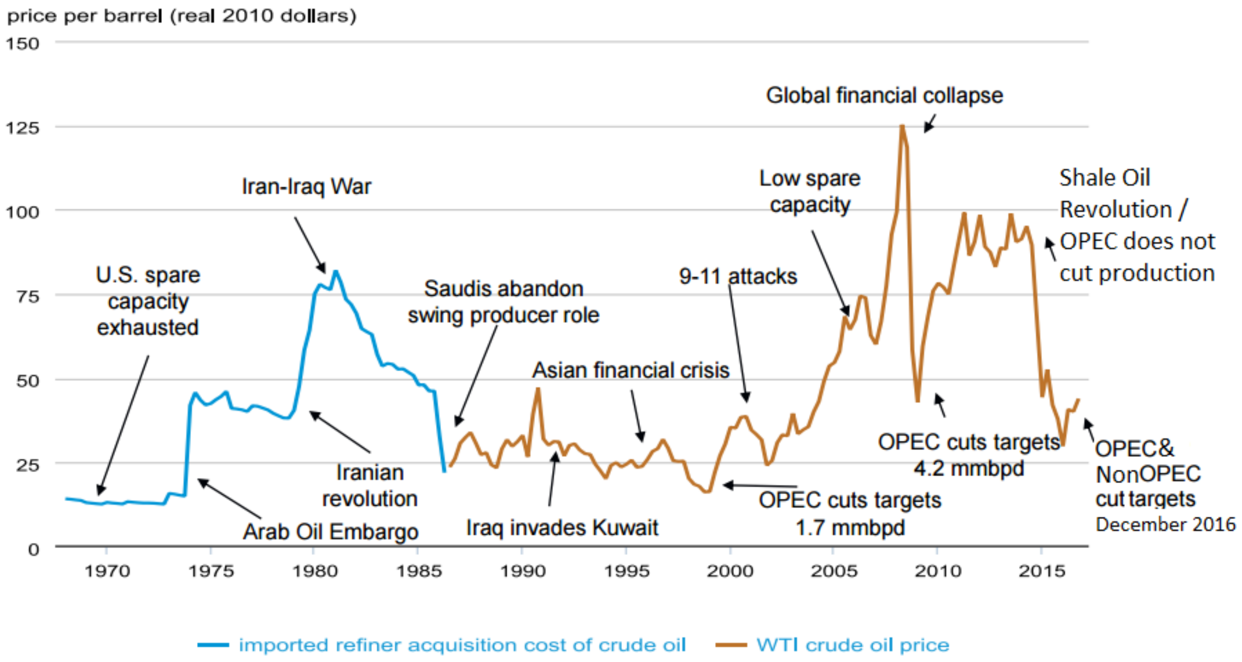
[13] Lately, the Arab Spring, Civil War in Syria, the rise of the Islamic State, Ukraine Civil War as a result of the "orange revolution" (Yergin, 2011; p. 379). But most importantly the "price war" orchestrated by Saudi Arabia to lower oil prices and gain market positions at the end of 2014 (see more in chapter 4).

Graph 3.3 Changes in Relative Prices of Oil.



Source: Modified from EIA (2017); p. 2

Available Online: http://www.eia.gov/finance/markets/reports_presentations/eia_what_drives_crude_oil_prices.pdf (accessed 12/02/2017)

In the next decades it's possible that geopolitics in energy will drastically change also, the steady decline in OECD countries as in IOC's reserves and the consolidation of diverse NOCs, like the 'new seven sisters' (Graph 3.4), will have a great effect on the distribution of the world's energy supply and demand. Some of these changes have already started prompting the shale gas revolution and other unconventional fossil fuels in the United States and Canada for Development and Energy Security reasons. It is now expected that in 2035 the United States will possibly be able to meet domestically it's energy demand (IEA, 2013;p.1). The energy demand balance is shifting to developing countries, "non-OECD countries will drive the increase in total energy use" (EIA, 2016; p. 10). All these effects will probably make the notion of Energy Security shift to a broader sense (but for now we will keep the 4 A's theory of APERC as the central for this dissertation).

Graph 3.4 The New 7 Sisters.

Source: Companies websites.

Another factor that can alter energy security is the lack of transparency in energy markets. Energy is a commodity exchanged in almost any way thinkable of in a variety of different markets (from long term future contracts to local barters). Secret over the counter operations and other type of undisclosed transactions can lead markets to be misinformed and create price distortions and instability (OICV-IOSCO, 2010; p.7). Programs like the Extractive Industries Transparency Initiative and other transparency, accountability and information sharing like the JODI[14] from the International Energy Forum improve transparency[15] and reduce price volatility, enhancing energy security.

There are many different values and factors that can enhance energy security but it is clear that price stability, security of demand and supply and diversification, especially to cleaner fuels, are recognized as very important factors to currently enhance energy security and eventually lead energy systems to a sustainable path. This way, it is possible to relate <u>intemporal</u> changes in Energy Security, for a predominantly importing country, in the form of:

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[14] Joint Organizations Data Initiative

[15] This is an example of market intervention that causes benefits in the medium and long run.

⚡ $\approx f(D, P, B, C, G, CC, I, B, A)$

Where: ⚡ ≈ Energy Security; in direct relation (+) of: D = Diversity in the Energy Mix.; P = Primary Energy Price Stability (supply/demand related); C = Certainty of supply of fuel or resource; G= Geopolitical Stability; CC= Lack of Climate Change Commitments, I = Energy Intensity, B = Budget, A= State of the Art in Primary Energy Generation.
Price stability and Uncertainty of Supply are correlated by all means with the diversity in the energy mix; a real inexpensive source of fuel can focus the energy mix to one energy technology (E.g. natural gas in North America or Coal in China). Geopolitical factors can alter the market for good or bad (E.g. Venezuela price cuts on oil to Cuba, Arab Oil Embargo). If a country lacks GHGs reduction commitments it faces lower production costs and can deliver cheaper energy, nevertheless it will be less likely to diversify its energy mix to cleaner fuels (or diversify at all). Lower Energy Intensity means higher energy savings. A higher state of the art means lower production costs or energy savings increasing energy security.

Energy harvesting is the human activity that drives economic growth and poverty reduction, but also, alongside agriculture, the greatest cause of environmental degradation and the loss of environmental security, especially trough GHGE.

3.2 Environmental Security

Environmental security is essential for economic development, it provides four classes of inputs: resource inputs, waste sinks, amenities and life support (Common and Stagl, 2005; p.87). Nevertheless, it has been historically (at least since the industrial revolution) undervalued and due to this problem, extensive harvest of natural resources has in some cases reached a point that counters the benefits of the harvesting (Engels, 1978; p.145). Environmental security allows economic agents to have a degree of confidence in the provision of natural goods and services and goes hand in hand with the development stage of the economy[16].

The loss of Environmental Security or Environmental degradation can take the form of:

$$S_t = S_{t-1} - E_t.$$

Where S is the stock and E is the extraction. When $St = St_{-1}$ there is no degradation, but if the amount degraded is greater than natural recuperation there will be a depletion of the environment (unless future savings) (Common and Stagl, 2005; p. 114,115). This is especially important for energy and poverty matters. But can be further expanded to include natural capacity charges from an Inflow, Outflow view:

$$S_t = S_{t-1} + A_t + O_t$$

Where A_t stands for the recovery and O_t for the depletion. If we take more than the environments recovery capacity we will eventually run out or that good or service. This also applies to the loss of resilience[17] in a system and to the change in its carrying capacity[18]. Our economic system has led to overshoot the planet´s capacity for the past 40 years, today the world uses around 50% more resources that the planet can sustain leading to a consistent loss in natural services and biodiversity (WWF, 2014; p. 32). We will get back to this with the fact that the loss in environmental goods and services lowers the welfare of the world today and for future generations. This problem has been addressed basically in two ways; by suggesting a perfect substitution of assets between environmental goods and services and manufactured ones creating equivalent income growth rates between generations (Solow, 1991; p.181), which lead to a blind technological determinism (Xhemalce, 2011; p. 123)[19] including backstop technologies; and, by simply discounting welfare today to provide welfare tomorrow, as described in the DICE Model (see chapter 2). There is no consensus on witch of the two is fair and probably won't be because

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[16] This relationship could be inferred from and Environmental Kuznets Curve, were least developed societies highly dependent on natural resources can take more care of their natural resources as highly developed ones with an ecological awareness.

[17] Defined as the ability of a system to recover from a disruption. (Common and Stangl, 2005;p.53)

[18] Defined as the maximum population size that the environment can support (Ibid.;p.45)

[19] That gave the certainty technology would eventually create perfect substitutes and life support for the goods lost.

it's virtually impossible to tell if technology will eventually be capable of fully assuming nature´s role; which eventually leads to the most accepted accord to be, the precautionary principle[20]. Concerning the differentiated valuation between generation, there is a lack of literature and consensus around compensating between inter and intragenerational justice.

3.2.1 Climate Change

The highest lag to achieve a sustainable development path recognized today is Climate Change which is likely to have an adverse effect through global warming (IPCC, 2007; p.32). Global warming and its devastating possible future effects could allegedly cost near future generations from 5% up to 20% of their GDP creating incredible focalized damage to least developed countries and small island states (Stern, 2006; p.V) (IPCC, 2007).

There is extensive literature that recognizes a series of consecutive problems derived from overshooting the planets carrying capacity, in what could be called an unbalanced predator-prey model (humans are the predators); and in which developing countries (closer to the earth's Equator, or the "south") would be much more affected than developed ones (or the "north"). To address these problems the international community has recognized Climate Change as a treat and has created a protocol for action based on the precautionary principle to address CC (IPCC,2007;p.31) and ultimately limit global GHGE and thus Global Warming to 450 ppm or 2ºC respectably. A way to introduce the mitigation challenges for Energy Systems is by limiting the amount of GHGEs that an economy can release into the atmosphere; later, a public agent (E.g. UN trough a post Kyoto Protocol) can implement a Tax for polluting equal to a CCS price. The way the DEMERTER model deals with this is by adding a cost to Fossil Energy to the total production in a CES[21] production function (Gerlag, 2006; p.55), were the producer can chose to pay taxes or to use CCS technologies when using FET:

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[20] The Precautionary Principle "states that where the environmental consequences of regulatory inaction are in some way uncertain/ambiguous but non-negligible, regulatory inaction is unjustified (Commmon and Stagl, 2005; p. 389)

[21] Constant Elasticity of Substitution.

$$Y = C + I^{FET} + I^{CCS} + I^{RET} + M^{FET} + M^{CCS} + M^{RET} + Em^{FET}$$

Where Fossil fuel producers (^{FET}) must invest in CCS (I_t^{CCS}), maintain CCS (M_t^{CCS}) and pay for a carbon tax levied on emissions (Em_t^{FET}); when non carbon producers only account for their production costs (^{RET}). This leads to the advocacy for a carbon tax.

Although climate change is the most recognized Environmental challenge, it is important to remember that Fossil Energy activities are not only responsible for environmental degradation trough GHGEs but in the whole upstream and downstream process[22]. On another hand RET also face environmental problems that must not be left aside (E.g. protection of natural habitats from dam constructions, protection of migrating birds from wind parks, chemical manufacturing for battery storage, etc.).

Increasing environmental security and energy security trough RET is likely to have a positive effect on health security (diminishing GHGE) and other human securities; nevertheless, concerning energy generation systems the benefits can be outweighed if the overall costs of RET are significantly higher than those of FET, hampering economic performance and ultimately poverty alleviation efforts. This is of special importance when taking into account that different governments set dissimilar policy priorities. When advanced economies set policies to guarantee intergenerational justice (e.g. a better environment for future generations), less developed ones are battling to achieve intragenerational justice (e.g. poverty alleviation). The common example of intergenerational injustice is unrecoverable natural resource depletion, but for intragenerational injustice is extreme poverty.

3.3 Poverty

The nexus between poverty, energy and the environment (including their specific aspects) is recognized by many organizations and there is a good amount of literature that accounts for the

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[22] E.g. The Deepwater Horizon oil spills (ultra deepwater), more recently the Tesoro Pipeline spill in North Dakota (Unconventional shale oil play); In Mexico the second largest oil spill was in Campeche exploratory well Ixtoc 1 (Conventional); and also the Sewage Explosions in Guadalajara in 1992 that caused the deaths of nearly 1000 people (Downstream Distribution). It's worthy to mention that the greatest oil spill was caused allegedly by Iraqi troops in scorched earth tactic while fleeing Kuwait in the Gulf War in 199. Sources: Reuters L. Mayton 10/10/13– Proceso 18/01/2002 – R. Chilcote CNN 03/01/2003

trade-offs that are generated when addressing these issues and the importance RET have in reducing them (Common and Stagl, 2005; p. 45-47). Extreme Poverty[23] abatement is not a treat but a reality and represents the single most important challenge humanity faces today. Progress has been made in the world reducing extreme poverty from 1.9 billion in 1990 to 1.2 billion in 2010, achieving the poverty MDG ahead of time (UN, 2014; p.9); nevertheless the remaining poor are by any standard unacceptable in our society, still one in eight people in the world suffer from hunger (Ibid; p.12) and half of the world's wealth is concentrated in only 8 people (Oxfam, 2017). For this dissertation poverty is more related to intragenerational justice and environmental security with intergenerational justice. As it will be further elaborated, form an abstract point of view, nevertheless CC mitigation is designed to avoid poverty in the future designating relatively too many resources for it can mean stopping to address poverty in the present. This is especially important when considering relative poverty. Relative poverty between countries has been for long a source of debate. Nowadays there is a very important progress in poverty abatement, in part thanks to the, so called, Rise of the South led by China, Brazil and India, nevertheless this rise is unequal especially for the 49 least developed countries especially the landlocked ones (UNDP,2013;p.3). The role of the South comes naturally, to be more aware of poverty abatement.

3.3.1 Population and Carrying Capacity.

One of the main problems for poverty, especially from a Malthusian perspective, is population growth in least developed and developing countries. The main counter of the evident problems of over populating relatively scarce resource economies is, and has been, technological change. A Logistic Population Growth can be programmed around an economy's carrying capacity and can take the form of[24]:

$$N_t = \left\{1 + \left(r\,\frac{K - N_{t-1}}{K}\right)\right\} N_{t-1}$$

Were K and N are the parameters for Carrying capacity (expressed in amount of people to the year t) and Population respectively. For 2035 the population is expected to booster in developing

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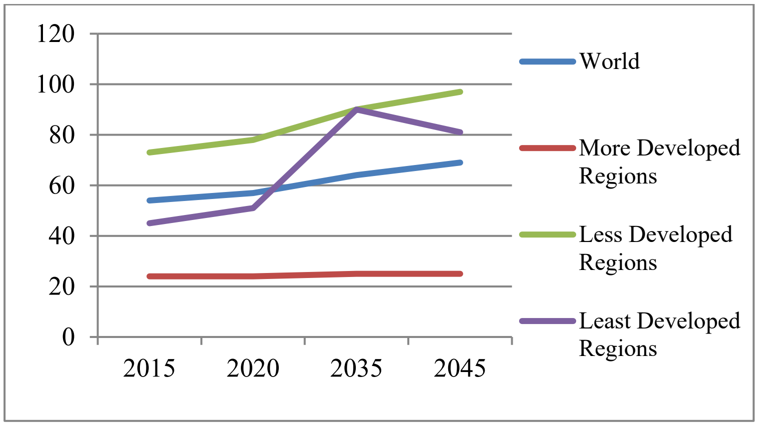
[23] As the lack of basic human needs quantified by the World Bank as the amount of people living under \$1.25 (for US prices)

[24] Common and Stagl, 2005; p. 45-47.

countries (especially BRICS) with rising middle classes, which evidently demand more energy services. The world population will grow from 7 to 9 billion in 2045; this will be mainly driven by developing countries that will face a overshooting in their countries carrying capacity increasing their population density, already critical (especially in urban areas) in 33% (Graph 3.5). By 2045 almost 90% of the world population will live in developing countries (UNDATA)

Graph 3.5 Population Density to 2045 UN Medium Variant (people per km^2).



Source: Based on Data from the United Nations Statistics Divisions.

3.3.3 Universal Energy Access.

The lack of energy services no only indicates poverty but also an impediment for development. It's evident that people need to have their basic necessities satisfied to be more productive and positively participate in a market society; but also, to have better lives and possibilities to access basic services like education or health services. The conversion of traditional energy systems (such as biomass burning) brings key benefits to poverty alleviation. On one hand, of great importance, burning firewood in rural communities for cooking and heating claims over one million lives every year for CO_2 poisoning globally[25], the figure is alarming and is the only main premature death cause expected to increase to 2030 (IEA, 2010;p.14) (Graph 3.6). On the other, the use of charcoal and wood fuel as energy sources accelerates deforestation (UNDP, 2010; p.66).

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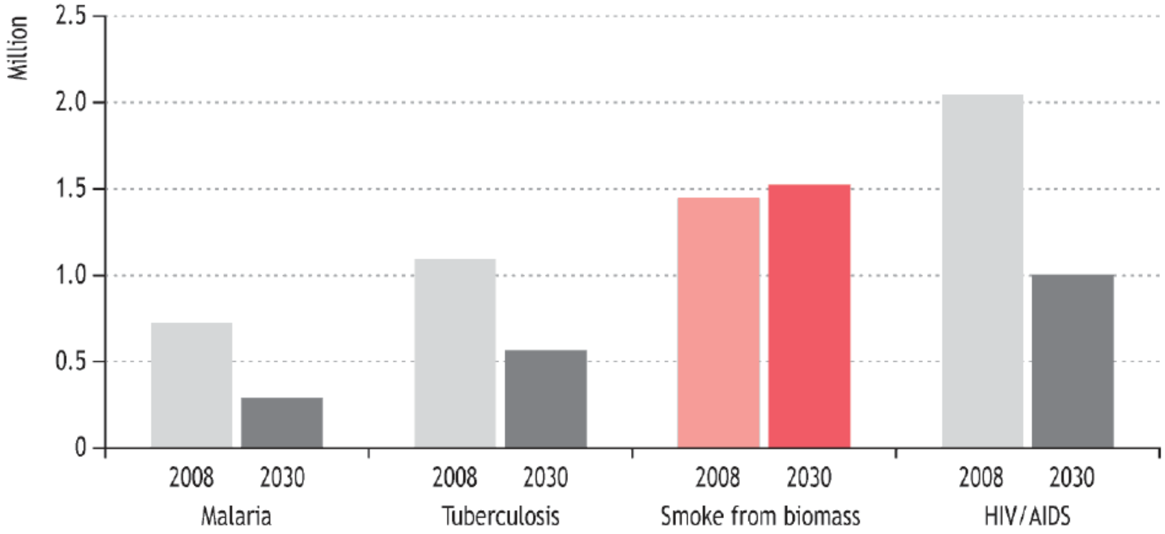
[25] This does not include the problems associated with recollecting firewood and health issues caused by burning animal manure fuel.

More than 1.3 billion people in the world lack of electricity to achieve universal energy access by 2030, 1 trillion USD in cumulative investment will be needed (IEA, 2013; p.1). Around 2.7 billion lack clean cooking facilities, highly concentrated in least developed countries (Table 3.7), it is necessary to devote up to 3% of the total of energy investment to 2030 to alleviate this problem (IEA, 2011; p.45).

Graph 3.6 Causes of Premature Annual Deaths.



Source: IEA, 2010c; p.14

Table 3.7 Lack of Universal Energy Access (million people).

	2009			2030 (Tendencies Scenario)		
Region	Rural	Urban	Population that represents	Rural	Urban	Population that represents
Africa	466	121	58%	539	107	42%
Sub-Saharan Africa	465	121	69%	538	107	49%
Asia*	595	81	19%	327	49	9%
China	8	0	1%	0	0	0%
India	268	21	25%	145	9	10%
Latin America	319	60	36%	181	40	16%
Middle East	19	2	11%	5	0	2%
Developing Countries	1106	208	25%	879	157	16%
World	**1109**	**208**	**19%**	**879**	**157**	**12%**

* Excluding Japan.

Source: Based on IEA, 2010c; p.14 and World Bank World Development Indicators

Nowhere is the relation cleared between Poverty alleviation, energy and environmental security that in the imperative to guarantee universal energy access. No country in the world without universal energy access has a high human development index (IPCC, 2012; p.120) and can be able to overcome poverty or develop.

3.4 The Global Challenge

The global challenge is to place our world in a sustainable development path through poverty alleviation, the enhancing of energy security and stopping environmental degradation. Energy harvesting (in the search of energy security) generates two thirds of GHGE, thus "will be pivotal in determining whether or not climate change goals (and environmental security) are achieved" (IEA, 2013; p.1); nevertheless, extreme poverty abatement will be needed to be placed as the corner stone to attach energy and environmental objectives to sustainable development closer to justice in the temporal allocation of resources. As counties will abide by their pledges in the 2016 Paris Agreements, by 2040 500 million people will not have access to electricity by 2040 (EIA, 2016; p. 2). These 3 challenges, as seen before, are the core lags from the energy sector for sustainability. The way to address these is through a comprehensive policy for energy architecture that addresses them while minimizing tradeoffs.

3.4.1 Global Energy Architecture and the Energy Trilemma

Global energy architecture (Box 3.8) has evolved in the last decades to include sustainability and poverty issues, and two mainstream currents have emerged from the debate:

- The "Energy Triangle", comprised by economic growth and development; environmental sustainability; and energy access and security (WF, 2013; p.7), which uses the Global Energy Architecture Performance Index (EAPI); and,
- the "Energy Trilemma", closer to this dissertation, includes energy security, energy equity, and environmental sustainability (WEC, 2013; p.8), which uses the Energy Sustainability Index (ESI).

Box 3.8 Global Energy Architecture

"Energy architecture is defined as the integrated physical system of energy sources, carriers and demand sectors that are shaped by government, industry and civil society" (WEF, 2013; p. 11). Energy Architecture is changed to balance Energy Supply and Demand accordingly to the specific policy goals that should be related to the Triangle and the trilemma to avoid higher tradeoffs. Nevertheless, past decisions on Energy Architecture make shifts and hard (or costly) to change thus Energy Architecture must be based on long term policies on hand, and on the other must be flexible (or resilient) to adapt to technological and scientific breakthroughs (partially based on WEC, 2011;p.3).

Source: Indicated on box.

Both the trilemma and the triangle are based on physical constraints and social elements, these create an optimal zone were the energy mix reduces tradeoffs (Graph 3.9). The ESI and EAPI helps us comprehend a clear interdependence between energy, economic development and the environment; nevertheless, both could fall short to take into account poverty issues beyond energy[26]. One of the basic reasons for the distance between growth and development is distribution of wealth of "inclusion" of the poor in the economic system.

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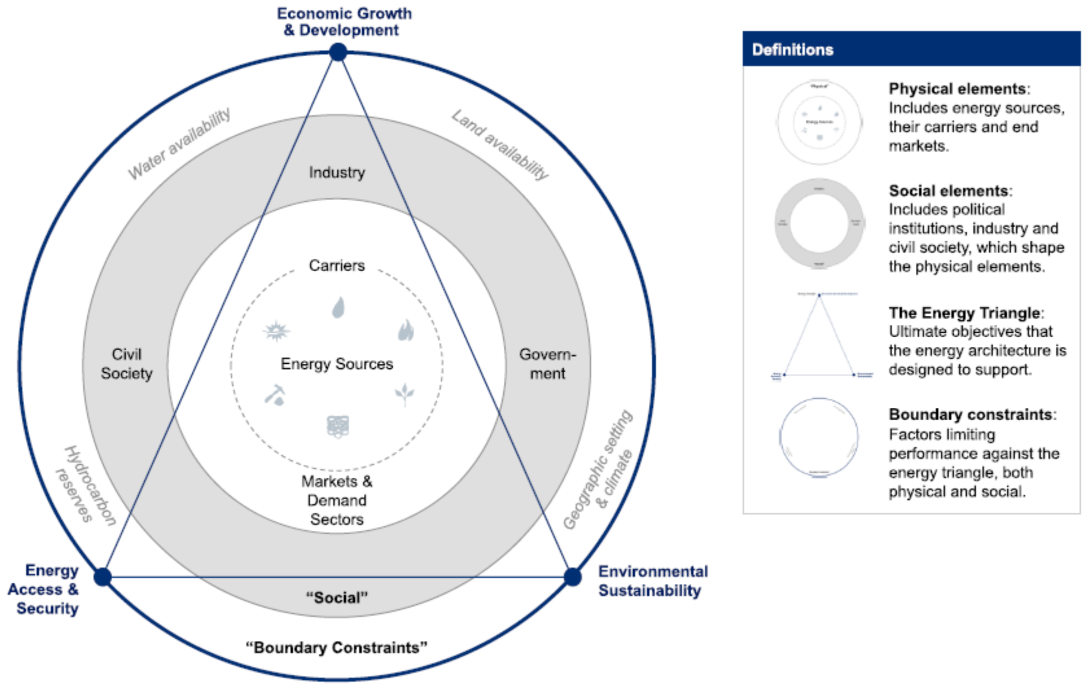
[26] Economic growth does not imply a reduction of poverty; development does but not establishes a pace for extreme poverty eradication.

Graph 3.9 The Energy Triangle.



Physical elements: Includes energy sources, their carriers and end markets.

Social elements: Includes political institutions, industry and civil society, which shape the physical elements.

The Energy Triangle: Ultimate objectives that the energy architecture is designed to support.

Boundary constraints: Factors limiting performance against the energy triangle, both physical and social.

Source: WEF, 2013; p. 11

3.4.2 Inclusive Green Growth

The distribution of wealth has been a key topic to explain economic performance and ethical principles in development. Economic Growth and inequality play a major role in poverty reduction. Low levels of inequality are correlated with higher rates of economic growth and in the past years focalized reductions in inequality have led to higher rates in poverty reduction (UNDP, 2010; p. 27). This is the founding for inclusive growth, and can be based on the marginal propensity to consume were lower income population increase spending in sectors that are more likely to grow with their income and have a faster multiplication effect. For energy and the environment this has especial implications, there is a clear inequality in the distribution of energy and natural resources, both highly correlated with geography. Poorer countries tend to have a higher inequality in both aspects and developing countries have high urban poverty resulting high density of population with scarce access to natural resources[27]. It is clear that in this situations the poor pay more for natural resources, especially energy and water (based on

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[27] e.g. Chalco in Mexico City or the 'rat tribes' in China

Shayd, 2016). These and other problems have driven development theory to the Inclusive Green Growth tough (Box 3.10).

Box 3.10 Inclusive Green Growth

Inclusive Green Growth is a concept for policy making that can help sustainable development, it focuses on two challenges: expanding economic opportunities for all in the context of a growing global population (…) and addressing the environmental global pressures that if left unattended could undermine our ability to seize these opportunities" (OECD, 2012; p.8).

Source: Indicated on box.

Inclusive Green Growth, tries to distinguish between intra and intergenerational justice. It recognizes the benefits of abating poverty and global warming to economic growth. At the international level, non-inclusive growth has been a rule in economic development. The "Equatorial Paradox" has been an interesting cultural theory on the differences in development between societies; were there is a higher income in places in higher latitudes and lower natural resources (Common and Stagl, 2005; p. 185). Still countries are divided between the north and south. It is clear that energy access, economic development and poverty abatement are clearly related; this is even clearer at a microeconomic level considering people without access to modern energy services. The acknowledgment of interdependency is driving a fundamental change, demanding a new energy architecture (WEF, 2013; p. 12) for an inclusive green growth that will lead to sustainable development, this objective will need to build a flexible energy system that can allow to change the energy mix according to opportunities provided by technological change.

Chapter Remarks

- In this chapter we have made a short review on the relationship between energy, poverty and environmental degradation. These three are issues that heavily compromise a sustainable development path. To avoid duplication of efforts as well as to minimize future and present trade-offs, it is necessary to promote policies that focus on the relation of the three.
- Energy security is determined by 4 main causes Availability, Accessibility, Affordability and Acceptability. Acceptability is primarily related to the recognition it can affect other securities, especially environmental. Accessibility can be seen related to poverty abatement. Focusing on affordability will cause an inefficient tradeoff in acceptability and the other way around. This recognition takes us to realize energy security depends directly on environmental security and poverty abatement.
- Environmental Security is nowadays realized as vital for human life, any reduction in it will affect inter and intragenerational justice. Climate change has set a new focus on Environmental Security due to the proximity and catastrophic events it can bring. Environmental impacts are much more related to intergenerational justice and impacts on poverty abatement are related to intragenerational justice.
- Poverty abatement must not be seen only as a moral duty, it is proven to be better for the economy; nevertheless, it can be expensive to guarantee energy security and environmental security wile combating poverty. No country in the world without universal energy access can have an inclusive development. The increasing population in developing countries and their economic growth will have a great impact reducing poverty but also on energy consumption and environmental degradation; limiting the global carrying capacity, resources for future generations and thus the capacity to achieving a sustainable development path.
- The Energy Trilemma and Inclusive Green Growth theories can help distinguished better objectives to achieve a sustainable development path. The Energy Mix must take into account the complex tradeoffs that arise in the present and future challenges optimizing in heavy correlated social, economic and environmental fronts.

Chapter 4: Energy Technologies and Sustainable Development.

"The theoretical potential for renewable energy exceeds current and projected global energy demand by far, but the challenge is to capture and utilize a sizable share of that potential to provide the desired energy services in a cost-effective and environmentally sound manner"
Special Report on Renewable Energy Sources and Climate Change Mitigation IPCC, 2012.

The world has been drastically changing in the past years. Economic agents have, realized of the loss of welfare from depleting natural resources as the high future cost it will take to recover these goods (when recoverable, like a proper climate) and the great set back poverty represents in a 'modern world'. Before Ecological Awareness on Climate change and the technological efforts that followed on Renewable Energy, limiting the hydrocarbon society was even seen as a treat to Energy Security (Yergin, 1991; p.15). Nowadays diverse efforts have been made to stop anthropogenic climate change, natural resource degradation and poverty (including energy poverty), however these don't seem to be enough (based on IEA, 2011; p.2) and the most accepted goals towards sustainable development can be out of reach. It's recognized that the effort to achieve the basic elements for a sustainable development path described in chapter II (energy, environment and poverty) must come from multilateral sources; nevertheless, technological advancement might be the single most likely contributor to achieve these goals. As stated in the literature review, Technology as the driver for sustainable development is recognized by diverse authors, especially through renewable Energy Technologies and Energy Efficiency, to cut in GHG emissions (focusing particularly in CO_2) while providing modern energy services for economic development and poverty abatement. The world energy system is under stress and the main reasons for optimism are the advancements in technology and efficiency (IEA, 2014a; p.1).

In this chapter some specific forms and goals of the "Energy Architecture" challenge to reduce tradeoffs previously described and their respective technological 'solutions' are outlined. At first, the description of the goals for a sustainable development are briefly outlined from a technological point of view describing the different scenarios presented by international organizations to advance in climate and energy goals. On the second part a description of the different technology stages is made for Renewable Energy Technologies (RET) and Fossil Energy Technologies (FET), including Non-Conventional FET (NCFET).

4.1. – Achieving Sustainable Development and Technology.

Our Energy Architecture will have to rely heavily on Technological Change (and choice) to, as previously stated, guarantee a trilemma around Energy Security, Environmental Security and Poverty Abatement. There are key policies that foster market puled of technology pushed technological change, these are driven mainly by collective action.

4.1.1 Information for Collective Action and Scenarios to 2035.

Today, it is widely recognized that to achieve a sustainable development path CC must be minimized, the main goal has been to limit the rise in temperature below 2°C, which represents the 450 ppm objective, by reducing greenhouse gas emissions (GHGE)(IPCC, 2007; p.39). Due to the continued growth of the world's economies based on fossil fuels, emissions have keep increasing and "the door for 2°C is closing" (IEA, 2011, p.40).

With the available information of the high future costs of CC, the rationality principle would lead countries to choose to cooperate for CC mitigation and adaptation. Nevertheless there is a series of problems beyond standard orthodox economic theory, which make sustainable development a true global challenge. Achieving sustainable development, as any objective, demands resources. Resources that could be used for other objectives reflect opportunity costs (Pindick and Rubinfield, 2001). When there is more than one objective the flow of resources from one to another reflects *trade-offs*. Given that economic agents (from individuals to supranational organization) have different preferences, these normally follow a set of different objectives. Minimizing these *trade-offs* economic agents set their preferences and maximize their utility (or benefit).The way economic agents interact in society provides them with more information, which makes them have common interests (like avoiding a climate catastrophe) ultimately creating collective rational action (Van Eijck and Verbrugge, 2009); nevertheless economic agents face uncertainty on climate change outcomes, natural resource degradation, substitutability of natural and capital goods, between others. All this uncertainty or lack of information raises the tradeoffs between mitigating and adapting to CC and other goals (Newel and Pizer, 2003). Thus, increasing the amount of information reduces tradeoffs between objectives and might be one of the pillars to spur collective rational action.

Different international organizations develop possible scenarios to increase awareness and provide more information to agents. Next, we briefly describe the ones made by the IEA; the WEC uses similar scenarios one with more governmental participation “Symphony” and one with a higher free market approach “Jazz” (WEC, 2013); also, GPI uses a “Reference”, and a guided “Energy [R]evolution” scenario (GPI, 2012).

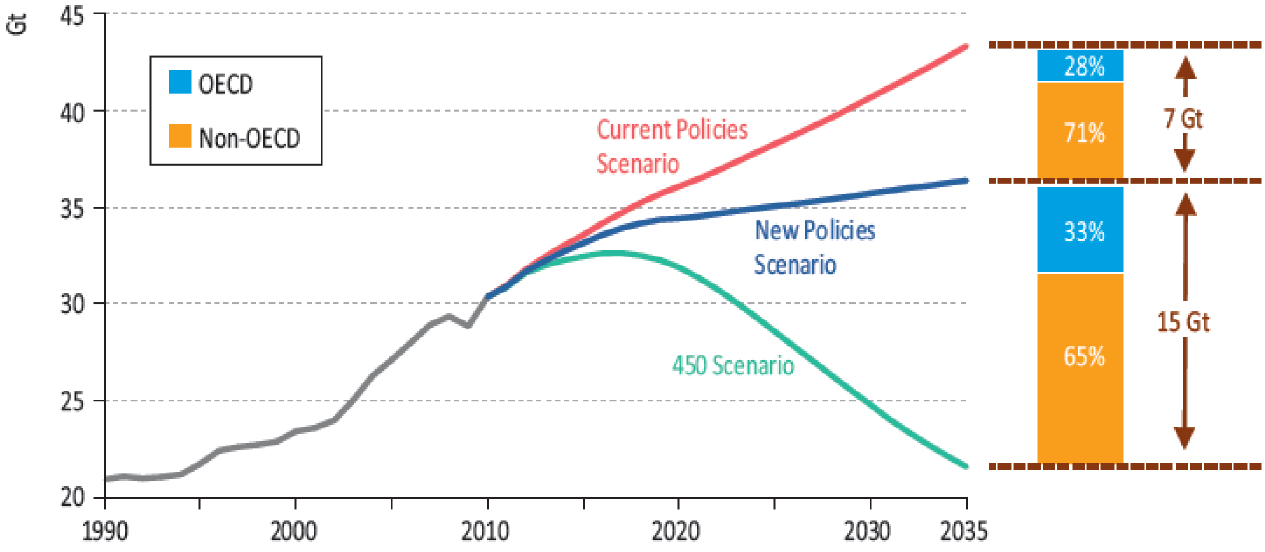
Scenarios from the IEA are based on policy goals for Climate Change the most accepted ‘desirable’ scenario to achieve a sustainable development path is to limit the increase of GHG emissions to 450 particles per million of particles of air (ppm), which would probably (50%) limit the increase of global temperature to 2°C (IPCC, 2007a). This scenario considers that from 2020 an agreement will be made in which OECD countries will provide $100 billion USD in annual financing to non-OECD countries. This scenario is the most expensive, requires an investment of around $36.5 of dollars from 2011 to 2035 of which $15.2 accounts to low carbon technologies and energy efficiency; “for every $1 of investment avoided in the power sector before 2020 an additional $4.3 would need to be spent after 2020 to compensate for the increased emissions” (IEA, 2011a, p.2, 224). However, as stated before, it would seem like this scenario is not possible anymore (Ibid.), and recently action is being diverted to adapt to CC.

The main scenario for the WEO 2013, and for this dissertation, is the “New Policies Scenario” were 650 ppm equal to a 3.6°C (fluctuating range of 2.4 to 5.5°C) (IPCC, 2013; p.66); this could be seen as a more ‘realistic’ point of view since the lack of cooperation has swamped the international negotiations on a post Kyoto bidding agreement and economic and social barriers added to a worldwide recession and cheaper stagnant fossil fuel prices, thanks to the prospects of the ‘Shale Revolution’, are limiting the implementation of RET on a full scale. This scenario requires a 38 trillion (2010 USD) investment in the energy system (IEA, 2011; p.96) of which, 6.5 trillion (2011 USD) investment would be in RET including 250 billion for their integration to the energy grid (IEA, 2013; p. 197).

Finally the "Current Policies Scenario" (previously called the Reference Scenario) reflects the lack of action (to mid-2013) on a comprehensive Post Kyoto Agreement and the high costs of forgetting that maintenance costs are cheaper than correcting costs. Technological change is this scenario is overall the lowest due to the lack of fostering policies, being counter weighted by induced technological change over higher oil prices (IEA, 2011; p.67). The current policies scenario could eventually lead to an increase in temperatures of 6°C or more, that would cause a chain of catastrophic events and might cost, as previously quoted, the world 5% of its GDP each year (IPCC, 2007), or up to 20% (Stern, 2006; p.V).

All the scenarios[28] consider GDP and population growth to be fairly equal until 2035 the basic changes could be seen years after (due to GHGE reductions); variations come from GHGE and these change between develop and developing countries (Figure 4.1).

Figure 4.1 IEA World Energy CO_2Emissions by Scenario



Source: IEA, 2012; p. 2011

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[28] Other scenarios used by WEO include: Efficient World Scenario (WEO 2012), Deferred Investment, Energy for All and Low Nuclear (WEO 2011).

Based on the latter scenarios it is possible to set goals to reach a sustainable development path. As seen on the previous chapter basic goals for, Energy Security, Poverty Abatement and Environmental Security mush be achieved (Box 4.2), but these are only foreseeable if, there is continuous guided technological development and, as we will see in the next chapter, Political will, International Cooperation and Free Trade.

Box 4.2 Joint Sustainable Development Goals

Poverty Abatement:

Eradicate Extreme Poverty and achieve universal energy access, for the remaining 1.3 billion people.

Energy Security:

Guarantee Energy Availability, Accessibility, Affordability and Acceptability for Economic development. Stable competitive prices and steady investments that allow security of supply and demand.

Environmental Security (Energy Sector Driven Climate Change):

Stabilize GHG concentration at 650ppm to level the growth in temperature around 3.6ºC and achieving an economic development that does not exceed nature's carrying capacity.

4.2 The Role of Technology.

Sustainable development objectives must be met by a new Energy Architecture, it is clear that the rate at which the efficiency of current energy technologies improves and new technologies are adopted will be a crucial determinant" (IEA, 2012;p. 33). On the previous chapter we described how energy the environment and poverty are related; these areas are challenges for development, and are highly related to the state of the art in power generation and the way we use energy (that reflects Energy Intensity) overall energy is the cause and the answer of many problems face today (IEA, 2014; p.1). On one hand, the type of Energy Technology used has a great impact on a society in various fronts and will normally depend on the allocation of natural resources in an economy or region; on the other hand, the usually referred as Energy Efficiency is more related to the way we use transformed energy than to the way we produce it and can be seen in the Energy Intensity of an economy. Both have a technological innovation process from prices (or induced technological change) that drives demand (market pull), and from policies and entrepreneurs (technological push).

4.2.1 Innovation

Overall, the evolution of technological systems (including ET) is due to a transformation in the techno-economic paradigm (Perez, 1992; p.38), but probably not mainly because of a radical technological change, but because of the divergence and volatility of prices of inputs that prompt incremental innovations. These innovations are given in parallel to the paradigm, leaving radical change to science breakthroughs. This can be seen around fossil fuels, in which technological systems have had marginal changes since the first oil shocks to access increasingly difficult resources and to make them competitive on the market, such as unconventional fossil fuels; it was after these shocks that conservation, now referred to as energy efficiency, an renewable started to reappear in the game field (partly based on Yergin, 1991; p. 718). On another side, under the same effect but potentiated by induced technological change and ecological awareness (translated into fostering policies) RET are rapidly developing, after they had been forgotten in the oil bonanza in the early XX century.

4.2.2 Induced technological change.

Induced technological change has occurred in recent years largely due to surges and wanderings in the relative prices of oil (see Graph 3.3) and by the ratio oilfield discovery versus aging that has been countered by the unconventionals' "revolution" on one side, and supported by the growing demand of developing countries on the other; everything potentiated in by issues of governance and security. Such erratic price hikes have seriously affected energy security, and have led agents to promote technological change towards replacing more expensive and uncertain, inputs. Technological changes have enhanced RET to the point of being, in some cases, market competitive with FET; and have also fostered technological systems like horizontal drilling or hydraulic fracturing to make non-conventional FET competitive and enabling an unconventional revolution (WEC,2013; p.58).

4.2.3 Oil prices.

Despite the Shale Revolution accounting for both scarcity and information effects suggest that oil prices may rise suddenly and rapidly at any time (Daly and Farley, 2004; p.115) and "energy price variations are set to affect industrial competitiveness, influencing investment decisions and company strategies" (IEA, 2013; p. 2). Induced technological change is complemented by market, institutional and cultural factors, which together disrupt the balance of the playing field for competing technologies, leading the selection of technologies to be more complex. In coming years there is uncertainty on what will be the evolution of oil prices and estimates vary up to 330% (Table 4.3) this uncertainty comes from the possible market driven political decisions of OPEC (EIA, 2016; p. 20) but also from technological innovations that will make more oil resources available (based on IEA, 2015; p.113).

Table 4.3. Volatile Prospective Oil Prices.

Year	Oil Price Scenario	EIA (IEO)	IEA (WEO)*
2020	High	**149**	83
	Low	58	**55**
2025	High	**169**	106.5
	Low	64	**62.5**
2030	High	**194**	113
	Low	**69**	70
2040	High	**252**	150
	Low	**76**	85

2013/2014* USD

Source: Elaborated base on EIA, 2016; p.20; IEA, 2015; p. 47

Uncertainty in oil prices can spur technological change: i) if prices are expected to remain high, consumers will look for substitute goods (induced technological change); and ii) if prices are expected to remain low (or volatile) investment will look for more stable markets. Both of these effects would favor renewable energy.

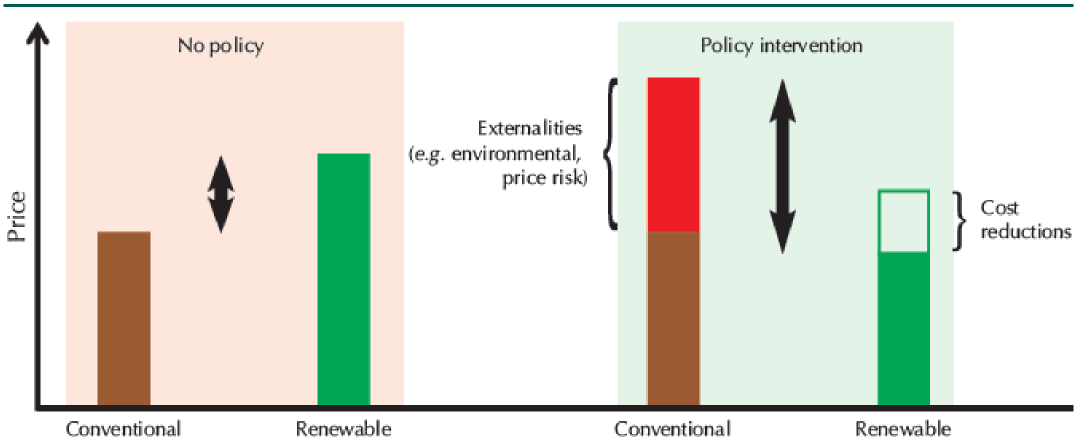
Besides the direct effect of prices and induced technological change, there are two main causes that have accordingly favored the development of RET and FET as the two main technologies to achieve economic growth and development and that will be heavily taken into account in this dissertation: the first is environmental awareness that has favored RET; and the second is the path dependency resulting in technological lock in favor of FET.

4.2.4 Environmental Awareness *versus* Path Dependency.

a) Environmental Awareness: Also referred to as ecological awareness, it starts formally in the seventies. From The Limits of Growth through the Stern report on climate change impacts and the Energy Revolution Reports of GPI. This awareness fostered from the first oil spills and industrial disasters made civil society understand the necessity to protect nature for the services it provides, from having a beautiful landscape to the natural water cycle provision. This awareness has driven aggregated public opinion that leads to the creation of policy. The process has allowed technological policy and individual actions to be directed to RET beyond the simple economic benefits they have (and will be a key factor in and oil price instability scenario). For standard economics the main outcome has been the development policies that create fiscal incentives that level the playing field of ET due to the recognition of negative externalities associated with FET generating taxes to internalize this externalities (or try to), that ultimately benefit competing RET (Figure 4.4).

   As stated in Chapter 2, the radical change comes when natural sources are defined as irrecoverable and noncomensurable, later this view is reinforced by CC and its costly effects. This is manly to the recognition of RET as a viable option for economic development overcoming the decree and the small is beautiful theories with green growth gave policy makers the confidence to generate a Renewable Energy Boost. Consequently, even as RET were far more expensive that FET they were technologically pushed to the point they are today. Ecological awareness will continue, and is still the central mandate of organizations like IRENA, WWF and GPI who recognize wider benefits from faster RET deployment than the one would occur under fee market circumstances; nevertheless, in some developed countries this point of view and policy intervention is tending to be phased out due to what has been an inappropriate planning of subsides that only make energy more expensive (IEA, 2013; p. 225), without providing technological change.

Figure 4.4 Environmental Awareness in Policy for RET



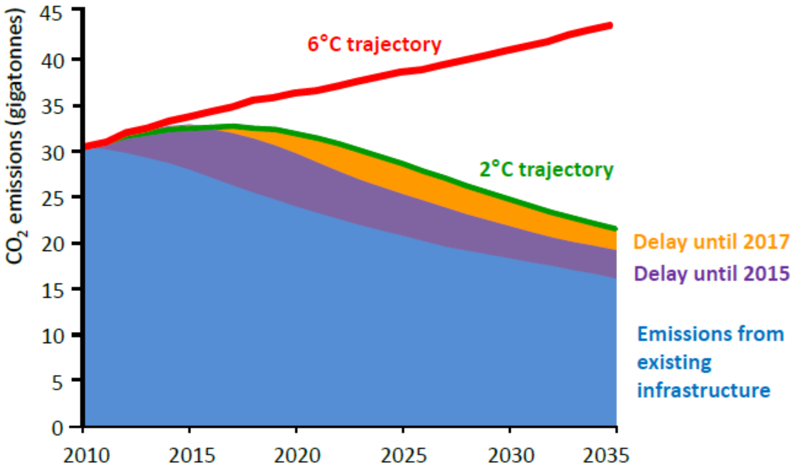
Source: IEA, 2011x; p. 17

b) <u>Path dependency</u>: In our case, it is the progressive accumulation of technological systems for instance around an energy carrier. This means eventually that a high interdependency in the techno-economic paradigm changes the costs structures, making technologies that are further away from that energy carrier more expensive, thus creating a technological lock-in.

In the beginning of the XX century a change was made from energy carriers, Coal to Oil. In England, a country that saw the development of steam and coal since the Industrial Revolution, Coal was so locked-up in the Techno Economic paradigm that it kept to be the main fuel for many years more even petroleum was cheaper and more efficient, and the internal combustion engine was a true radical change (based in part from Yergin, 1991; p. 116). At the start of the century new technologies were competitive due to the technological lock-in of coal, were the implementation of the new technologies was relatively more expensive. At the time was common to see electric or biomass powered vehicles; nevertheless, oil, as a technological cousin of coal, could have made transition much easier and cheaper. Oil Energy Technologies created a second industrial revolution and are still the corner stone of development, less than years ago thanks to ecological awareness and the development of the Service Economy, but still the main driver. Everything is defined around fossil fuels electricity, fertilizers, jet fuel and the growing polymer-plastic industry. This has two effects, a higher demand and dependency of fossil fuels creates volatility in prices on one side (benefiting RET) and on the other side, and more importantly, make technological advancements focus on FET that even adapts marginally to Ecological Awareness with Carbon Capture and Storage Technologies (CCS).

A radical technological change, reflected in an high cost reduction would be needed to break the lock-in and generate a Creative Destruction Process (based on Schumpeter, 1942; p. 20), until this happens marginal changes will continue to struggle and RET will be in disadvantage with FET even with CCSFET, requiring market guidance to internalize negative externalities not being realized by economic agents. This is like the case of storage challenges for renewables, nevertheless incremental innovation are expected to reduce sola PV up to 70% by 2040 (IEA, 2016; p. 4), likely making it a cheaper and more reliable source of power than hydrocarbons. So, "Without further action by 2017 all CO2 Emissions permitted in the 450 scenario will be locked in by existing power plants, factories buildings, etcetera" (See Figure 4.5).

Figure 4.5 Technological Lock-In and Climate Change



Source: IEA, 2011a; p. 17

The above effects for NCFET and RET are in conflict. Even recognizing superior costs of FET thanks to the internalization of externalities the greater present costs of RET can derive in an intergenerational versus an intragenerational justice. This is clear at times of economic downturns when policies fostering RE tend to diminish and a greater free market approach are promoted by politics (WEC, 2013a; p.27).

On one hand environmental awareness tends to be, greater in more developed economies than in developing ones (based in part on Grossman and Krueger, 1991), even though this varies very much between economies and policy goals (Common and Stagl, 2005; p. 250). On the other hand, developed countries tend to have a higher dependence on fossil fuels because of a greater consumption per capita and access to modern energy services, so their technological lock-in tends to be greater. This, is boosted by the fact that 2/3 of energy demand will come from developing countries (IEA, 2013; p.1) and it is less costly and more environmentally friendly to build a RET plant for new demand, than to shut down (before time) an replace existing FET one; the higher the lock-in the more expensive the transition.

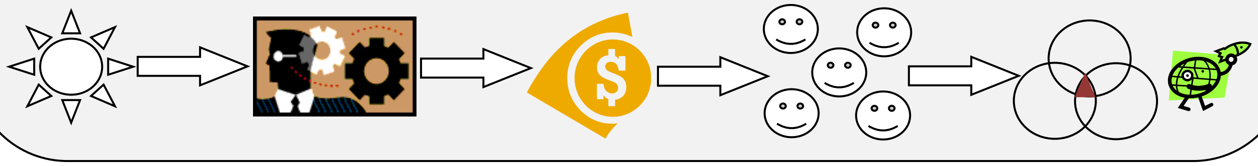
Assuming present and future costs of Technologies (environmental security versus on an technological change point of view, both RET and FET can evolve, with the proper technological push, to be less costly and less contaminating. So, why should we use policies to prioritize RET over FET? To make a more informed technological choice we must, take a look at the Technological Stages.

4.3 Technological Stages.

The development and implementation of new technologies follows a set of capabilities. The implementation of "new technologies" would have to fulfill every stage to eventually contribute to sustainable development (Box 4.6). Just as an illustration and in an extremely simplistic example on solar energy (Figure 4.X; as simple as the Word Art® used to draw it) we could imagine: i) Hard Scientists could develop the Theoretical capabilities (e.g. how much sun light reaches the earth's surface); ii) Engineers the Technical capabilities (e.g. what are the average efficiency conversion rates of the PV panels, Y%); iii) Financial Project Managers, based on a classical theoretical economic agent looking to maximize its benefit, the Simple Economic Capabilities (e.g. is it profitable to make the shift from buying electricity from the grid or from this decentralized mini-grid); iv) Policy Makers and Development Economists on another hand will try to have the greatest amount of information including market failures, to try to determine the Complex Economical Capabilities (in what measure will it work for an economies energy mix); and finally v) Ecological Economists will try to get all the way to the Sustainable Development Capabilities (environment, development and security).

Box 4.6 The 5 Technological Stages for Energy Technologies

- Theoretical Capabilities: Where is the Energy, can it be captured?
- Technical Capabilities: Does the technology have a positive EROI?
- Simple Economic Capabilities: Is the technology profitable LCOE, NPV and/or ROI?
- Economic Capabilities: Does it represent the lower tradeoffs?
- Sustainable Development Capabilities: Will it help drive to a sustainable development?



Source: Own elaboration, based on the cited sources on this chapter specially IPCC, 2012.

4.4 Theoretical Capabilities

Continuing Solar Energy´s example, it's been known that harvesting the sun's energy that is otherwise reflected into space could easily, theoretically, cover the demand of our world present and future energy needs (Peet, 1992; p. 7, 8)[29]. This is that the energy carrier has the necessary physical elements to be converted and used by mankind, not the case for other energy carriers with higher entropy than our system; thus based on the second law of physics, theoretical capabilities will converge around higher and lower levels of entropy and thermodynamics (partially based on Wilson and Buffa, 1998; p.42). For renewables, "the theoretical potential (…) exceeds current and projected global energy demand by far, but the challenge is to capture and utilize a sizable share of that potential to provide the desired energy services in a cost-effective and environmentally sound manner" (IPCC, 2012; p. 36). Concerning unconventional hydrocarbon resources globally, estimated non-conventional oil and gas reservoirs are equal to conventional resources (WEC, 2010, p.125). Basically all the RET Theoretical Resources exceed the 500 EJ/y amount of energy used today (See table 4.7).

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[29] Over 6% of the solar energy received is reflected completely back to space and could generate 1 petawatthour of electricity equivalent far exceeding the 150, 000 average terawatt hours consumed by mankind (Ibid.).

Table 4.7 Capabilities by Energy Source (EJ/y)

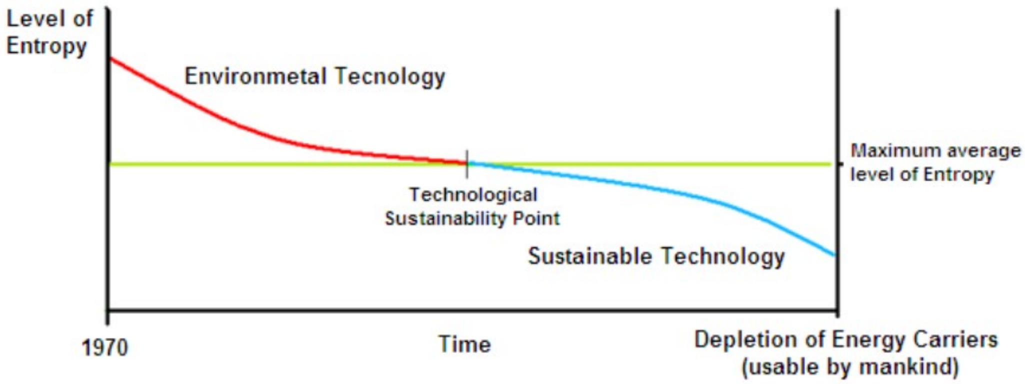
Energy	Theoretical (Resources)	Technical*
Solar	3.9×10^6	1575
Wind	450**	85
Hydro	52.47	50
Geothermal	34×10^6***	10
Bioenergy (Biomass)	1,500	500
Ocean	7,400	7

*Minimum estimate of the Global Technical Potential. *** On and close to shore. ** Down to 3km depth.

Source: IPPC, 2012; p. 39, 47, 60, 86, 95.

On my previous grade's dissertation (see Xhemalce, 2011), especial attention was given to theoretical and technical capabilities focusing on the sustainability of technology and technological progress to achieve sustainable development. One of the conclusions around this, taking into account the Solow-Hartwick rule, is that given the proper guidance technology could keep advancing in energy efficiency and different energy carriers; so, to by a combination of incremental and radical technological changes tend to zero entropy (for some back stop technology) (Figure 4.8). Nevertheless, this process is not automatic; simply assuming it will naturally lead there substituting capital stock for nature to what could be called a 'blind technological determinism'. Technological progress must be guided to reach cautiously established goals based on scientific assumptions an taking into account the precatory principle.

Figure 4.8 Sustainable Technology



Source: Xhemalce, 2011; p. 148

4.5 Technical Capabilities

Technical capabilities represent human capacity to harvest energy. Basically we can make a distinction between FET and RET, but also can include a brief description of Energy Efficiency as the key Technical capabilities to achieve a sustainable development path. Technical capabilities represent the greatest engineering efforts and are were radical technological breakthroughs could occur. These represent a state of knowledge (or “state of the art”) that is applied for human use, they are not measured on economic efficiency but scientific achievement, this is how can theory is made reality; for example in Solar Photovoltaic panels this is measured in solar cell conversion efficiency that represents how much sunlight is absorbed by the module[30]. Internal combustion engines´ efficiency is a technological capability, FET literally burns the energy carrier; a common internal combustion engine dissipates 80% of the energy transformed, in the form of heat and friction (IEA, 2007; p. 2). Technical capabilities have changed drastically in the past years tanks to market pull and technological policy driven pushes for the main energy carrier an technologies as described in this segment. One of the basic formulas for calculating technical capabilities is Energy returned on energy invested (EROI) that represents the amount of energy used to produce another energy carrier. Unconventional fossil fuels tend to have a lower EROI because they use a lot of energy. Better technologies reduce EROI. An example of the formula is described below:

$$(EROI) = \frac{\left(\dfrac{E_{lifetime\quad output}}{\eta}\right)}{E_{materials} + E_{manufacturing} + E_{transport} + E_{install} + E_{end-of-life}}$$ [31]

4.5.1 Energy Efficiency

One of the key technologies for a sustainable development path is Energy Efficiency with has been historically market pulled but now thanks to its recognition as the ´first fuel´, is being policy pushed. Energy Efficiency allows for the provision of the same service with less use of energy. This is achieved by technological means (e.g. a LED light bulb that consumes 5W can

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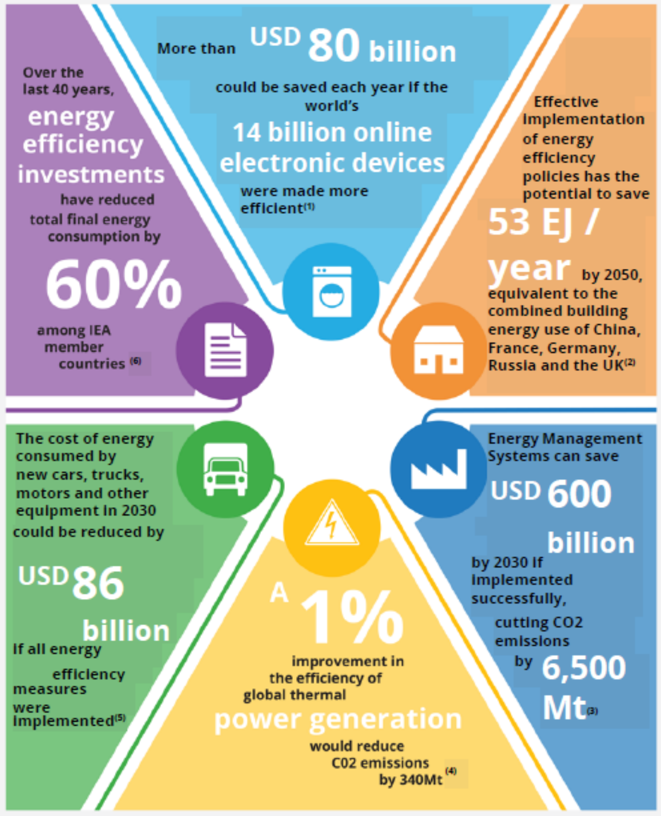
[30] This includes the thermodynamic efficiency limits of the panels.

[31] (from Kittler et. al., 2016)

produce the same amount of light that a 50W incandescent bulb). Energy conservation on the other hand is consuming less energy services (e.g. turning of lights when not in use) integrated approaches typically use both types for greater savings (e.g. smart grids). Energy Efficiency comes primarily from incremental technological change so it's easier to implement it in a system that is locked-in. This has led to EE to become the single greatest option for short run sustainable development with savings spreading in all sectors (see Graph. 4.9) and countries as the "first fuel" providing benefits even for CC mitigation and poverty abatement (IEA, 2016;p. 3).

Graph. 4.9 Energy Efficiency Capability Opportunities per Sector



Source: IPEEC, 2017; p. 6

4.5.2 Fossil Energy Technologies and CCS.

Fossil Energy has likely been the main cause of human development since the industrial revolution, first with coal and later with petroleum and its distillates. Fossil Energy technologies are expected to keep dominating the world energy mix for many more decades. Induced technological change caused two main changes in FET one related to technological lock-in and the other to environmental awareness. For FET Technical Capabilities have been mainly driven by Market Pull, and induced technological innovations of the 2004 – 2014 price hike period.

a) Carbon Capture and Storage FET: Environmental awareness (and to a lesser extent advanced recovery technologies) has led to the creation of Carbon Capture and Storage Policies that reduce tailpipe emissions from conventional power generation. "Widespread deployment of carbon capture and storage (CCS) technology would be a way to accelerate the anticipated decline in the CO2 emissions intensity of the power sector, but in our projections only around 1% of global fossil fuel-fired power plants are equipped with CCS by 2035" (IEA, 2013;p.5).

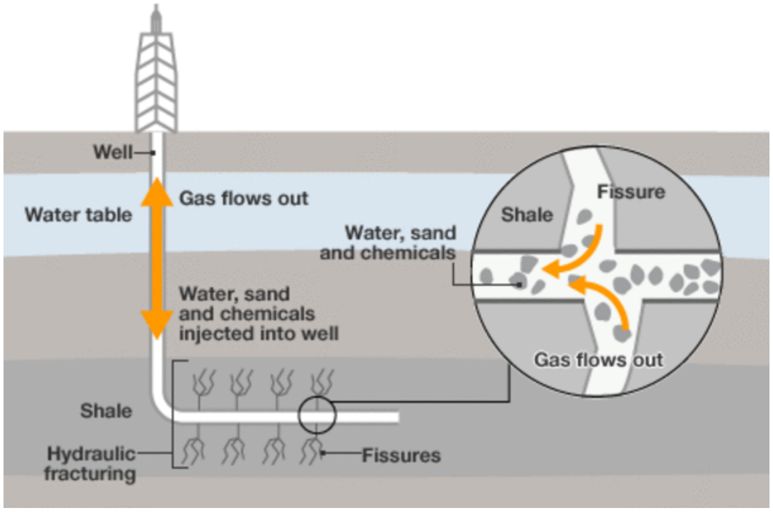
   The development of Carbon Capture and Storage technologies on FET (FCCS) seems to create a new paradigm for the reliance on fossil fuels (Jaccard, 2005; p.196-203), and therefore will be a major determinant in formulating CC policies. The carbon capture cost of one metric ton of CO2 is already a guide for different international organizations, reaching even 50 USD by 2035 (IEA, 2010; p.168). This has been very important in addressing the challenges of implementing a carbon tax.

b) Nonconventional FET (NCFET): The high oil prices in the 2004-2014 period induced technological innovation that has been the cornerstone of the unconventional revolution in North America. "In 2005, shale gas production accounted for 6% of US total gas production and 1% of global gas production. By 2014, shale gas production had grown to a staggering 52% of US output and 11% of world output" (IEA, 2015; p. 237). While in theoretical capabilities the amount of non-conventional resources is the same as conventional, differentiate technical and -other capabilities- makes this unconventionals revolution of North America not repeatable in other parts of the world. Also, the technological applications NCFET have focused their efforts on the reduction of costs given the nature of attraction of the market (technology pull) instead of policies that push them to make them cleaner. Additionally, besides being energy and GHG intensive, Coal to Liquids and Gas to Liquids (CTL and GTL) provide great flexibility for energy security on resource disparity on certain economies depend on Fisher-Tropp process for refining.

- For Shale Gas and Tight oil, the development of Horizontal Drilling allowed for disperse tight and low thickness hydrocarbon resources to be connected and hydraulic fracking permitted to efficiently break these small oil and gas deposits for production (see Figure 4.10). While Horizontal drilling is a common technology used in now conventional E&P, hydraulic fracturing is water intensive and poses a high treat to the contamination of aquifers (based on IEA, 2015; p. 152) (WEC, 2011, p.8). Horizontal drilling and hydraulic fracturing development was incentivized by induced technological change and the search of energy security trough the development of domestic energy resources in the US, and have been key elements for the shale revolution.

- For Bituminous Sands (BS), the main factor was not technological but price, nevertheless incremental innovations allowed for an increased inefficiency in the transportation of this high sulfur extra heavy crude oil that has a density gradient of less than 10 API by transforming it into synthetic crude oil (SCO) blends. Still NCFET for Bituminous Sands is very intensive, around ¼ of an equivalent energy barrel of SCO is needed to produce 1 barrel of SCO (GPI, 2009; p. 3-4). Overall, oil extraction from bituminous sands (BSO) represents a "nightmare" because it emits 3 times more emissions than conventional oil (GPI, 2009; p.5), on the other hand, conventional technologies have begun to use advanced oil recovery (EOR) techniques in mature wells, drainage techniques (SAGD) and, more importantly, well established Combined Cycle Gas Turbines (CCGTs), which enabled developed countries to reduce their GHE emissions significantly and reach the Kyoto protocol commitments by switching from fuel oil and conventional power plants to more efficient gas CCGTs.

Figure 4.10 Horizontal Drilling and Hydraulic Fracturing



Source: BBC, 16 December 2015.

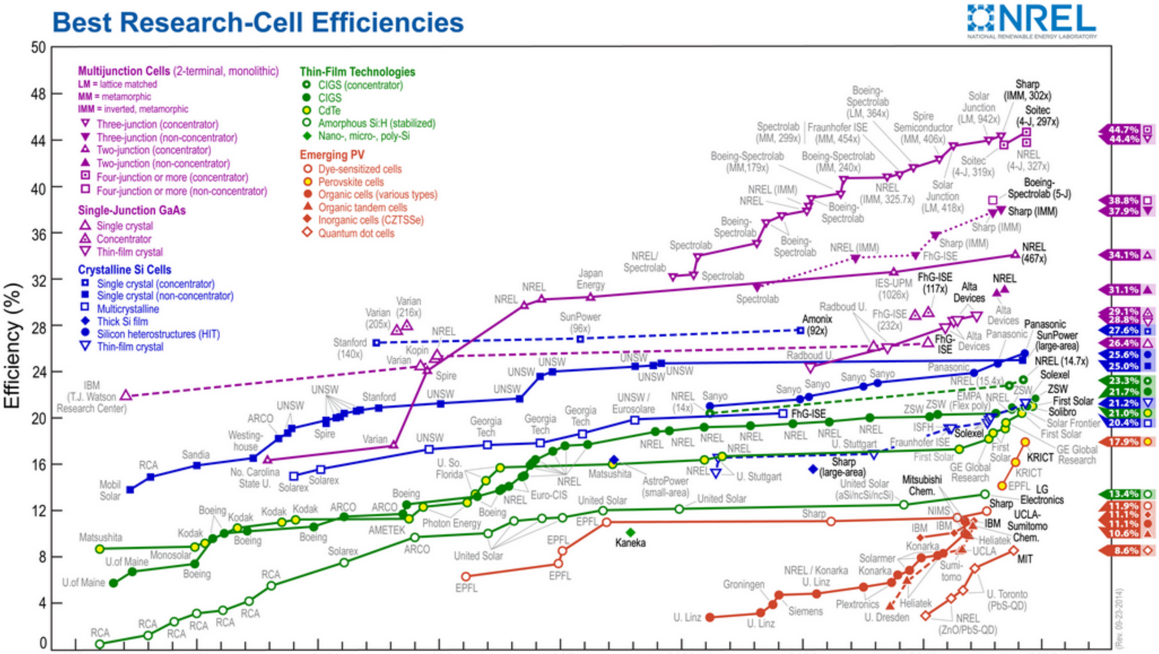
4.5.3 Renewable Energy Technologies (RET).

Technical capabilities for RET have changed enormously since Ecological Awareness created a Technology Push and high and unstable oil prices from the 2005 – 2015 period (See Graph. 3.3) Induced technological change and environmental awareness driven policies have helped drive efficiency and incremental innovations in all RET.

- For Solar Energy, there are four main technologies to harvest solar energy: i) Solar Thermal and primary appropriate energy application that concentrates heat from solar energy directly to the element for final use, this includes water heaters that have gained efficiency and market share thanks to their competitively in the last years; ii) Concentrated Solar Power optical concentration of solar radiation to heat fluids for electricity generation; iv) photovoltaic energy generation, solar panels cells that separate solar photons to generate electric charges, which have had incremental innovations in cell efficiency, at least of 50% for commercial panels in the 2005 -2015 period (Figure 4.11) and all along their value chain reducing cost and facilitating their integration into the grid, including micro and mini as closed home or isolated systems; and, v) Solar Fuel production, that has electrolysis as its main technology that separates water molecules

(H_2O) into Hydrogen (H) and Oxygen for vehicle fuel and chemical processes (IPCC, 2012; p. 60-64). Solar energy's technical potential 3 folds the current energy production in the world (See figure 4.11).

Figure 4.11 Solar Cell Efficiencies 1975 to 2015

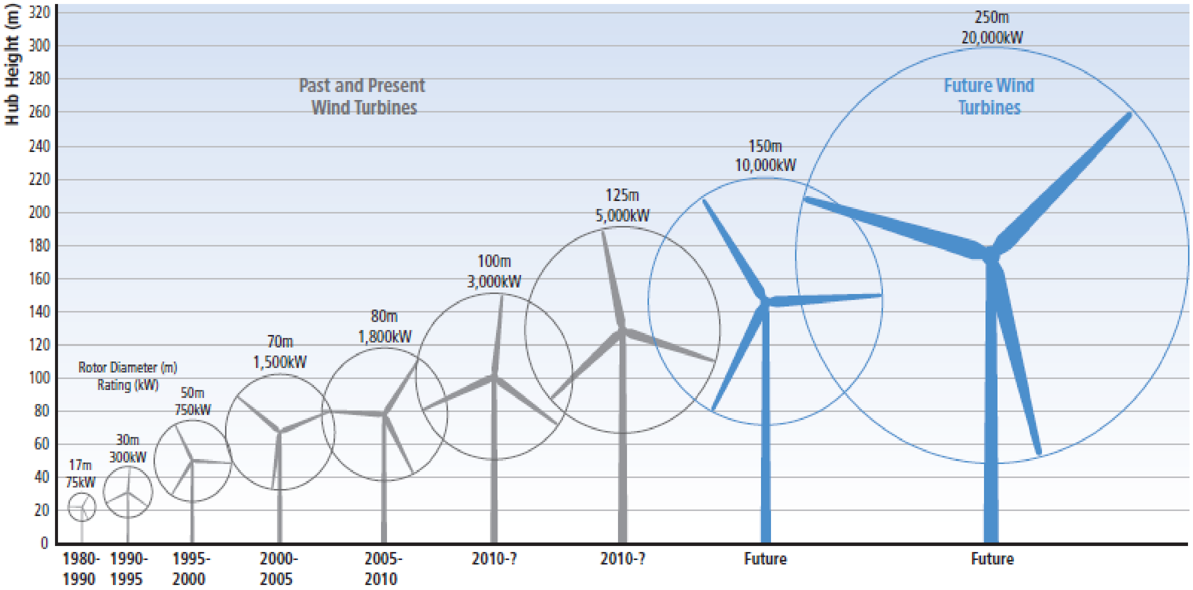


Source: National Renewable Energy Laboratory, National Center for Photovoltaics, Efficiency Chart (2017).

- For <u>Wind Energy,</u>

Mechanical wind energy has been harvested for millennia, nevertheless until the 1970´s it was used to produce electricity. The changes in wind technology have been incremental creating bigger wind turbines. In the 2004 – 2014 periods technological incremental changes in rotors and foundations have led to the production of wind turbines that produce 300% more electricity (see Figure 4.12) (IPCC, 2012; p.95). Other technological advancements have been the well-established offshore wind through pillars, storm safer wind turbines and semisubmersible foundations that are expected to be a "game changer in the following years" (IRENA, 2016; p.1).

Figure 4.12 Technical Capabilities Changes in Wind



Source: IPCC, 2013; p. 9.

- For Hydropower, as wind energy its mechanical power has been harvest for millennia but was not used to produce electricity until 1882, it's a mature technology that is used to both produce electricity as to store it. There are 4 different types of projects that rely on relatively the same technologies: i) Run-of-river, generally small scale that have no water reservoirs and variable energy production output; ii) Storage, generally large scale that allows to regulate the production of electricity; iii) Pumped Storage, medium scale that allow to pump water back up to regulate energy production, avoiding overproduction; and, iv) In-stream, small mini and micro grid scale variable off-grid power generation. (IPCC, 2012; p. 80).

- For Geothermal Energy, while the theoretical potential is huge, it´s technical potential is very different. Harvesting energy from the heat of the earth´s core is still difficult. Geothermal energy technologies mature and very similar to the ones for Fossil Energy Technologies. There are 3 types of geothermal power plants: i) steam condensing turbines, from 20 to 110 MW plants, are used in high heat wells; ii) binary plants, that use the hot water to heat a lower boiling point fluid that drives the generators allowing for lower temperature wells production; and, iii) Cogeneration Plants, that produce electricity and direct hot water for heating.

- For Ocean Energy, different from other renewables ocean energy is still considered to be a developing technology with a considerable theoretical capability there are 6 types of ocean energy harvesting being developed: i) Wave Energy, classified in 3 subgroups oscillating water columns, oscillating bodies, and overtopping devices; ii) Tidal range (tidal rise and fall); iii) Tidal currents; iv) Ocean currents; v) Ocean thermal energy conversion; and, vi) Salinity gradients. Some of the technological challenges that will come from other industries will be corrosion, infrastructure and off-shore grid connections (IPCC, 2012; p. 87–90) (IRENA, 2014; p. 20).

- For Bioenergy (excluding traditional biomass[32]), its main technologies are: i) Anaerobic Digestion for combined or conventional electricity production; ii) Transesterification, and Hydrogenation for production of first and second generation biofuels; and, iii) Biomass gasification for the production of Hydrogen for industry of vehicle fuel. The development of chemical processes and technologies in this sector has allowed lifecycle emissions of biogases for electricity production and biofuels[33] for vehicles to be lower than conventional fuels (IPCC, 2012; p. 49, 52) while staying price competitive.

4.6 Simple Economic Capabilities of Energy Technologies.

Simple economic capabilities are the next capability stages, were a profitability assessment of a specific project is made to provide rational investor with information that allows them to pick between different energy technologies using a cost benefit analysis. Besides standardized energy prices (kWh/$, MPG/$) there are various indicators that show simple economic capabilities for investment in different Energy Technologies. The most common for energy projects, described in Short et. al, 1995, are:

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[32] That uses appropriate technologies for firewood and charcoal burning.

[33] First generation biofuels are made with raw agricultural products like sugarcane or soy, the harvesting of these can highly contribute to agricultural emissions; which are probably the greatest source of GHG emissions (FAO,2014)

i) Net Present Value (NPV). A dollar today is more expensive than in the future, thanks to earnings in interest rates and opportunity costs. The discount rate is given according to the estimated interest rate. “NPV analysis is recommended when evaluating investment features and decisions such as mutually exclusive projects” (Ibid; p. 40). A positive NPV means that the investment makes sense to receiving an interest rate for having the money in the bank:

$$\mathrm{NPV} = \sum_{n=0}^{N} \frac{F_n}{(1+d)^n} = F_0 + \frac{F_1}{(1+d)^1} + \frac{F_2}{(1+d)^2} + \dots + \frac{F_N}{(1+d)^N}$$

Were,[34]

PV = present value
PVIF_n = present value interest factor
F_n = cash flow n years in the future
d = annual discount rate

ii) Simple Payback Period (SPB): Represents the time necessary to recover the investment costs of a project, and it is widely used as a simple indicator for Energy Efficiency applications. The formula is expressed as:

$$\text{Paybak (years)} = \frac{\text{Installed costs (\$)} - \text{Rebates (\$)}}{\text{Net Annual Energy Savings (\$/year)[35]}}$$

or,

$$\sum\nolimits_n [\Delta I_n \div (1+d)^n] \leq \sum\nolimits_n [\Delta S_n \div (1+d)^n]$$

Were,[36]

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[34] (Ibid; p. 40)
[35] (Rashford; 2010; p. 3)
[36] (Ibid; p. 58)

DPB = minimum number of years required for the discounted sum of annual net savings to equal the discounted incremental investment costs

ΔI = incremental investment costs

ΔS = annual savings net of future annual costs (i.e., ΔS equals the incremental energy costs, incremental nonfuel operation, maintenance, and repair costs, incremental repair and replacement costs, minus the incremental salvage costs)

d = annual nominal discount rate.

iii) Total Life-Cycle Cost (TLCC): These include the costs for the lifetime of the energy project that are discounted to a base year using present value analysis. The formula for calculating TLCC is (Ibid. ; 42):

$$\mathrm{TLCC} = \sum_{n=0}^{N} \frac{C_n}{(1 + d)^n}$$

Were,[37]

TLCC = present value of the TLCC

C_n = cost in period n: investment costs include finance charges as appropriate; expected salvage value; nonfuel O&M and repair costs; replacement costs; and energy costs

N = analysis period

d = annual discount rate.

iv) Levelized Costs of Energy (LCOE): This indicator allows comparing different energy technologies according to their technical capabilities and investment cost. It takes into account the total life cost of the investment. LCOE can be directly compared to the price the local utility charges. If the RE system generates electricity for less than the utility price, then the project is economically feasible (Rashford; 2010; p. 2). The National Renewable Energy Laboratory of the Department of Energy of the United States provides a practical online levelized cost of energy calculator for both utility-scale and distributed generation RET[38]

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[37] (Ibid; p. 43).

[38] Available at: http://www.nrel.gov/analysis/tech_lcoe.html

$$\text{LCOE}\left(\frac{\$}{\text{kWh}}\right)=\frac{\text{Initial Costs}(\$)\ +\ [\text{ Operation \& Maintainance Costs }(\$)\ x\ \text{Present Value Annuity Factor }]}{\text{Annual Energy Output (kWh/year) } x \text{ Present Value Annuity Factor}}$$ [39]

or,

$$\text{LCOE} = \text{TLCC} \div \{\sum_{n=1}^{N} [Q_n \div (1 + d)^n]\}$$

Were,[40]

LCOE = levelized cost of energy
TLCC = total life-cycle cost
Q_n = energy output or saved in year n
d = discount rate
N = analysis period.

Non-conventional fossil energy resources, either bituminous sands oil, extra heavy oil, shale oil and gas and arctic oil, is generally LCOE more expensive to produce, refine and transport and resource/emissions intensive than conventional resources (Table 4.13). A key element for its development came only in the change in price that allowed simple resources to be marked as reserves especially with US Shale Gas and Tight Oil, and Canadian Bituminous Sands. The 2004-2014 high prices allowed Canada to become the second country with the higher reserves of oil thanks to the bitumen sands of Alberta (IEA, 2010; p.5). The use of NCFET, together with the increase in transport prices, was interpreted as the end of cheap oil (GPI, 2009; p.5), (IEA, 2011a, p.3); nevertheless, incremental innovations made some wells, such as those of Eagle Ford in Texas, produce oil at a cost of even 20 USD per barrel, matching the cost of several conventional fields, and on the other hand most small and medium flexible NC producers efficiently adapted to the price drop crisis of 2015-2016.

On the other side RET have been reducing their LCOE and are at some points lower than FET while reducing Deployment of renewables tends to generate on the go/know by doing capabilities that reduce prices. “Rapid deployment brings lower costs: solar PV is expected to see its average cost cut by a further 40-70% by 2040 and onshore wind by an additional 10-25%”

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[39] (Source: Rashford; 2010; p. 3).

[40] (Ibid; p. 49).

(EIA, 2016; p. 4); and "Investing in energy efficiency presents one of the most cost effective options to accelerate transition toward a sustainable energy system" (WEC, 2013; p.24). On another hand fuel costs in many RET are virtually zero which helps them have a more favorable LCOE and profitability indicators since once the project is paid for only maintenance costs must be covered (see Box 4.14).

Box 4.14 Zero Marginal Costs

"In the foreseeable future countries with marginal costs of energy production that tend to zero will be the ones in advantage and with the greatest energy security (...) in a changing world FET, and their end pipe 'solution' CCS, will likely never achieve this (...) Renewable Energy in hand with Energy Efficiency is the way to go"

Interview to Dr. Hugo Lucas, Director of Knowledge, Policy and Finance Centre, International Renewable Energy Agency (IRENA). Interview on the 30th of October, 2013

4.7 Economic Capabilities. RET versus FET. Competing trade-offs.

After the profitability analysis comes the economic one, focusing on energy resource/economics and including sustainable development principles that allow assessing each technology for the longer run and taking into account externalities and social benefits. The competition between FET and RET can be based on the perceptions of the tradeoffs (which vary between economies) in relation to: the preferences of the individuals (their benefit), the market (in competition), their natural resource endowment (North and South) and institutions (energy security and environmental security policies).

From the previous sections we have seen that in terms of levilised costs of energy non-conventional and conventional fossil fuels not equipped with CCS technologies are still cheaper that renewables, but are far more contaminating (see Table 4.13). RET can reduce GHG emissions caused by energy systems and are seem cheaper than Carbon Capture and Storage technologies, which will probably only be competitive until 2020 (IEA, 2011a; p.5), making more ambitious reductions rely on RET[41] (IPCC 2012,p.794). RET replacing FET can significantly contribute to de reduction of GHG emissions (IPCC, 2012; p. 128) enhancing environmental security immediately and for all; also it enhances health security[42] and trough the diversification of energy sources enhances energy security (Ibid. p. 127).

4.7.1 Fosil Energy Technologies.

Globally, estimated non-conventional oil and gas resources equal conventional resources (WEC, 2010, p.125). In the North American region a "revolution" of the non-conventionals has been generated (WEC, 2013, p.58). Its impact has triggered events in all the global economic areas that are linked in the framework of this dissertation with issues of productive security, governance, food security, environmental security, etc. Unconventional sources of oil, due to the increase in conventional fossil fuel prices in the period from 2001 to 2014 and technological change, have allowed production costs to be lowered, and their deposits have been classified as "reserves "Rather than mere resources eventually leading to over-production that has drastically reduced oil and oil prices.

The use of Non-conventional FET, either bituminous sands oil (BSO), extra heavy oil, shale oil and gas, arctic oil, is generally more resource-intensive and emissions-intensive than (or conventional) TEFs (Table 4.13)The use of NCFET, together with the increase in transport prices, was interpreted as the end of cheap oil (GPI, 2009; p.5), (IEA, 2011a, p.3). Incremental innovations, however, have made some wells, such as those of Eagle Ford in Texas, profitable at costs of 20 dpb, matching the output of several conventional fields. The technological applications of the NCFET have focused their efforts on the reduction of costs given the nature of attraction of the market instead of policies that push them to make them cleaner. Hydraulic fracking presents a series of complications, especially due to its intensive use of water and contamination of aquifers (WEC, 2011, p.8), while oil extraction from bituminous sands (BSO) represents a "nightmare "Because it emits 3 times more emissions than conventional oil (GPI, 2009; p.5), on the other, conventional technologies have begun to use advanced oil recovery (EOR) techniques in mature wells, drainage techniques (SAGD) and, more importantly, for

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[41] CCS technologies help solve the energy system lock-in, helping phase out (when applicable) FET power plants in a cost effective way.

[42] Burning of traditional biomass is not considered as a RET.

Combined Cycle Gas Turbines (CCGTs), which have enabled developed countries to reduce their GHE emissions significantly. FET represent lower LCOE, some even considering a carbon tax on emissions. This is a key element when assessing energy projects especially in developing countries that have intergenerational priorities to reduce energy and fuel poverty.

4.7.2 Renewable Energy Technologies.

Renewable Energy supplies about 13% of the world's energy, of which RET represents 19% of total power supply. RET are capable of providing energy and environmental security, nevertheless despite technological diversity, their implications are similar trade-offs between environmental security, health security, energy security and productive security. The interaction between RET and sustainable development is probably more ambiguous that what literature would acknowledge. Some RET can help reduce pollution and help with mitigation and adaptation to environmental degradation problems, but their true potential to lead to a sustainable development path will depend on each technology and the specific context in which it is implemented. Faced with a scenario of scarcity of renewable resources and a bonanza of fossils, RET could cause bigger trade-offs than FET.

Within an economy focused on FET there is usually an inverse relationship between the securities, achieving more energy security causes less environmental security. An economy based on RET would likely still have an inverse relation (almost all energy technologies have negative environmental impacts) but depending on the technology and the energy mix it could have a much lesser correlation. This means that achieving energy security, and environmental security objectives can stop being contradictory depending on the technology used; the implementation of RET in initial stages causes a clear reduction of the tradeoff between securities. The cost of obtaining this reduction will have to deal with the costs of different technologies for generating new systems and with the technological lock-in of actual energy systems.

The IPCC points out 4 basic contributions of RET for SD. From the human security perspective these contributions enhance economic security (and energy security), environmental and health security (Box 4.15).

Box 4.15 Basic Contributions of RET for Sustainable Development.

1. Social and Economic Development, part of green growth
2. Energy Access, poverty reduction
3. Energy Security, diversification of the energy mix
4. Climate Change Mitigation and the Reduction of Environmental and Health Impacts.
5. Marginal Costs tend to Zero (main inputs are free).

Source: Based in part on IPCC, 2012; p. 119 and IEA, 2013; p. 226

It is possible; by the end of XXI century to have universal access to modern electricity services, provided entirely by RET (IEA, 2011; GPI, 2011; WWF, 2011). But the implementation of RET faces a series of barriers and relative high costs that undermine their capability to achieve development. These barriers are especially related with socio-cultural, information and awareness, market-related and economic barriers, and technical challenges (Box 4.16) (IPCC, 2012; p. 192) that impede social action.

Box 4.16 Basic Technical Challenges for RET integration.

1. Variability: Bound to natural cycle variations
2. Resource Location: May be far away from load centers.
3. Modularity: Smaller than conventional electric plants
4. Uncertainty: Hard to forecast future energy production
5. Non-synchronous generation: RE at different frequency
6. Overproduction and storage needs Overproduction and storage needs (e.g. the duck curve from solar production at peak hours).

Source: Based on IEA, 2013; p. 208

Concerning poverty and policy trade-offs: there are a variety of reasons for energy and fuel poverty, one of them is the physical distance to the power grids, over 85% of the people lacking modern energy services live in rural areas in least developed and developing countries (IEA, 2011x; p.10) (Table 3.X) RET decentralization capabilities, can be key to secure energy supplies for communities at a cost, in some cases even, lower than that provided by conventional systems.

Nevertheless fuel poverty[43] can be incremented from heavy regulation on existing FET that produce energy from the grid or any other regulation that makes energy more expensive in the short, medium and long runs. Sometimes the best options come from hybrid systems that mix decentralized mini-grid RET and small diesel fired generators to avoid intermittency (IRENA, 2013; p.32) Universal modern energy services access is a basic tenant for meeting the MDGs, and RET can help eradicate this aspect of poverty, especially in developing and least developed countries. It is possible; by the end of XXI century to have universal access to modern electricity services, provided entirely by RET (IEA, 2011; GPI, 2011; WWF, 2011). Barriers are key elements and, as treated in the next chapter, can only be overcome by technological breakthroughs and policy intervention.

The most important trade-offs between securities represented by RET and FET are distinguished. Classified, these may represent to have mainly positive, mixed or negative trade-offs (Box 4.17). From a static profitably, and technical point of view, RET are clearly disadvantaged against FET. Turning to issues of decentralization FET mobile plants are a fast and cheap option to combat energy poverty, leaving renewable applications to niche markets. However, by including full cost pricing, externalities (e.g. carbon tax), distribution of resources and opportunities for international cooperation, the alternatives are matched sometimes going from FET and some for RET. Sustainable development capabilities are reviewed in the next chapter.

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[43] While energy and fuel poverty could understood as one problem, fuel poverty can be bounded to the incapacity to afford energy services or were energy bills surpass 10% of the household income (Bouzarovski and Petrova, 2015).

Box 4.17 *Summary Trade-offs* for Securities and Technologies

a) Energy Security and **FET**; mostly positive *trade-offs.*
   - *+ Lower cost fuel*
   - *+ Fosters industrial development y and job generation*
   - *+ Attracts FDI to resource rich global south countries (energy carrier mobility)*

b) Environmental Security and **FET**; mostly negative *trade-offs*.
   - *- Intensive CO2 and GHG emissions to energy output*
   - *- High Risk of environmental damage from activities (e.g. oil spills).*

c) Energy Poverty Abatement and **FET**, mixed *trade-offs.*
   - *+ Public Resources Generation for Social Net Programs*
   - *- Universal Energy Access in the global south can be relatively less reliable and more expensive from small FET minigrids that RET.*

d) Energy Security and **RET**; mostly negative *trade-offs.*
   - *-Greater Relative Costs*
   - *+Diversification of energy carriers*

e) Environmental Security and **RET**; mostly negative *trade-offs.*
   - *+Very low GHG emissions*

f) Energy Poverty Abatement and **RET**, mostly negative *trade-offs*.
   - *+Greater applicability for off grid applications*

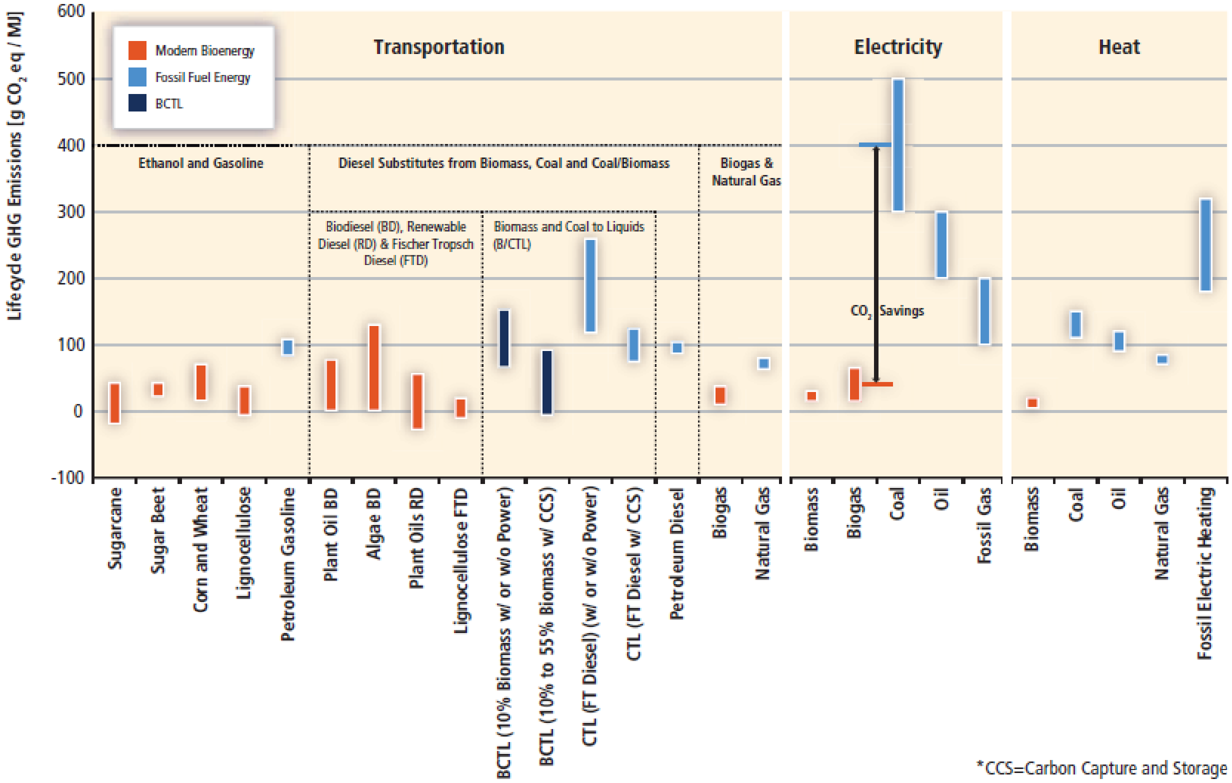
g) Fuel Poverty Abatement and **RET**; mostly negative *trade-offs (short-medium run).*
   - *- Higher costs of energy for feed in tariffs and carbon taxes that foster RET.*

Source: Author, based on cited biography.

4.7.3 GHG Emissions Taxation.

Achieving a global carbon pricing and taxing has been one of the main goals of environmentalist for many years. While efforts in this matter have created local and country carbon markets, beyond the carbon policies of the Kyoto protocol a legally binding agreement for a carbon market has not been achieved. Carbon taxes while capturing a great amount of externalities, alone may not be capable by to promote renewable energy technologies (IPCC, 2012; 147), nevertheless it is a simple assessment tool used to compare different policies. In Table 4.X we assume a carbon tax of 50 USD per ton that is comparable to the CCS price making considering FET like Clean Energy in the mentioned table. For this comparison lifecycle emissions are used these allow us to determine the proper tax, cap and trade or market mechanism to search for a policy that helps reduce GHG emissions. Coal for power and termoelectrical heating are the greater lifecycle GHG emitters, two sectors were RET have been gaining market share very rapidly in the last years (see Figure 4.18).

Figure 4.18 Lifecycle GHG Emissions for RET and FET



*CCS=Carbon Capture and Storage

Source: IPCC, 2013; p. 51.

Photograph 4.19 Integrated Renewable Energy.

Source: Remzi, 2017. Integrated Wind and Charging Station in South Florida. Unpublished.

Table 4.13 Key Energy Technologies, Emissions and Costs[1]

	Resources	Key Technology*****	CO2 Emissions for each BOE Produced	CO2 Emissions for each BOE Consumed	Total CO2 Emissions	Average Cost of BOE*	Average Cost for 1700kWh	Average Cost after a Carbon Tax of 50 USD per Ton of CO2 for 1 BPE	Cost per Kilowatt hour including a Carbon Tax. ***
NCFET	BS	HD, CSSI, SAGD	0.18	1.3	1.48	60	423	305.14	0.18
	Shale Gas	HD, HF, CCGTs	0.306	0.612	0.918	146	146	185.47	**0.11**
	Shale Oil	Retort ,CSSI, SAGD	0.25	1.3	1.55	75	423	315.65	0.19
	Extra Heavy Oil	EOR, CSSI, SAGD	0.18	1.3	1.48	60	423	305.14	0.18
	CTL / GTL	Fischer-Tropsch	0.5	1.3	1.8	80	423	328.90	0.19
	Artic Oil and Gas y AHP	Semi-submersible platforms, Drilling Ships	0.306	1.3	1.606	67.5	423	314.31	0.18
FET	Coal	Carbon Capture and Storage	1.7		1.7	148	148	221.10	0.13
	Natural Gas	CCGTs	0.153	0.612	0.765	146	146	178.90	**0.11**
	Oil	Enhanced Oil Recovery	.16	1.3	1.465	57.5	423	303.25	0.18
RET	Wind	Turbines	0.11	0	0.11	231	231	235.73	0.14
	Solar	CSP, PV	0.094	0	0.094	468	468	472.04	0.28
	Hydro	MPT, HRoR	0.02	0	0.02	68	68	68.86	**0.04**
	Geothermal	EGS, GHPs	0.13	0	0.13	306	306	311.59	0.18
	Ocean	OWC,OB,OD	0.01	0	0.01	476	476	476.43	0.28

Sources: IEA, 2008; p. 217-220. IEA, 2010; p. 157,158. IEA, 2011i; p.43, 49, 62, 64. IPCC, 2012 p.67, 74,75,85,57

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[1] * Levelized Costs of Energy for 2010 (LCOG) and KWh as in IPCC, 2012; p. 137.
***A BOE equals to around 1.6 MWh of potency.
**** Cost of Production Energy equivalent to one barrel of oil including a mitigation cost of $ 50 dollars per ton of CO2. Similar to the expectation of the IEA of 42USD per barrel by 2035.
***** The abbreviations can be seen in the previous sections of the chapter or in IPCC, 2012; p.968-970.

Chapter Remarks

- Technological Change might be the single most likely contributor for Energy Security, Environmental Security and poverty abatement to achieve a more Sustainable Development path.
- Increasing the amount of information reduces tradeoffs between objectives and might be one of the pillars to spur collective rational action to cut environmental degradation.
- The technological locked-in fossil fuel system makes it almost impossible to achieving the 2° objective of the IPCC.
- Induced Technological change has been likely the main factor driving innovation; nevertheless, path dependency has affected technological choice favoring market pushed FET and from the other side environmental awareness has driven technological choice to RET.
- There a 5 stages of Energy Technology Capabilities that help make a comparative analysis of technological choices: i) Theoretical Capabilities: Where is the Energy, can it be captured?; ii) Technical Capabilities: Does the technology have a positive EROI? iii) Simple Economic Capabilities: Is the technology profitable LCOE, NPV and/or ROI? iv) Economic Capabilities: Does it represent the lower tradeoffs? and v) Sustainable Development Capabilities: Does it help lead to sustainable development path?
- Fossil Energy Technologies must be accompanied by CCS so they can economically avoid the threshold of highly damaging climate emissions for intergenerational justice.
- While Renewable Energies are clearly the way forward for the longer run thanks to the less trade-offs they create, still face a integration barriers from social and technical aspects and today have higher levelized costs for RET than most FET, even taking into account a carbon tax and CCS implementation (Clean Energy).These higher LCOE associated with RET are very important considering the technological lock-in around FET and has imperative implications for developing countries who seek to achieve climate goals without sacrificing key poverty alleviation programs that seek intragenerational justice.
- Prices, technological lock-in and sunken costs make highly inefficient to immediately switch from FET to REF.

Chapter 5: Technological Sustainable Development Capabilities under Climate Change and Poverty: International public goods and trade.

> "While this is a step forward it goes nowhere near far enough. The planet is in crisis. We need bold action in the very near future and this does not provide that."
> Bernie Sanders, Press Release on the Paris Agreement, 12th of December, 2017.

This chapter, core for the dissertation, underlines the importance of the factors that sum up for a country to choose its energy mix concerning energy security but environmental degradation and poverty abatement in a global scale. For this, a first part describes based on the previous chapter how climate change and poverty abatement can be considered international public goods. On a second part a simple methodology for determining the energy mix, considering the provision of public goods for climate change (intergenerational justice) and poverty abatement (intragenerational justice). The international CC and Poverty abatement system is described were countries face the prisoner's dilemma on international cooperation on CC and Poverty Abatement. Different countries have different tradeoffs depending on their natural resources, technological endowments and stage of technological locked-in energy systems. There are also taken into account the prices of over emissions of an economy, its natural resources stock, and its technological lock-in, its learning by doing and technology absorption capabilities.

5.1 International Political Economics of Energy Security and Climate Change

At the level of international relations, the aspects that differentiate the results of application in RET or FET, depend on the state of energy at world level and international treaties in search of energy security. Political Economics of Climate Change and Energy Security, are changing the influence of diverse economic agents at the international level; which is creating a complex system that involves a wide variety of interests. "The mayor treats to sustainability, and hence to sustainable development, are global in nature" (Common and Stagl, 2005; p.117)". A basic challenge for achieving SD is generating a consensus in the international scenario for CC mitigation. At an international level the political economic system is anarchic (based on Rowlands, 1991) and countries face a prisoner's dilemma in CC cooperation. They do not know who is mitigating and who is not. CC mitigation is a public good, non-rival and non-excludable, so a set of countries can absorb all the cost concerning mitigation while others free ride. The opportunity costs for mitigating climate change against other national objectives can be much higher. Also “The reason international climate governance has proven to be such an intractable affair relates both to the enormity of the challenge at hand and to the gaping disparity in states' capacity to tackle climate change” (Savaresi, 2016). These challenges summed to the opportunity costs of climate change abatement and to the differentiated responsibilities create a series of constraints that delay CC mitigation and are a key challenge for international cooperation.

Most countries recognize anthropogenic climate change and have created policies for the integration of RET to their energy mix based on CC, Energy Security and Poverty alleviation challenges (Box 5.1). Nevertheless international debate and cooperation tends to be divided between the global north and south. There has been a relatively clear separation between developed and underdeveloped countries. Their differences rely on the historical contribution to anthropogenic climate change and natural resource degradation these are explicit in the Kyoto Protocol[44] but not in the Paris Agreement.

Box 5.1 Increasing interest by governments in RET is driven by 3 challenges

i) Responding to global warming and environmental degradation costly and irreversible treats.
ii) Fostering Energy security to guarantee economic development and mitigate relative poverty
iii) Providing universal energy access to eradicate energy poverty

Source: Based on IRENA, 2010; p. 4

Climate agreements and international cooperation recognize a 2 ° C tipping point that if exceeded could cause havoc in the environment and thus in populations. It is desirable to continue with the described stop of 2 ° C, however, it is recognized that "the door to reach 2 ° C

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[44] Were countries were separated as Annex I, developed, and Annex II, underdeveloped, countries.

is closing" (Ibid). This is related to a potentiated use beyond the technological change induced by NTFs, for three reasons: 1), because countries that lack conventional oil resources in the face of international price volatility (in the medium term), TEFNC and TER are presented as important alternatives for strengthening energy security; 2) for underdeveloped countries, especially those that are growing (such as the BRICS), where increased demand for energy must be offset by supply to avoid slowing growth, and (3) lack of an international treaty Which facilitates the transfer of technology from abroad together with the lack of domestic technological innovations to make the TERs more competitive in the market.

At the same time, the development of NTFPs is partly due to an inefficient distribution of financial resources fostered by geopolitical or security reasons; That is, that it is invested in safe areas for policy (e.g. Alberta, Canada) instead of others with less polluting and even cheaper conventional resources (e.g. fields in the Niger Delta, Western Siberia).

5.1.1 International Cooperation Agreements.

There are two main cooperation agreements that relate environmental, energy and human securities.

- Kyoto Protocol: On the one hand, the Kyoto protocol has been the main international treaty on CC, which has helped eliminate the technological gap that prevents developing countries from covering their excess energy demand with more environmentally friendly technologies such as RET and Clean Energy. The protocol has had favorable results and in 2012, it was decided to extend it until 2020 when it will be replaced by the Paris Agreement. Annex I countries to the Kyoto Protocol (Chapter 2, page 43), on average, have reduced CO2 emissions by 1990 levels by 14.4% (IEA, 2011b, page 46). In part, thanks to the reduction in energy intensity and the use of CCGP technologies, but especially thanks to the efforts made to comply with the commitments made in Kyoto in 2012. At the same time, countries that are not part of Annex I and do not have protocol obligations to reduce emissions have increased their emissions by about 124%. Countries such as the United States, which do not belong to the protocol, have reduced their energy intensity but increased their emissions by 14.4%; Underdeveloped countries like Mexico have increased it by 54% and developing countries such as China by 191%. Canada, despite being a developed country, and having reduced its energy intensity thanks to tar sands, has increased its CO2 emissions by 28%, so it has withdrawn from the Kyoto Protocol after COP 17 Mexico is expected to be the country with the highest increase in OECD emissions by 2035, with an annual increase of 1.7% (EIA, 2011a, p.140).

Box 5.2 **The Kyoto Protocol**

- Sets internationally binding emission reduction targets on developed countries.
- 192 countries have signed and ratified the Kyoto protocol.
- Recognizing that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities."
- Developed countries committed to reduce GHG emissions to an average of 5 percent against 1990 levels. During the second commitment period, Parties committed to reduce GHG emissions by at least 18 percent below 1990 levels in the eight-year period from 2013 to 2020; however, the composition of Parties in the second commitment period is different from the first.

Source: Source: UNFCCC, 2017 Available online at: http://UNFCCC.int/kyoto_protocol/items/2830.php; Savaresi, 2015; and Emandi, 2016.

The Kyoto Protocol includes 3 market-based mechanisms designed to help countries achive their emissions reductions goals by promoting technology exchanges for leapfrogging, emissions trading and multilateral cooperation. The Mechanisms are based in free market principles and efficiency and are vital for cooperation between Developed countries and underdeveloped (or developing) ones (Box 5.2). Market and international trade supports technology and other vital North-South resource transfer which has to date registered 8114 projects accountable for more than 3 billion tons of CO_2 each year (UNFCCC[45]).

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[45] Available online at: http://cdm.unfccc.int/Projects/projsearch.html

Box 5.3 The Kyoto Mechanisms.

- **International Emissions Trading:** GHGE are an international public cost and represent a loss of welfare for the world has a whole. The Kyoto protocol makes them a commodity that can be traded on a scheme of assigned amounts allows countries that have emission units to spare - emissions permitted them but not 'used' - to sell this excess capacity to countries that are over their targets". Other unit of trade is the Removal Unit for land use. E.g. forestation
- **Clean Developing Mechanisms**: Allow parties committed to reduce emission (Annex B) to invest in developing non annex B countries reducing emission by a series certified CDM projects that reduce (or sink) emissions that provide "saleable certified emission reduction (CER) credits". E.g. Desertec Project.
- **Joint Implementation:** Allows Annex B countries to implement emission reduction projects together in any of the countries. This is essential for North-North cooperation. These projects generate emission reduction units (ERUs)

Source: Based on UN, 1998 articles 6, 12 and 18 and the UNFCCC[46,47].

- Paris Agreement: On the other hand, the Paris Agreement, adopted at the 21st Conference of the Parties in Paris the 12 of December of 2015, aims is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. Additionally, the agreement aims to strengthen the ability of countries to deal with the impacts of climate change (UNFCCC, 2017[48]). The agreement will phase out the Kyoto protocol in 2020 and its main difference is that it provides a more flexible approach to reach climate goals in each country.

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[46] Available online at: http://unfccc.int/kyoto_protocol/items/2830.php
[47] Available online at : http://cdm.unfccc.int/index.html
[48] Overview. Available online at: http://unfccc.int/paris_agreement/items/9485.php

Box 5.4 The Paris Agreement

- Requires all Parties to put forward their best efforts through "nationally determined contributions" (NDCs) and to strengthen these efforts in the years ahead.
- 141 countries have signed and ratified the Paris Agreement.
- Common Responsibilities, no differentiation.
- Establishes a periodic process for the submission of information on Parties' efforts, as well as a process for their review, both at the individual and at the aggregate levels.

Source: UNFCCC, 2017 Available online at: http://UNFCCC.int/paris_agreement/items/9485.php and Savaresi, 2015.

As a good, successful example on international cooperation in environmental protection is the "The Montreal Protocol on Substances that Deplete the Ozone Layer". This international agreement is designed to protect the ozone layer. Chlorofluorocarbons under the Montreal Protocol are subject to more effective control, that the GHGE under the Kyoto Protocol (Common and Stagl, 2005; p. 518) and probably the Paris Agreement. This is can be due to a series of factors:

i) Common Responsibilities, the MP applies to all with no difference even if the USA was by far responsible for the depletion of the ozone layer.

ii) Innovation, North American companies (especially DuPont) recognized the treaty and invested to create ozone safe substitutes. Only 130 nations ratified the Kyoto Protocol and "Far from leading technical innovation, American companies have sharply opposed efforts to regulate greenhouse gas emissions" (Sunstein, 2006; p. 4).

iii) Short term benefits, "the benefits of the Montreal Protocol were anticipated to be substantial in the short-term as well as the long-term (…) the benefits from the Kyoto Protocol were perceived to be effectively zero" (Ibid.; p.64).

5.1.2 International Investment Requirements

Investment is a top necessity to achieve a sustainable development path and one of the key areas of opportunity for international cooperation. There are different development scenarios for investment, tree of the main ones are made by the IEA and GPI. GPI scenarios focus on a high implementation of RET and its benefits. Both recognize that a forced induction of renewable is far more costly in the short run especially to achieve the 2°C goal of the IPCC efficient investment for renewables uptake is differentiated between the two studies but clearly higher than in the current policies scenario (see Table 5.5).

Table 5.5 IEA *versus* Greenpeace scenarios to 2050.

	World Energy Outlook 2015 (IEA)					**Energy [r]evolution 2015 (GPI)**				
Scenarios	Δ Primary Energy Demand	% of RET in Primary Energy	% of RET in Electricity	Required Investment in RET (billion USD)	Δ °C	Δ Primary Energy Demand	% of RET in Primary Energy	% of RET in Electricity	Required Investment in RET (billion USD)	Δ °C
Desirable	23	30	53	< 7.9	2	- 19	92	100	55.55	< 2
"Minimum"	32	19	32	≈ 5.7	3.5	-15.86	76	92	39.36	≈ 2
Current Policies	45	15	34	≈ 4	≥ 6	60.78	20.5*	23*	10.3	> 6

Fuentes: i) IEA 2015; p. 35, 55,60, 67,85, 271,347,348. and ii) GPI, 2015; p. 15,59,87 y 92.

5.2 Different Countries, Different tradeoffs

Energy supply is necessary for development and a basic human need, worldwide income per capita and human development index (HDI) are positively correlated with per capita energy use (IPCC, 2012; p.42). The availability of energy services has been a major factor leading to economic growth in developing economies. As the Kuznets curve energy intensity expands parallel to a country's industrial development and then drops after the country turns to a services economy. For industrial developing countries high energy intensity is necessary, this is specially the case of the called BRIC economies.

International cooperation is necessary, facing a global treat an agreement has to be made. Developed and developing countries must take commitments to mitigate and adapt to CC (as recognized in the Paris Agremment). Even non-orthodox organizations like GPI recognize the urgency that "Developing countries should reduce their greenhouse gas emissions by 15 to 30%

as compared to the projected growth of their emissions by 2020" (GPI, 2010; p.16). But, how can they do this? By 2035; 90% of the increase in population, 70% of the increase in economic output and 90% of the rise in energy demand will be attributable to non-OECD countries (IEA, 2011; p.4). Leapfrogging is necessary and good for all; developing countries must have basic tools to build their energy the further they can from FET. In Table 5.6 it is possible to see that in some cases least developed countries like Bangladesh have very high energy intensity and very low GDP this is because of many factors including low capital formation and poor technological progress. More technological transfers should be made from developed countries to avoid high contamination with low development. This can be achieved with differentiated commitment levels, in a Post Kyoto Agreement, if no international bidding agreement is made, and no technological transfer is done, at the end both developed and developing countries will be severely damaged by climate change. SO the appropriate mechanisms must be created to enhance this leapfrogging before more and more developing countries expand their FET systems. Additionally the poorest countries pay relatively more for energy services (GNES, 2010, p.4).

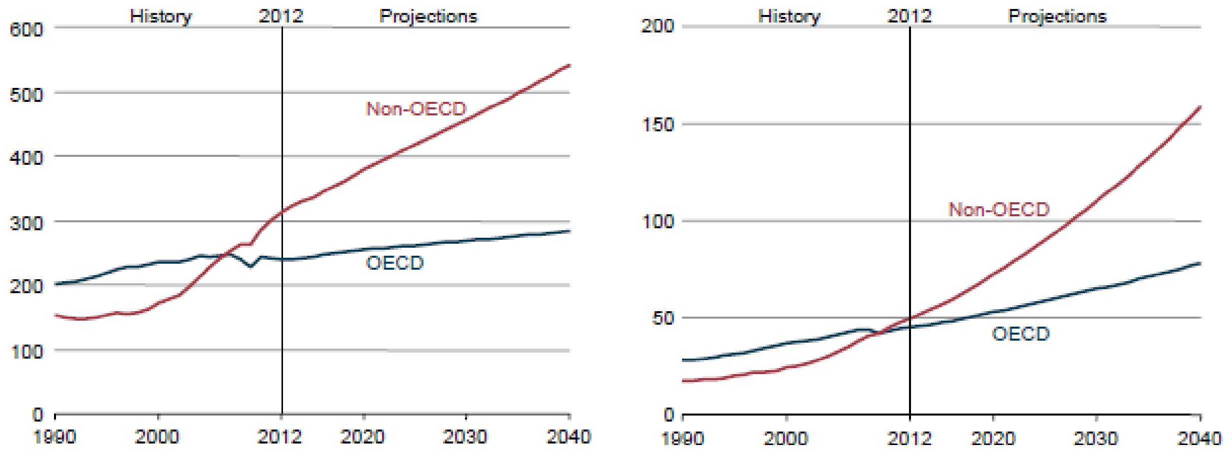
Table 5.6 Different Countries, Different tradeoffs. Energy and Basic Indicators: selected Economies (2010).

Country	Population (million)	GDP (PPP) (billion 2005 USD)	TPES per capita (MTOE)	CO2 Emissions per capita (Mt)	Electric Consumption per capita (kWh)	Energy Intensity TPES/GDP(PPP)	CO2 Intensity CO2/GDP (PPP)	Energy Imports of TEPES
China	1338.3	9122.24	1.81	5.43	2942	0.26	0.8	13.89%
Mexico	108.29	1406.83	1.64	3.85	2085	0.13	0.3	-24.53%
Norway	4.89	229.33	6.64	8.01	25177	0.14	0.17	-531%
Switzerland	7.79	411.66	3.37	0.15	8216	0.09	0.15	57.03%
United States	310.11	13017.02	7.15	17.31	13361	0.17	0.41	24.07%
Russia	141.75	905.23	4.95	11.16	6460	0.35	0.79	-44.8%
Bangladesh	148.69	221.30	0.21	0.36	279	0.38	0.65	22%

Source: IEA, 2012; p. 48-57

As described, the Annex I countries of the Kyoto Protocol have reduced on average 14.4% CO2 emissions from 1990 levels (IEA, 2011G, p. 46). Thanks in part to the reduction in energy intensity, but especially thanks to efforts in 2012 to meet the commitments made in Kyoto. In turn, the countries that are not part of Annex I and not loaded with protocol obligations for emission reductions emissions have increased by about 124%. Countries like the United States that do not belong to the protocol and reduced its energy intensity but increased their emissions by 14.4%, developing countries like Mexico have done in 54% and developing countries like China in 191%. In turn Canada despite being developed and have reduced their energy intensity, thanks to the oil sands has increased by 28% CO2 emissions so withdrew from the Kyoto Protocol after COP 17. Thus a priori data may show that international agreements in effect help global cooperation among countries who continually face the "prisoner's dilemma" in both cooperation for common goods such as environmental degradation. This is where they play an important role supranational institutions and organizations that can punish those who do not meet emission reduction, provide peer to agents and thus materialize the cooperation as the Kyoto Protocol. It is expected that Mexico is the country most OECD emissions increase to 2035 with an increase of 1.7% annually (EIA, 2011, p.140). Even in conservative scenarios, by 2040 economic growth, energy use and consecutively the construction of new power plants) will be dominated by non OCDE (Graph 5.7)

Graph. 5.7 Energy consumption OECD versus non OECD countries.



Source: EIA, 2016;p. 8

5.1.1 Energy and Fuel Poverty in Latin America

Energy and Fuel poverty (Bouzarovski and Petrova, 2015) could be the single most challenging factor for overcoming urban and rural poverty in Latin America. In Latin America, around 75%

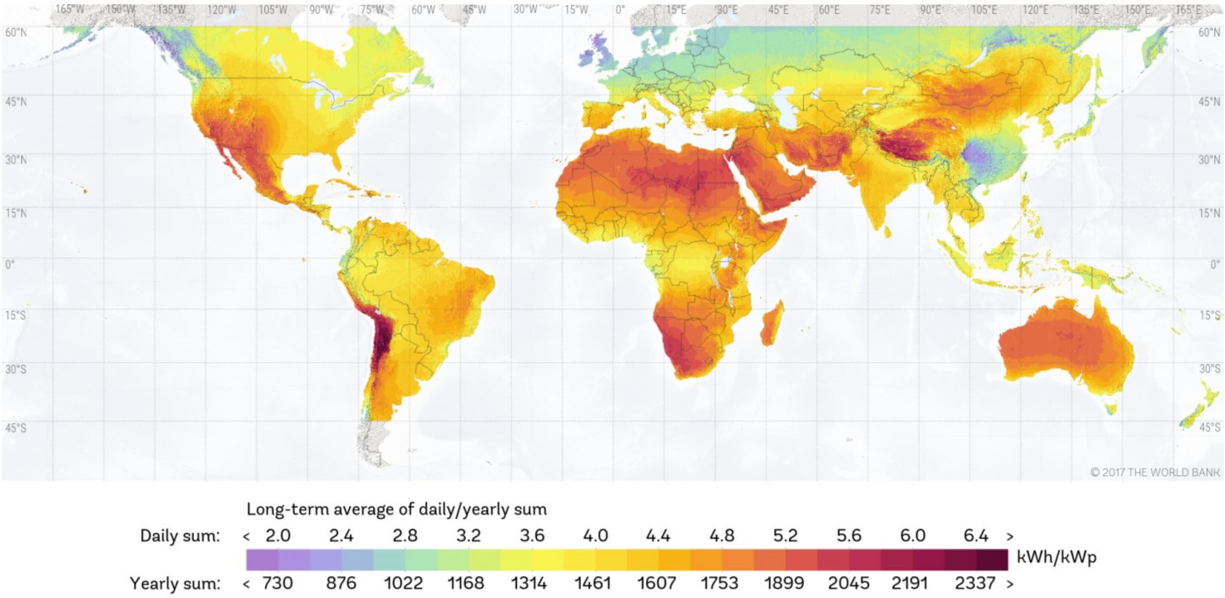
of the total access gap is concentrated among the poorest households living in rural areas (Jimenez, 2016).While there have been great advancements in overcoming energy poverty in the past decades, fuel poverty is growing on most of the region. In Latin America there is an access rate of 98.8% in urban and 73.6% in rural areas with 31 million people living in energy poverty (IFC, 2016), 85 million rely on traditional biomass for cooking (Sheinbaum and Ruiz, 2012) and an uncalculated number in fuel poverty. Most inner-cities in the region have physical access to the power grid but a considerable amount of their inhabitants lack the resources to purchase electricity, continuing energy poverty, or spend a great percentage of their incomes in it, generating fuel poverty. Differentiated progressive level tariffs are the most widespread energy policy to help alleviate this problem, nevertheless since their conception and further implementation in Latin America fuel poverty continues to rise.

As described previously, energy poverty has clear health impacts due to biomass burning that claims over one million lives every year for CO2 poisoning, and is the only main premature death cause expected to increase to 2030 (IEA, 2010); nevertheless uncalculated fuel poverty has also severe health impacts in LATAM and causes an inadequate participation in society (Bouzarovski and Petrova, 2015). Data for the UK reveals that young couples with dependent children are by far the most affected by fuel poverty (DBEIS, 2016), while energy poverty is different in an aggregated lever in the north and the south, health and social exclusion affected populations can be similar, young women being the greater part of the 19 million unemployed in the region (ILO, 2015). LATAM is one of the regions with the fastest implementations of renewables, with almost all countries setting renewable energy targets due to relative higher fossil generation costs (IRENA, 2015). Providing renewable energy, appropriate and energy efficiency technological solutions for modern energy access can prove to be a much better policy than inefficient subsidies (IEA, 2016) and can help empower people and promote gender equality in the region (FAO, 2006).

5.2.2 Natural Resource Endowments

The Global South and North tend to have very different natural resource endowments, generally countries in the South have more resources, thus this is not and exception (e.g. oil resources in the North Sea or wind energy). The greatest example of this is solar energy, for which countries near the Ecuador receive much higher radiation that the ones in the northern hemisphere (Graph 5.8). This is a key factor for the sustainable development of these economies and their clean transition to the service sector.

Graph 5.8 World Solar Photovoltaic Power Potential



Source: World Bank Group, founded by ESMAP, and prepared by Solargis.
Available online at: http://globalsolaratlas.info (accessed 01/04/2017)

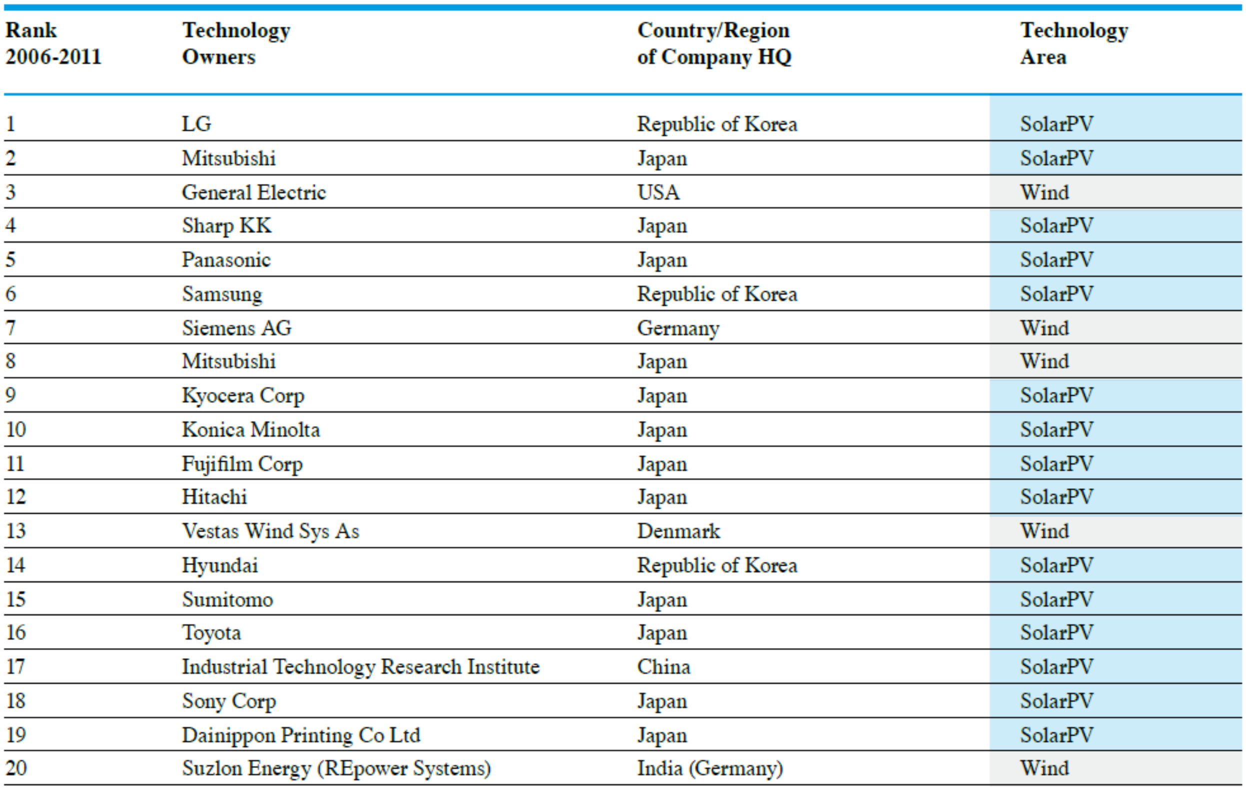
For our case a very important example is hydrocarbon resources. The extraction of these in the global South has been very troubling causing wars, environmental devastation and other problems. This causes a strong effect for countries heavily dependent of oil resources, for example small island States are heavily dependent on imported fossil fuels to cover their energy needs this is especially important in SIDS (IRENA, 2013;p.29). Fossil fuel prices can vary extremely due to stationary and geopolitical factors and can cause great stress on Energy security for these countries.

As described previously, unconventional Fossil Energy Technologies were developed in the United States thanks to a period of unusual high oil prices; this made former unreachable natural resources exploitable and led the US to become the greater producer of oil in the world. The technologies and social institutions developed for the shale basins in the US have been hard to adapt to other deposits (e.g. Poland). This makes clear that besides natural resource endowments technology can be a major player in the energy system.

5.2.2 Technology Endowments

While for our solar energy example the greatest potential is in the global South, with Technology Endowments, the greatest potential is in the North (Graph 5.9). Better R&D for both RET and FET takes place in the global north.

Graph 5.9 The Top Patent Owners are in the Global North



Rank 2006-2011	Technology Owners	Country/Region of Company HQ	Technology Area
1	LG	Republic of Korea	SolarPV
2	Mitsubishi	Japan	SolarPV
3	General Electric	USA	Wind
4	Sharp KK	Japan	SolarPV
5	Panasonic	Japan	SolarPV
6	Samsung	Republic of Korea	SolarPV
7	Siemens AG	Germany	Wind
8	Mitsubishi	Japan	Wind
9	Kyocera Corp	Japan	SolarPV
10	Konica Minolta	Japan	SolarPV
11	Fujifilm Corp	Japan	SolarPV
12	Hitachi	Japan	SolarPV
13	Vestas Wind Sys As	Denmark	Wind
14	Hyundai	Republic of Korea	SolarPV
15	Sumitomo	Japan	SolarPV
16	Toyota	Japan	SolarPV
17	Industrial Technology Research Institute	China	SolarPV
18	Sony Corp	Japan	SolarPV
19	Dainippon Printing Co Ltd	Japan	SolarPV
20	Suzlon Energy (REpower Systems)	India (Germany)	Wind

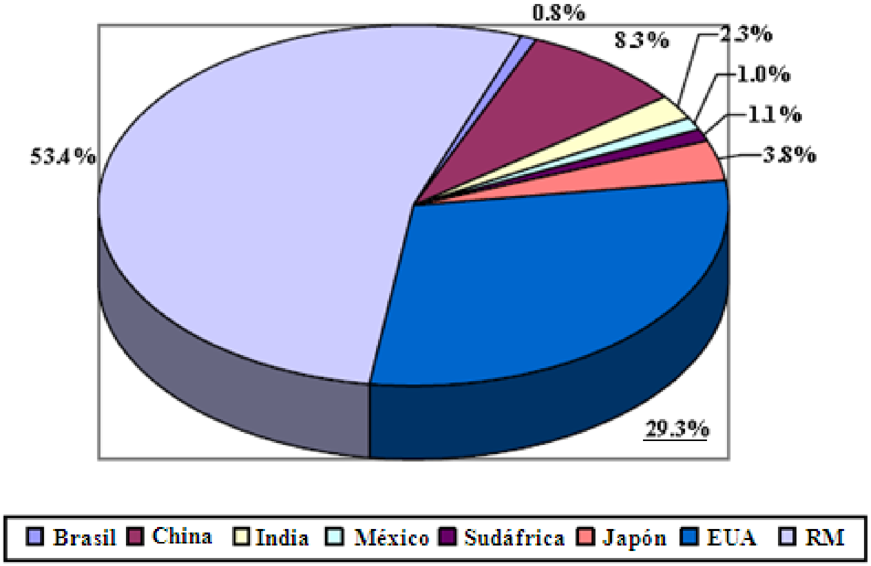
Source: WIPO, 2014; p. 6

5.3 Differentiated but Common Responsibilities on another approach

There has been a key change from the Kyoto Protocol to the Paris Agreement regarding the distinction between developed and underdeveloped countries and historical contributions to CC.

The basic cause behind a lack of economic action to reduce GHG seems to be a high opportunity cost of implementing measures that will affect present economic development and growth, against future uncertain benefits[49], with has historically caused severe tradeoffs between economic security and environmental security. At a the macroeconomic level, the probable basic cause for the lack of unitarily action on CC, is because mitigation of GHG is a public good, countries who mitigate CC under an mostly international anarchic regime will be providing a public good and face a free-rider problem; problem that is enhanced due to uncertain country specific impacts, some including possible positive impacts (melting of permafrost in Russia and Canada). The Paris Agreement eliminated virtually common but differentiated responsibilities bring more countries on board nevertheless it challenges the recognition of historical emissions, present in the atmosphere today that were put in place by developed countries.

Graph 5.10 Historic GHG Emissions from 1890 to 2005.



Source: WWF (2010; p.7, 8) and *ClimateAnalysisIndicatorsTool*, Versión 6.0 (Washington, DC: WorldResourcesInstitute, 2008)

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[49] These have to do with intertemporal choices. If the Net Present Value of adapting of mitigating CC is not known agents don't have incentives to invest.

5.2 Inter versus Intra-generational justice. Supplying international public goods for poverty and CC abatement

Given the lack of collective action, countries seek their energy security in the cheapest way possible, according to their natural and technological resources and technological lock-in: coal in China, biofuels and hydroelectric plants in Brazil, gas and oil in Russia, nuclear power in France, RET in Costa Rica, etc. In turn, they address specific political ideologies and energy policies that vary between developed and developing countries and energy suppliers.

The trade-offs between human securities are interrelated, but they change according to the levels of analysis. At the microeconomic level, agents have changed their stance and now recognize externalities not market reflecting them in the market. At regional and community level, it will depend on the availability of natural resources (insolation, coal, wind, water, etc.).
At the national level, it will depend on the previous levels, coupled with specific policies for development. OECD countries promote freedom in investment in the energy sector (OECD, 2007); while some developing countries, as well as energy-supplying countries, promote a kind of return to energy nationalism such as Russia and China (see Yergin, 2011)

It is necessary to identify that underdeveloped countries have different trade-off relations between securities other than the ones developed countries have. It is possible to ensure that in a "poor" (not developing) country the trade-off between security (environmental and energy) is desirable when it leads to poverty abatement. As described by the IEA “Universal access by 2030 would increase global demand for fossil fuels and related CO2 emissions by less than 1%, a trivial amount in relation to the contribution made to human development and welfare” (2011, p.45).

The international system is complicated in its anarchy, since any unilateral action to eliminate a global problem causes worldwide benefits, but causes relative losses to the country that is carrying them out, as it is providing a public good and dealing with various free-riders. International agreements help cooperation among countries, which continually face the "prisoner's dilemma", in terms of cooperation for common goods and environmental degradation. The problem of collective action to combat poverty and CC is practically at the dawn of altruism.

The effects of GHG emissions, no matter where they are generated, will have negative effects that will affect the welfare of the world in general. This makes the fight against CC, especially through GHG emissions, based on a public good that is easy to recognize. The cooperation reduces the free-riders, maximizing collective action. However, combating poverty is more difficult to recognize as an international public good; this is due to the lack of recognition by the economic agents of the benefits derived from the elimination of poverty. Sadly, negative effects of sea rise are more easily recognized that forced migration and famine in poor countries. Some benefits from reducing poverty are: global political stability, greater world growth (economic exchange is not zero-sum), less illegal migration, greater marginal propensity to consume which leads to rapid growth (driving away from poverty), among others, both moral, ethical and economic. It is necessary to recognize the fight against poverty as a global public good. It may be illogical, to speak of intergenerational justice if we don't recognize intragenerational justice[50].

Poor countries, seeking to provide public goods for the elimination of poverty, seek energy security to bring goods and services to communities; as well as developed countries provide public goods by combating CC. Both efforts must be recognized along with comparative advantages in a free international market to provide such public goods.

This means that the fight against poverty must be supported by resources and technologies from countries that have technological endowments to fight it better; but in turn implies that the fight against CC must be supported also by countries that have the natural resources for the use of cleaner technologies and were technological lock-in can be easier to overcome. The points of the previous statement are based on two very important concepts:

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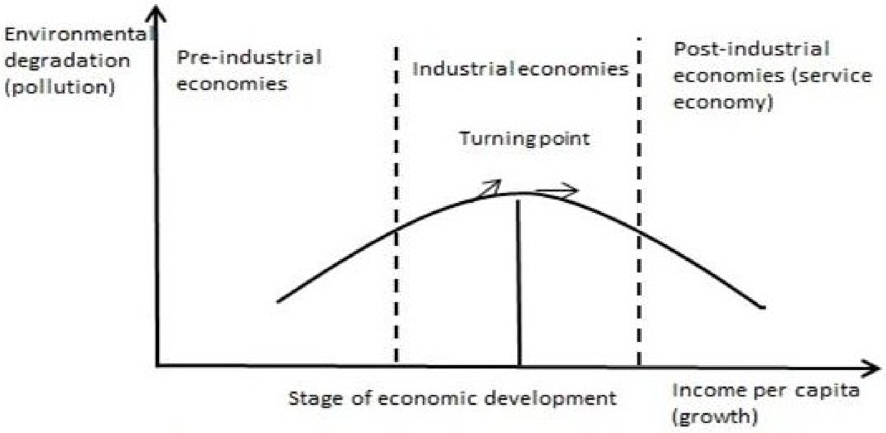
[50] The first notion of the elements of Euclid can be compared with this; Intergenerational and intergenerational justice are equal between them and must be equal before international law (as there are national determined contributions for CC in the Paris Agreement there must be for poverty alleviation including support from the global North to the South).

a) *Leapfroggin*: According to the state of development of nations, they consume more energy in households and in the countryside (underdeveloped regions with low energy intensity), in industry (in developing regions with high energy intensity) and in services (developed and developing, with medium and high energy intensity). This is pictured in the environmental Kuznets curve (see graph 5.11) However, it is desirable for developing countries to achieve a decoupling of energy intensity in the process of reaching developed states especially in their passage through a highly industrialized stage. This low impact economic growth that "flattens" the curve is possible with different approaches, one of the key ones is by the implementation of technologies that reduce energy intensity. Some of these technologies and standards are already available in countries that face this dilemma. The transfer of these technologies and best practices avoids duplication of effort and accelerates cleaner development processes.

   Focused technology transfers could lead to a technological leapfrogging process (IPCC, 2012;p. 120). This "frog leap" can make the dreaded upward slope of Kuznetz's environmental curve minimized in underdeveloped countries during their economic and high energy intense growth process. However, it should be mentioned that the transfer of technology requires a minimum amount of technological capabilities for the absorption in the recipient countries, if there are no such capabilities leapfrogging cannot be performed. At the same time, leapfrogging is not enough for countries to reduce their emissions, is not automatic, and must be accompanied by national policies (Jakob, 2011); so it will not cause effects on the development of energy systems around RET.

Graph 5.11 The Environmental Kuznet´s Curve.



Source: Panayotou, 1993

b) *Free Trade and Energy Intergration.* Elimination of restrictions on Foreign Direct Investment (FDI) in RET and CCS. Beyond seeking geopolitical stability in international cooperation, it may be desirable to transfer technology to underdeveloped countries so that they avoid generating new energy systems with a technological lock-in to FET. In this sense, developing countries with broad access to FTE could allow FDI in their energy sectors to implement FTEs or CCS systems; which will allow them to investment to combat poverty.

Access to the development of alternative energy systems will enhance the energy security of both the host country and the country issuing FDI. There is more room today for reducing more energy intensity trough EE in developing countries and adding extra generating capacity from RET that in developed countries; however, financing for these projects is harder to find than in developed countries. Such mechanisms, although not explicit, are being developed by the EU and MENA countries; with solar projects in the Sahara [51].

Facilitating FDI enables the generation of jobs and technological spillovers in developing countries. The cost of allowing the use of natural resources located in the

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[51] The DESERTEC foundation, in cooperation with Megrid, uses "High Voltage Continuous Current" systems to connect plants in the Sahara with the European Mediterranean. Such technology (which could be considered as a radical innovation for the international trade of electric power), can help integrate energy systems across the world.

least developed countries represents their contribution in the provision of the international public good; which must be added to the provision of the public good of combating poverty that these countries provide.

The combination of the two previous principles, through international cooperation, could allow the reduction in the use of fossil fuels, which would lead to the elimination of the need for the use of No conventional FET. However, translation to policy recommendations is a process that has a number of complications at the meso-economic level.

Chapter Remarks

- At an international level the political economic system is anarchic and countries face a prisoner's dilemma in CC cooperation. They do not know who is mitigating and who is not. CC mitigation is a public good, non-rival and non-excludable, so a set of countries can absorb all the cost concerning mitigation while others free ride. Climate Change mitigation is based in intergenerational justice, this is to provide resources for the future generations.
- On the other hand poverty abatement is also a public good, non-rival and non-excludable that is primarily addressed by poor countries and is based on intergenerational justice.
- Different countries have different tradeoffs depending on their natural resources, technological endowments and stage of technological locked-in energy systems. Poor countries tend to pay more for energy than developed ones.
- The Paris Agreement was able to include much more countries thanks to the recognition of common responsibilities for all trough national determined contributions; nevertheless, this is clearly not enough and eases of pressure to developed countries responsible for most of the current GHG present in the atmosphere.
- The Environmental Kuznets curve shows that poor and developed countries would go through a highly contaminating phase as they pass from agricultural to industrial economies, to avoid this catastrophe two recommendations are broadly layd out: i) Available technology and best practices must be transferred internationally North-South, South-South to promote leapfrogging processes, and ii) Free Trade and DFI must be facilitated internationally to help promote RET in developing countries who are increasing their energy demand.

Chapter 6: Conclusions.

“Overcoming poverty is not a gesture of charity. It is an act of justice”
Nelson Mandela, Campaign to end poverty in the developing world, Speech, 2005.

For the proper formulation of public policies not only is the analysis of the incentives for the implementation of RET and FET with CCS necessary; it is also necessary to take into accounts who are the recipients of benefits and who are harmed by action and non-action.

Without a policy intervention to correct market failures, RET could in some cases jeopardize the immediate development of present generations by making them pay for much more "expensive" systems of power generation. Thus, coordinated action is needed to allow the exchange between comparative advantages of countries with appropriate technologies and countries with natural resources. This with the right policies to support industry and international technology transfer, it is possible to generate competitive advantages in order to provide international goods for combating CC and poverty (based on IPCC, 2012, p.191).

6.1 Technological lock-in for International Cooperation

Given a specific set of public policy, technological lock-in can play an important role for the international trade in technological and energy resources of RET to combat the CC and poverty by developed and developing countries. The fact of having an energy system already constituted generates additional costs for the necessity of the early retirement of FET or nuclear energy plants, the opportunity costs make it more expensive to have to replace an existing plant to create a new one. This problem applies to developed and underdeveloped countries. Developed countries generally already have the necessary infrastructure to meet their energy demand, so the lock-in effect is already present. In contrast, underdeveloped countries, especially developing ones, face a supply deficit with respect to demand so they have to open new plants (and not close existing plants). Thus the application of RET and CCS technologies differentiates for existing and new plants; being the relative cost of CCS technologies similar for both cases and that of cheaper RET covering new demand, and more expensive if existing plants are replaced. This leads to the possibility that it is relatively more expensive to open RET plants in developed countries than in developing ones.

In terms of the availability of natural resources it is necessary to reduce emissions, regardless of the country in which they are emitted (thanks to emissions trading systems). It is possible to direct the efforts in generation to the zones that have the necessary resources, as well as to promote carbon sinks. Given this, countries with large renewable resources can better use these resources to generate energy. This scheme should be continued and expanded so that countries can implement CCS technologies in their existing FET plants (especially coal). With international cooperation and regulated opening of the energy and emissions markets (for energy and environmental security), it is possible that the effort to provide goods for mitigation and adaptation to CC, environmental degradation, poverty and productive security is more evenly, recognizing the comparative advantages of countries and regions. Under these, -yes- "heroic" assumptions developing countries are encouraged to meet their growing demand with more RET and developed countries to implement CCS technologies in their existing FET plants and conserve nuclear power plants overall generating a positive global effect.

6.2 Policy Approach.

Due to the lack of international cooperation and discrepancies in temporary valuations regarding the provision of public goods to combat CC and poverty, RET or FET are not presented as the best sole options for energy security. Depending on various determinants, including natural and technological resources, technological lock-in and commitments to combat CC and poverty abatement, the ideal energy mix will be a combination of different technologies.

The policy to ensure the energy and natural resources necessary for energy security must be strongly related to all levels of analysis to avoid excessive and avoidable trade-offs between securities. The Paris agreement made an extraordinarily achievement by focusing on NAMAs for all rather than on historical emissions and / or common but differentiated commitments; nevertheless it must further strengthen the Clean Development Mechanisms (CDM) and NAMAs internationally (North South and South South) to seek a technological leapfrogging process and regional energy integration to enhance efficient natural resource use.

The homologation of regulations and liberalization of the energy trade will continue to favor the generation and transmission of renewable energy from territories with adequate natural resources, where it is cheaper to produce and there are greater needs for employment generation and poverty abatement, compared to countries that can take advantage of their existing infrastructure combining energy efficiency and CCS strategies and policies to avoid having to dismantle power plants ahead of time (including nuclear energy). International cooperation must emerge from current contexts and the expiration of market barriers. There are two basic aggregated conclusions that can be translated into general guidelines (Table 6.1):

ii) **Intergenerational** approach. On the one hand, emerging from the fight against climate change as an international public good, the technological lock-ins, natural resources and technology endowments make it cheaper to strengthen the implementation of Renewable Energies in developing and least developed countries. Growing energy demand is a business opportunity for developed countries and with the CDM allows them to achieve emissions reduction targets globally providing an international public good for future generations.

iii) **Intra-generational** approach. On the other hand, combating poverty is also an international public good. Developing and least developed countries allocate more efficiently resources for ending poverty than developed ones. The integration of energy regions across the world, taking advantage of new technologies for energy transmission, natural resource endowments, lower cost of labor and freer markets will allow for a better flow of foreign direct investment. North-South and South-South FDI will allow countries to mitigate CC and abate poverty at the same time, reducing tradeoffs and creating an overall positive effect for sustainable development trough technology transfers, which can cause a leapfrogging process to avoid and catastrophic environmental Kuznets curve, while providing an international public good for present generations.

TABLE 6.1 OBJECTIVES, MEANS AND STRATEGIES

<table>
<tr><th>STRATEGY</th><th>REDUCING TRADEOFFS BETWEEN ENERGY AND ENVIRONMENTAL SECURITY</th><th>POVERTY ABATEMENT
UNIVERSAL ACCESS TO MODERN ENERGY SERVICES
(Intergenerational Justice)</th><th>CLIMATE CHANGE AND ENVIRONMENTAL DEGRADATION ABATEMENT
(Intergenerational Justice)</th></tr>
<tr><td rowspan="4">TECHNOLOGY</td><td colspan="3">Meta-Economic: Energy Efficiency, Decoupling of Economic Growth and increased energy consumption. Transport technologies other than FET. At least investment of 7.5 trillion dollars by 2035 in RET. More storage options, on site generated hydrogen for transportation. Greater triple helix projects for R&D+i in RET and Clean Energies, mostly CCS. Strengthening of knowledge-intensive energy services and higher participation of private sector in the provision of radical and incremental innovations.</td></tr>
<tr><td>Macro: Comprehensive national policies to strengthen RET and CCS for Clean Energy. Policies for change in public transport to sources other than FET including electricity and, in some cases, Hydrogen as an energy carrier.</td><td>Macro: Decentralized provision of energy with the combination of RET, FET and appropriate technologies. Energy Poverty and Energy Security abatement in urban areas by energy efficiency standards and progressive energy tariffs.</td><td>Macro: New Energy Architecture for developed and developing countries, promoting EE financing by energy savings, RE power plants -according to natural technological resources and technological lock-in. Federal level R+D&i policies for RET and Clean Energies (CCS).</td></tr>
<tr><td>Meso: Regulatory frameworks for the opening of new energy plants. Efficiency of national electricity networks to transfer deficits and surpluses to other regions. Smart Grid deployment and EE outreach policies for home buildings and industrial uses.</td><td>Meso: Opening of wholesale electricity markets promoting small and medium energy producers, long term energy contracts for off grid rural energy provision, and Feed in Tariffs.</td><td>Meso: Promoting policies for phasing out inefficient fossil fuel subsidies, implementing CCS in highly contaminating thermoelectric plants and when possible switching to combined cycle gas plants. Other measures should be taken in the agricultural sector and to promote natural carbon sinks.</td></tr>
<tr><td>Micro: The environmental awareness process is ongoing and much can be achieved by recognizing externalities that affect the populations' health from transport and energy creating emissions and byproducts. More information could empower consumers to continue achieving energy and environmental goals.</td><td>Micro: Education in rural areas in engineering careers and around decentralized energies and appropriate technologies.</td><td>Micro: Provide more information to consumers about the benefits of more energy-efficient products and financing schemes. Also around the actions to reduce their carbon footprint in the energy sector trough energy conservation.</td></tr>
<tr><td rowspan="4">PUBLIC POLICY (Paris Agreement and Post-Kyoto)</td><td colspan="3">Meta-Economic: Public Policy that integrates Energy and Environmental Security to achieve the international provision of public goods for abating CC and poverty. For this it is essential to promote international cooperation and North-South / South-South aid. International public registry (good will monitoring system) to NAMAS and CDM to discourage the free rider problem in international CC and poverty abatement public goods. Sharing information to identify investment needs and business opportunities in the global energy sector.</td></tr>
<tr><td>Macro: Post Kyoto Agreement that enhances CDM and complements these with the NAMAS of the Paris Agreement.</td><td>Macro: According to a treaty to reduce emissions, preference should be given to RET for PS.,</td><td>Macro: Abiding by International Commitments for CC, supporting NAMAS and CDM. Energy efficiency policy for the reduction of emissions. Fiscal incentives for efficiency, international mechanisms for leapfrogging and free FDI.</td></tr>
<tr><td>Meso: Use of mechanisms for technology transfer and FDI proposed by international treaties. National R&D+i.</td><td>Meso: Public policies designed to comply with the international agreement, and to promote the provision of decentralized energy in distant regions.</td><td>Meso: Support to economic sectors so that they have availability of technologies to achieve efficiency Generation of capacities for reception in technology transfer.</td></tr>
<tr><td>Micro: Awareness of the global challenge posed by CC and poverty. Increased environmental education.</td><td>Micro: Provision of information on treaties including the MDG and SDG. Development of human capital in remote communities to generate productive projects in the region.</td><td>Micro: Regulatory policies to make buyers aware of the technical specifications in the production of goods (cradle methodologies), as well as in their energy consumptions of operation and live-in-energy cycle (LCOG).</td></tr>
</table>

SOURCE: Author, based on the cited biography on this thesis.

Overall as a broad example, it is cheaper, reduces more emissions and fights poverty in greater way to produce one megawatt of concentrated solar energy in Morocco than in Germany or one megawatt of geothermal energy in Baja California, México that the same energy in solar or wind in California in the US. In addition, it can avoid the construction of a thermoelectric plant in Morocco and the installation of a CCS system in the German plant. There is no point in dismantling coal plants with high efficiency and emissions standards and possible CCS applications and were there are natural coal resources in Germany to replace it with and relatively big solar plant due to the low solar radiation in the country, when it is possible to invest in a solar plant in Morocco and interconnect it to the EU. This example is easier to see nationally, Coal power plants in the Chinese province of Xinjian would not be dismantled to build more hydro plants in the Tibet region, each region develops their resource and technology and inputs it to the grid, this in the context that China today is the country that is generating more RET in the world. Decision alternatives for accelerated provision of international public good for poverty and climate change abatement can then be demarcated into four levels of analysis[52]:

1. **Metaeconomic:** Governments, private companies, supranational organizations and economic agents in general must be coordinated to seek the right policies to generate incentives that allow collaboration to jointly increase energy and environmental security reducing tradeoffs and thus generating the right conditions for the provision of international public goods to fight the CC and poverty.

2. **Macroeconomic:** International cooperation for the global good must be mediated to support as deemed correct for inter and intergenerational justice, so countries according to their goals and resources for combating CC and poverty can take appropriate actions. The Paris agreement correctly sets aside common but differentiated responsibilities; nonetheless the historical emission debt must not be forgotten and must be taken into account alongside the benefits of promoting energy integration and RET development in the global south for which there should be

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[52] For a description of the guidelines for the Meso and Metaconomic analyzes please see Mamalakis, 1996 and Pang, 1999.

technological transfers to enable leapfrogging process to avid the environmental Kuznets curve. The CDM of the Kyoto Protocol must be enhanced so they allow for RET and Clean Energy to overcome market barriers and failures. For example, promoting the use of RET in new plants (developing and underdeveloped countries) and the implementation of CCS and EE in existing plants (developed countries).

3. **Meso-economic**: National energy security and environmental security policies must be broadly related. Both should ensure universal access to modern energy services in relation to the MDG and their superseding Sustainable Development Goals of the United Nations. Decision makers at the national and local levels should seek policies that promote decentralized, private generation based on RET with mechanisms such as long-term contracts and Feed-In Tarifs. In turn, the creation of knowledge-intensive services around RET and CCS should be promoted both in the global north and south. The mesoeconomic environment has to have a strong humanistic vision that counteracts the microeconomic business vision of traditional economic efficiency, decision makers must take into account the 5 technological stages of energy technologies to properly asses the best energy mix in their economies.
4. **Microeconomic:** Uncertainty should be reduced with prospective studies on the implementation of the RET, FET and CCS in their 5 technological stages, so that their risks and opportunities can be better understood leading to a greater security for the investment and private R&D+i in these technologies. This information provided, will allow economic agents to recognize the benefits of different energy technologies according to the specific environment in which they are applied.

The international system to promote Sustainable Development is anarchic; this work intends to show that the evolution of human conception of economic equity has been taking a weird shape. The Kyoto Protocol and the Paris Agreement are very different, while the Paris Agreement achieve its key goal of bringing the most important players on board it did it by sacrificing the necessity of having an international legally binding mechanism. Even now the recently elected

President of the US has announced its intention to withdrawal from this “lax” Paris Agreement that would make a major scaffold on the hull of this international effort. This leaves us thinking of the future with a growing climate denial movement and a loss of international leadership to tackle CC; it is clear now that more arguments are necessary to promote sustainable development “The grave environmental crisis facing our world demands an ever greater sensitivity to the relationship between human beings and nature” (Pope Francis, 25 of November, 2015). The catastrophic recognized effects of Climate Change seem to have little influence on business and far right politicians who fail to acknowledge that the debate is over and that more people in the near future fighting for scarce resources can lead to war and death caused by rising health problems (Sanders, 2016).

This thesis aims to give a unique theoretical approach to intergenerational and intergenerational economic justice from the technology locked-in and poverty abatement perspectives. CC and Poverty abatement are the two greatest challenges faced in our time and there is a clear lack of literature that binds them in relation with technology and the state of the energy system. Distinguishing technological stages in chapter 4 allows for policy markets to make better decisions concerning an interdisciplinary approach; while some technology may present advantages in some technical of business context aggregately it can prove to be bad for poverty abatement or sustainable development. Mitigating Climate Change by developing countries is not only a way to combat Poverty in developing and underdeveloped counties but also a ethical duty and a business opportunity that unveils a win-win scenario for develop and developing countries, as for present and future generations.

Acronyms

BSO: Bituminous Sands Oil
CC: Climate Change
CCGTs: Combined Cycle Gas Turbines
CDM: Clean Development Mechanisms
GHG: Green House Gases
CCS: Carbon Capture and Storage
CE: Clean Energies
CTL/GTL: Coal to Liquids / Gas to Liquids
EE: Energy Efficiency
EIA: Energy Information Administration
EOR: Enhanced Oil Recovery
FCCS: Fossil Energy Technologies equipped with Carbon Capture and Storage
FET: Fossil Energy Technologies
FDI: Foreign Direct Investment
GPI: Green Peace International
IEA: International Energy Agency
IPCC: Intergovernmental Panel on Climate Change
IRENA: International Renewable Energy Agency
ITC: Induced Technological Change
NAMAs: Nationally Appropriate Mitigation Actions
NCFET: Non-conventional Fossil Energy Technologies
RET: Renewable Energy Technologies
R&D+i: Research and Development plus innovation
SCO: Synthetic crude oil
SE4All: Sustainable Energy for All
SRREN: Special Report on Renewable Energy Sources and Climate Change Mitigation
WWF: World Wildlife Fund

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