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Towards the Decarbonization of the Economy:

a Comparative Study between Sweden, China and Ethiopia

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Academic Year 2016/2017

Acknowledgements

First of all I would like to thank my parents for giving me the opportunity to study at this university and supporting me along the way. Secondly, I would like to express gratitude towards my grandparents who have always believed in me and have encouraged me to give the best in every situation.
Last, but not least, I am forever grateful to my sister Beatrice and my closest friends at university Ivana, Federico, Andrea, Simona and Giulia for accompanying me through these years, for helping me in multiple occasions and for never leaving my side. I would never have made it through without them!

Table of contents

CHAPTER ONE

Introduction

"Climate change does not respect border. It does not respect who you are – rich and poor, small and big. Therefore, this is what we call 'global challenges', which require global solidarity."
Ban Ki-Moon

In light of current events, this citation is ideal to remind us the importance of cooperation in combating climate change, a phenomenon which cannot be ignored since it affects each one of us, regardless of our national identity or socio-economic status. President Trump has announced on Thursday 1 June 2017 that the United States would withdraw from the Paris Agreement, weakening in this way the efforts that have already been made, and those which still remain to be made, to combat global warming. Under the accord, the United States had promised to decrease greenhouse gas emissions about 26-28% below 2005 levels by 2025 and devolve up to $3 billion in aid for poorer countries by 2020. Being the world's second-largest polluter[1], the US' withdrawal is dangerous not only for planet Earth, but also for all those populations which are severely affected by the natural disasters caused by climate change. Therefore it is important to underline once again that global warming is a universal threat, which cannot be stopped unless everyone – from politicians and scientists to citizens – comes together to find a solution.

1.1 Background of the thesis

1.1.1 Climate Change

There is no doubt that the climate has changed, and is still changing, due to the influence of human industrial activities and this is why the UN recognizes the historical responsibility of developed countries in causing global warming[2]. In fact, the majority of scientists nowadays agree that the main causes of global warming are anthropogenic changes, particularly the increase in greenhouse gases[3]. The "greenhouse effect" is a natural phenomenon which prevents the Earth from freezing: it is the warming that takes place when certain gases in the Earth's atmosphere trap the heat. The more greenhouse gases are in the atmosphere, the more heat gets trapped. CO2 is naturally present in small quantities in the Earth's atmosphere and English scientist John Tyndall was the first to discover that it could bring warming. However, the current amount of CO2 that is being produced is too much and it is contributing to the destruction of our planet. A big portion of the infrared radiation which is emitted by the surface is absorbed by CO2 in the air. In this way the air becomes warmer and some of the energy that is trapped in the atmosphere is radiated back to the surface, warming it

[1] Shear, Michael D. 2017. "Trump Will Withdraw U.S. From Paris Climate Agreement." *The New York Times*
[2] Saran, Shyam. 2015. "Paris climate talks: Developed countries must do more than reduce emissions." *The Guardian*
[3] Crowley, Thomas J. 2000."Causes of Climate Change Over the Past 1000 Years." *Science 289, 270*

even more[4]. This anthropogenic modification of the climate causes what is known as "enhanced greenhouse effect" or global warming[5]. In his article "Causes of Climate Change Over the Past 1000 Years" Thomas Crowly wrote that there are two different lines of evidence which show the unusual rise in temperatures during the late 20th century: first of all, the warming that we are experiencing is unprecedented in the past 1000 years. Secondly, the model that explains the change in temperatures in the Northern Hemisphere during the years 1000-1850 shows that only 25% of the 20th century temperature rise is due to natural variability. In short, the cause of our century's warming is the increase in greenhouse gases[6]. Why do greenhouse gases constitute a threat? The answer is simple: the rapid rise in greenhouse gases is changing the climate faster than some living creatures may be able to adapt. Furthermore, an unknown and more unpredictable climate poses unprecedented threats to all life, including that of human beings. We have evidence of this phenomenon since already during the course of the 20th century there has been an unprecedented rise in both global temperatures and sea levels. In addition to this, there is a risk that weather conditions will become harder to predict and there will be an increase in extreme climate circumstances, such as storms, floods, heat waves and droughts. Climate change is indeed the major challenge that our society is facing and the solution is well-known: fossil fuels need to be replaced by sustainable carbon-free renewable or alternative sources in order to decrease CO2 emissions[7].

1.1.2 The Kyoto Protocol and the Paris Agreement

During the last two decades, there have been major political and economic discussions about ways of reducing greenhouse gases or, at least, adapting to climate change[8]. A number of international summits, such as the Earth summit in Rio and more recently Kyoto, have taken place to talk about the main environmental problems and try to find solutions to them[9]. The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and has entered into force on 16 February 2005. Its main aim was to make sure that the parties to it reduced their greenhouse gases emissions and monitored them by keeping a precise record[10]. This meant that industrialized countries should reduce their emissions by an average of 5% below 1990 levels by 2008-2012. The Protocol's individual emissions obligations were legally-binding, which means that all the Parties had to make sure that they did not exceed their targets and this obliged them to actually achieve them, not just try. However, the per capita emissions of industrialized countries were typically ten

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[4] Weart, Spencer R. 2008. "The Discovery of Global Warming." *Harvard University Press*

[5] Owen, Anthony D. and Hanley, Nick. 2004. "The Economics of Climate Change." *Routledge London and New York*

[6] Crowley, Thomas J. 2000. "Causes of Climate Change Over the Past 1000 Years." *Science 289, 270*

[7] Maslin, Mark. 2012."The Science Rationale for Enhanced global investment in sustainable energy." *International Sustainable Energy Review: Volume 6, Issue 1*

[8] Owen, Anthony D. and Hanley, Nick. 2004. "The Economics of Climate Change." *Routledge London and New York. Chapters 1-5: pp. 1-80*

[9] Fenn, Kelly. 2017. "What is being done to stop climate change?"

[10] UNFCC. 2014. "Kyoto Protocol."

times higher than the average emissions of developing ones, such as Africa and India. This is why industrialized countries have accepted the responsibility for leading climate change efforts in the UNFCCC and subsequently the Kyoto negotiations. One of the most controversial aspects of the Protocol was the emissions trading, which permitted two Parties to exchange part of their emissions obligations, leading to a redistribution of the allowed emissions between them[11]. In the end, the Protocol hasn't proved successful since the majority of the growth in China and other developing economies has been lead by the production of goods and services that were then exported to developed nations. If we look at the carbon footprint of each country, the progress made under the Kyoto Protocol is really unsatisfactory, and in this aspect we can consider it as a failure[12]. A new attempt to limit the devastating effects of climate change has been made at the COP21 in Paris, where the Paris Agreement has been adopted on 12 December 2015. The Agreement has entered into force less than a year later, on 4 November 2016. Its central aim is to keep the temperature rise under 2ºC above pre-industrial levels or even under 1.5ºC. Furthermore, the Agreement aims to teach countries how to deal with the impacts of climate change, while at the same time making economic development compatible with low greenhouse gas emissions and a climate-resilient expansion. To reach these goals there needs to be a proper financial support as well as new technologies and appropriate competences[13]. The Agreement requires all countries to formulate, reveal, and maintain nationally determined contributions (NDCs) and implement domestic mitigation measures, in order to achieve the goals of these contributions. Emission targets are not legally binding by nature, but countries are required to prepare NDCs, enforce policies and other measures to accomplish the NDCs, and regularly assess and report their NDCs eventual achievements, considering that their main aim in the long-run is that of adjusting the emissions of greenhouse gases (GHGs)[14].

1.2 Methodology and objectives of the thesis

After the umpteenth time that global Protocols about climate change have failed to obtain the desired outcomes, we have decided to conduct a research on how different countries are responding to the threat of climate change and which measures they are implementing to comply with the Paris Agreement.
The thesis is based mainly on literature review and analysis, and it focuses on three countries in particular, analyzing the ways in which they are each coping with the decarbonization of their economies. The three countries that we are taking into consideration are very different in terms of wealth and economic development, but they are all participants in the Paris Agreement, thus committed to decreasing their carbon

[11] Owen, Anthony D. and Hanley, Nick. 2004. The Economics of Climate Change." *Routledge London and New York*
[12] Clark, Duncan. 2012. "Has the Kyoto protocol made any difference to carbon emissions?" *The Guardian*
[13] United Nations Framework Convention on Climate Change. 2016. "The Paris Agreement."
[14] Kameyama, Yasuko et al. 2016. "Climate change mitigation Policy Progression Indicator (C-PPI): a tool for measuring progression of climate change mitigation at the national level." *Research Project 2-1501: Development of Indicators to Measure Progression of Climate Change Mitigation Policies*

emissions. These are Sweden, China and Ethiopia. The reason why they were chosen is because they represent, in a way, the current world's composition: the first is a western, developed country, the second is a developing country (but with the world's second-largest economy) and the third is a poor, Third World country. For every nation, we have analyzed the types of renewable energies developed and adopted and the policies, legislations, incentives and eventual disincentives introduced. We have taken as a model the "Climate change mitigation Policy Progression Indicator" (CPPI) which consists of two pillars: Action Indicators and Outcome Indicators. The first measure countries' efforts in reducing GHG emissions by introducing climate change mitigation policies, while the second determines the progress of countries in achieving actual GHG emissions reductions by comparing emissions data with those of other countries as well as by comparing each country's current data with its own past data. Although greenhouse gases emissions sources are different in every country and there are various factors which influence the increase and decrease in emissions, there are a number of goals which need to be shared by all countries in the world in order to fulfill the Paris Agreement targets. For this reason the authors of the CPPI study have selected four goals – decarbonizing the energy, improving energy efficiency, minimizing demand for energy service and land-use and non-CO2 gases – which are applied to both the Action and Outcome Indicators[15]. However, since our analysis is centred around the decarbonization of the economy, we have only focused on the first Goal. Thus, we have used the first two Outcome Indicators from the "Climate change mitigation Policy Progression Indicator (CPPI)" and, where applicable, the following Action Indicators to measure each country's actual progress in implementing climate mitigation policies.

Table i. Two Outcome Indicators and the corresponding equity considerations

Goal	**Outcome Indicators**	**Equity Consideration**
Goal 1: Decarbonization of Energy	**1.**CO2 emissions/Total primary energy supply **2.**Renewable Energy supply	Developed countries should aim at lower levels than developing countries Developed countries should aim at higher levels than developing countries

Table ii. Nine Action Indicators

Goal	**Category**	**Action Indicators**
	Promotion of renewable energy	**1.** The country sets concrete targets for renewable energy that are sufficient to reach its long-term goal. **2.** The country has regulatory and financial supports, such as RPS and FIT, for the enhancement of renewable energy at a sufficiently high level to allow for the rapid diffusion of

[15]Kameyama, Yasuko et al. 2016. "Climate change mitigation Policy Progression Indicator (C-PPI): a tool for measuring progression of climate change mitigation at the national level." *Research Project 2-1501: Development of Indicators to Measure Progression of Climate Change Mitigation Policies*

Goal 1: Decarbonization of energy		renewable energy. **3.** The country has policies to remove barriers against the enhancement of renewable energy, particularly in the area of electricity grids, including the use of smart grids and demand responses.
	Decarbonization of other energy sources	**4.** (The country sets an emission intensity target on power plants satisfying at least one of these criteria: (i) 0.612 kCO2/kWh for coal-fired power plants, (ii) 0.303 kgCO2/kWh for gas-fired power plants, and (iii) 0.256 kgCO2/kWh for the entire electricity sector). The country could implement an ETS that is as stringent as the intensity target. **5.** The total number of a country's demonstration and commercialized CCS projects during a given assessment period is larger than it was during the former assessment period. **6.** The country has a carbon tax or other effective tax rates for the power sector at a rate of at least US$5/tCO2.
	Decarbonization in transportation sector	**7.** The country has financial supports, such as subsidies and tax incentives that are effective enough to provide incentives for consumers to purchase non-fossil fuel vehicles. **8.**The country supports R&D on technologies related to next-generation vehicles, such as fuel-cell cars and light-weight batteries, with the aim of having 90% of all vehicles on the road be low-carbon by 2050. **9.** (The country has transportation rules such as priority lanes and parking spaces that give preferential treatment to carbon-free cars.)

Along with the Action Indicators we have also mentioned the main policies and legislations adopted in each state that are concerned with environmental protection, emissions reduction and the promotion of renewable energies. In the findings, apart from the two Outcome Indicators used in the CPPI paper, we have also made suppositions about the impact that decarbonization policies and renewable energies have on the economy and the challenges that the countries still have to face. The relevance of this paper lays in the fact that there is a lack of research in the current literature regarding the topic of decarbonization, especially referred to recent events. The issue of climate change is a current one and it has been talked about by news and journals everywhere. However, there is still a sort of lack of knowledge, or of interest, regarding it. This is the reason why we have considered it important to display which measures different countries are taking to respond to it. The structure of the thesis is laid out as follows: the Second Chapter is wholly dedicated to the analysis of Sweden's renewable energies, decarbonization efforts and the relative outcomes; the Third Chapter is centred around the attempts initiated by China, and the Fourth Chapter reports the findings about Ethiopia. In the Fifth Chapter we made a short summary and drew the final conclusions.

CHAPTER TWO

SWEDEN

2.1 Introduction

Sweden is the third-largest country in the European Union by area, with a total population of 10 million. The Scandinavian country is one of the leading powers in sustainability and the use of renewable energies. In fact, it was the first country to establish an environmental protection agency in 1967 and it was also one of the first countries to sign and ratify the Kyoto Protocol in 1998 and 2002 respectively. The country believes that to obtain a sustainable and secure energy supply there needs to be a focus on the efficiency of energy and a greater supply of renewable energy, especially in the long-run[16]. In 2015, 57% of its power came from alternative energies such as hydro and wind power, while the rest came from nuclear power. The aim of the country is to become completely fossil-free by 2040 and it has made a great beginning by increasing its output of wind power that is hopefully going to replace the nuclear one[17]. In the months following the Paris Climate Agreement, many countries will be seeking for ways to decrease their emissions while continuing to grow their economies. Sweden is often considered as a role model in this regard, since it has increased its GDP by almost 60% over the past 25 years while cutting carbon by a fifth[18].

2.2 Promotion of Renewable Energies

2.2.1 Types of Renewable Energies and Target Setting

(a) Biomass

The majority of CO2 emissions derive from the use of electricity, fossil transport fuels, heat for ventilation, and so on. The most efficient way to reduce CO2 emissions caused by the burning of fuel to produce heat is to start using biomass instead of fossil energy. The use of bioenergy is considered Sweden's greatest success, since it has become its primary energy source. It has, in fact, led Sweden to a 9% decrease in greenhouse gases between 1990 and 2010 and a 50% increase in GNP[19]. Biomass is generated by crops, agricultural residues and other biological materials that can be used as substitutes of fossil fuels to produce electricity or transportation fuels. Biofuels include ethanol and biodiesel: the first is generated by corn and sugarcane, while the second comes from soy, rapeseed and palm oil[20]. The Swedish industry uses primarily biomass and electricity to produce energy, and in 2013 these constituted respectively 38% and 35% of the industry's final

[16] Sweden's Official Website. 2016. “Sweden tackles climate change.”
[17] Sims, Alexandra. 2016.“Sweden on target to run entirely on renewable energy by 2040.” *The Independent*
[18] McGrath, Matt. 2016. “Is Sweden's 'green miracle' a model for the rest of the world?” *BBC News*
[19] Bayar, Tildy. 2013. “Sweden's Bioenergy Success Story.” *Renewable Energy World*
[20] Environmental and Energy Study Institute. 2017. “Bioenergy (Biofuels and Biomass)”

energy use. Among it, the industries of the pulp, paper and wood products are those that make the greatest use of biomass. Other than the industrial sector, other large users of biomass are the district heating and the transport sectors[21]. The main reasons for Sweden's bioenergy sector's large success are extensive political incentives, such as the CO2 tax introduced in 1991, the green electricity certificates introduced in 2003 and tax exemptions for transport biofuels. The development of biomass in the state happened as a consequence of two factors: the first was the increase in prices of imported oil and the second was the debate over nuclear power[22]. Like wind, solar and other sources of renewable energy, biomass can have positive effects on our planet by decreasing the dependence on fossil fuels which contribute to climate change. However, since it depends directly on farms, forests and other ecosystems for the acquisition of its feedstocks, it can have a series of negative effects on soils, water resources, biodiversity, ecosystems, and local communities. This is why it is of primary importance that biomass must be produced in the most sustainable way possible by choosing the proper management practices and improving land conservation, forest protection, food production and the control of wildlife. Another major problem is that of land use, since many food crops are used for energy feedstocks as well and in certain cases, land is used for the production of energy crops instead than for agriculture. To reduce this conflict there must be a better use of agricultural wastes, food leftovers and municipal solid waste. Finally, another issue related to biomass production is the greenhouse gases emissions caused by land management and use[23].

(b) Hydropower

Hydropower can be considered as another success in Sweden since in 2010 the country generated 67000 GWh of electricity from it, making it the biggest hydropower producer in the European Union and the tenth biggest worldwide[24]. In 2013, electricity production in the country was composed of 41% by hydropower, 43% by nuclear power and 7% by wind power[25]. Hydroelectric power comes from water in motion: the flowing water hits the turbines, which changes the energy's condition and turns it into a mechanical one. The turbines then turn the generator rotor, which convert the mechanical energy into electricity. Powerplants can be located on rivers, streams and canals, but usually dams are needed in order to have a reliable water supply. Dams can store water for later use such as irrigation, domestic and industrial use, or power generation. Once the electricity has been produced, it needs to be delivered to where it is needed. This is why

[21] Swedish Energy Agency. 2015. "Energy in Sweden 2015."
[22] Bayar, Tildy. 2013. "Sweden's Bioenergy Success Story." *Renewable Energy World*
[23] Environmental and Energy Study Institute. 2017. "Bioenergy (Biofuels and Biomass)"
[24] Rudberg, Peter M. 2013."Sweden's Evolving Hydropower Sector: Renovation, Restoration and Concession Change." *Stockholm Environment Institute, Project Report 2013-01*
[25] Swedish Energy Agency. 2015. "Energy in Sweden 2015."

there are vast networks of transmission lines, through which electricity is carried[26]. Vattenfall, one of Europe's largest producers of electricity and heat, is owned by the Swedish government and it provides energy for other countries as well, such as Denmark, Finland, Germany, the Netherlands, Poland, and the United Kingdom. The company has a long experience in hydropower and it has a leading position in Sweden regarding its development. Sweden's abundance of rivers and streams has proved as an invaluable source of energy for the industry and the increase in hydropower use. In the next years, Vattenfall plans to invest about one billion SEK annually in renovating and improving its power plants and carrying out intensive dam safety measures[27]. Hydropower can be a very important source of energy and its main positive characteristic is that it doesn't disperse pollutants, but the downside to it is that it can cause ecological damages due to the rivers' fragmentation from dams and water regulation. The challenge for the future will be to research and develop ways in which the generation of hydroelectric power will not damage fish, water quality and other resources[28].

(c) Wind power

The production of electricity from wind power has increased exponentially in recent years and it has almost tripled since 2010. Wind power production has kept increasing throughout 2013, reaching a level of 9.8 Twh. The following year, production has increased to 11.2 Twh which is equal to a 14% increase compared to 2013[29]. The setting up of wind farms depends on the Swedish Energy Agency while the regional councils have the responsability to plan the locations and identify the areas which are more suitable for wind power. The government then provides the money to carry out the planning activity in regions and municipalities. During the planning process there are certain factors that need to be kept into consideration, such as making the environmental impacts – like noise levels – as low as possible and protecting the landscape[30]. There are currently two types of wind turbines, the onshore ones and the offshore ones. During the last ten years of expansion, the offshore wind sector has improved thanks to the experiences of the onshore development, but it will probably become a more independent part of the energy sector in the future. The legal terms for the establishment of wind power constitute a major impediment for investors and consequently for the sector's development. Onshore installations in Sweden can require various legal rules and permits, while offshore installations only need two main permits as well as an environmental impact assessment. In short, the legal

[26] U.S. Department of the Interior. 2005. "Managing Water in the West: Hydroelectric Power." *Bureau of Reclamation, Power Resources Office*

[27] Vattenfall. 2017. "Hydropower at Vattenfall."

[28] Rudberg, Peter M. 2013; U.S. Department of the Interior. 2005.

[29] Swedish Energy Agency. 2015. "Energy in Sweden 2015."

[30] Tyrberg, Lennart. 2011. "Wind energy in Sweden." *Wind Energy in the Baltic Sea Region 2*

preconditions for offshore wind power development are less intrusive than those for the onshore installations. In the future, a greater financial support for the Swedish offshore projects could lead to an increased interest among domestic and foreign investors[31]. Despite these challenges, the success of wind power in Sweden is undeniable. In fact, in December 2016 the Scandinavian country has broken the record by producing almost as much wind power as six nuclear power plants. This was achieved thanks to the intense weather conditions that have been experienced by it over Christmas. The large amount of power generated has constituted 26% of the country's total energy consumption. The beneficial effects of this, apart from producing power in a clean way, are that the price of electricity has decreased by about a third not only for the Swedish population, but also for the nearby countries like Denmark[32].

(d) Geothermal energy

The extensive use of ground source heat pumps (GSHP) in the country has made Sweden the third leading country in the utilization of geothermal energy in the world, with respect to number of units installed, installed capacity and obtained thermal energy. The use of geothermal energy began in the 1970s and 1980s, initiated by the oil crises and the following attempts to create an oil-independent energy system.
Swedish geology is constituted by the Batic shield and its diversified crystalline eruptive rocks. In the southern parts of the country, there is the presence of thick sedimentary rocks which have very good hydraulic properties. The geothermal temperature reaches 28-30ºC/km in the south and rarely more than 15-16ºC/km in the Baltic shield regions. In most areas of Sweden there aren't the geological conditions required for deep geothermal exploitation and this is why, today, there is only one deep geothermal plant in function in the country: the Lund geothermal heat pump plant, which started working in the mid 1980s and which is the largest installation in the country. The plant provides about 140 GWh of geothermal heat to the Lund territory's heating system. A further number of exploration wells were drilled in other parts of the country, but had to be abandoned because of a lack of water and, thus, of production capacity. The most common type of geothermal energy is the one that comes from shallow geothermal systems, which are mainly heat extraction systems (GSHP). In addition to these, there are underground thermal energy systems (UTES) which are used to store heat and cold in the underground. In this way, heat can be stored from the summer season to be released in the winter, and cold is stored during the winter to be used as free cooling in the summer season[33]. The Swedish heat pump market has had positive and negative moments since the 1980s,

[31] Söderholm, Patrik and Pettersson, Maria. 2011."Offshore wind power policy and planning in Sweden." *Energy Policy 39: 518-525*

[32] Griffin, Andrew. 2016."Sweden breaks wind power record by half a million kWh after intense weather and storms." *The Independent*

[33] Gehlin, Signhild and Andersson, Olof. 2016. "Geothermal Energy Use, Country Update for Sweden." *Swedish Center of*

depending on the extent of governmental subsidies and contributions. In 1994-1995 the Swedish National Board for Technical Development issued a technology procurement on heat pumps and its two winners were ground-source units, which explains why this type of heat pump is currently leading the market instead of the air-source one. Since 1995 the heatpump market in Sweden has rapidly increased and the sales in 2002 almost reached 40.000 units. The ground source heat pump (GSHP), which works by extracting heat from a borehole, the ground or seawater, is the most used one, while the second most common type is the exhaust-air heat pump, used mainly in small buildings. The latter works by extracting heat from the exhaust-air and dispensing it to domestic hot water, a heating system, to the air or a combination of these. Future improvements for heat pumps are currently being tested, such as the creation of a combined exhaust-air and ground-source heat pump or ground-source heat pumps that could be used in the summer to provide cooling[34]. Geothermal energy is generally considered as an environmentally friendly technology and it also helps to increase the commercial value of a building. It has played a major role in replacing fossil fuel heating in the Swedish building market, especially for the small residential constructions[35].

(e) Solar Energy

A further renewable energy opportunity is that of direct solar heating which, however, hasn't been very successful in entering the Scandinavian market due to high costs and technical concerns. The Swedish experience with the solar heating sector began in 1975 when the Swedish Council for Building Research (BFR) was given the responsibility for RD&D (Research, Development and Demonstration) regarding the building sector. At the time, there was a proposal of studying how buildings could use solar energy. However, in the long run, the governmental support for RD&D research was gradually diminished and this was only partly balanced by the increased involvement of the European Commission. At the beginning, the Swedish Research, Development and Demonstration program was focused on large-scale applications for centralized solar heating plants, supported by loans granted by the Swedish Council for Building Research. The first experimental solar heating plant with seasonal storage, which means that it could provide heat all year round for an office building, was constructed in 1980 at Studsvik Energy. This first experiment was followed by many others, among which was the well known plant in Lyckebo, which was supposed to be extended to 20 000 m². Further developments followed these first attempts, with large module collectors being designed as well as block heating plants with roof-integrated solar collectors combined with wood blocks and pellet boilers. However, the Lyckebo plant was never increased and the investment to fund the project was denied. Thus the development of large-scale plants was more or less abandoned. In the end,

Geoenergy and Geostrata HB

[34] Karlsson, Fredrik et al. 2003. “Heat Pump Systems in Sweden.” *Country Report for IEA HPP Annex 28*

[35] Gehlin, Signhild and Andersson, Olof. 2016. “Geothermal Energy Use, Country Update for Sweden.” *Swedish Center of Geoenergy and Geostrata HB*

large-scale solar systems have been and are well developed, but there is a lack of interest among businesses and thermal services. The major reason for this outcome is the decline in the governmental interest for solar energy, a lack of subsidies and the development, at the same time, of other existing alternatives which have lower prices. The current use of solar systems is limited to single-family buildings and there is an increased interest in developing combined solar and wood pellet systems to offer complete alternatives for single-family households[36].

2.2.2 Financial Support

The Government offers public funds for certain types of renewable technologies, to which local councils, businesses and private actors can apply. These programmes are meant to address people's attention towards sustainable decisions, such as changing to district heating or using biofuels[37]. Since 2009, for example, there is a Government aid available for the installation of photovoltaic cells. The support is possible for the installation of all types of photovoltaic systems connected to the grid, as well as hybrid photovoltaic and solar heating systems. However, this assistance is framework-limited, meaning that it can only be granted as long as the funds are available and sufficient. From 1 January 2015, the government has also made it possible for all those who produce a small quantity of renewable electricity, to receive a tax reduction[38]. Finally, Sweden offers funding programmes for research in more efficient renewable energy technologies, such as hydropower, wind power, different types of solar cells, biofuel production and renewable energy gases[39].

2.2.3 Policies

(a) Climate and Energy Policy

Sweden's Climate and Energy Policy is regulated by two government Bills (2008/09:162 and 163) which were approved by the Swedish Parliament in 2009. The policy sets out determined goals for the attainment of the 20/20/20 objectives of the EU: the short and medium-term targets include a 40% reduction in greenhouse gases (GHGs) or about 20 million tonnes of equivalent carbon dioxide, compared to 1990, to be accomplished outside the European Union Emissions Trading Scheme (EU ETS); a minimum of 50% share of renewable energy in the total final energy consumption; a minimum 10% share of renewable energy in the

[36] Dalenbäck, Jan-Olof. 2005. "Solar Heating: Swedish Experience." *Department of Energy and Environment, Chalmers University of Technology*
[37] Sweden's Official Website. 2016. "Sweden tackles climate change."
[38] Swedish Energy Agency. 2015. "Energy in Sweden 2015."
[39] Ecologic Institute and eclareon. 2014. "Assessment of climate change policies in the context of the European Semester." *Country Report: Sweden*

transport sector and a 20% more efficient use of energy compared to 2008. The targets for the long-run consist of eliminating fossil fuels in heating by 2020; having a number of vehicles that is independent of fossil fuels by 2030; adding a third pillar in electricity supply, along with hydropower and nuclear power; increasing the coordinated generation of power; increasing the development of wind power and other renewables in order to enhance the security of the energy supply; and ensure that Sweden will have a sustainable and resource efficient energy supply with zero net emissions of GHG by 2050. Under the Climate and Energy Policy bill, Sweden has endorsed a five-year energy efficiency programme, for the period 2010-2014, with a total SEK 1350 million or SEK 270 million per year. This programme aims to reinforce regional and local energy actions, support green acquisition by the public sector, and to encourage small and medium sized businesses to manage their energy consumption and technologies in an efficient way. Furthermore, Sweden also wholly included the impacts of climate change adaptation into the climate and energy policy framework[40].

(b) The Green Certificate System

The green certificate system was introduced in 2003 in order to support the investment in renewable power plants, which would lead to an increase in the production of electricity from renewable energy sources[41]. It is aimed for industries which produce electricity from renewable energy sources and which receive a certificate back. These certificates are then sold in a market where prices are determined by supply and demand, which allows the producers to receive a further income in addition to the price of the energy. The demand for electricity certificates increases because energy suppliers and certain customers are obliged by law to buy a number of electricity certificates corresponding to a certain proportion of their electricity consumption. Sweden and Norway have a common market for electricity certificates since 1 January 2012, which is based on the Swedish one, in existence since 2003. The goal of both countries is to increase the production of renewable energy by a total of 28.4 TWh from 2012 to the end of 2020. There is no fixed target for each specific year, but by looking at the actual development in relation to the future goals, a prediction can be made of how much new production must be achieved by 2020. In Sweden there is an increasing number of electricity certificates that is being issued thanks to the expansion of wind power. In 2015, for instance, wind power produced on average 113% of the annual production and 15.6 million certificates were issued to wind power producers[42].

[40]International Energy Agency. 2013. “Energy Policies of IEA Countries: Sweden” *pp. 28-40*

[41] Bayar, Tildy. 2013“Sweden's Bioenergy Success Story.” *Renewable Energy World*; Teir, Sebastian et al. 2010. “Potential for carbon capture and storage (CCS) in the Nordic region.” *Research Notes 1556*

[42] Norwegian Water Resources and Energy Directorate (NVE) and the Swedish Energy Agency. 2015. “The Norwegian-Swedish Electricity Certificate Market.” *Annual Report*

(c) The Swedish Environmental Code

The Environmental Code, which entered into force on 1 January 1999, is the first body of environmental legislation that has been enacted in Sweden and it aims to provide a better coordinated, broader and more detailed environmental legislation for sustainable development[43]. It is concerned with the administration of land and water, the conservation of nature, the protection of plant and animal species, dangerous activities for the environment and health, water application, genetic engineering and chemical products and waste. The Environmental Code is a framework law, which means that its rules do not define limit values for the various operations but they are made more explicit by regulations ordered by central government agencies such as the Swedish Environmental Agency and the National Chemicals Inspectorate[44]. The code applies to anyone – citizens, economic agents, housing and public sectors – who commits acts that are potentially damaging to human health and the environment, who contaminates the natural and cultural environment or depletes its biodiversity. The main aim of the Code is to promote a sustainable development that will ensure a healthy environment for future generations. The most important general rules that are covered in the SEC are the "burden of proof principle", the "precautionary principle", the "polluters pay principle" and the "principle of application of the best possible technology". The first one states that operators must ensure that their actions do not endanger the environment and that they follow the guidelines established by the SEC, while the second, which is the fundamental rule of consideration in the Code, means that if there is only a remote risk of damage there is an obligation to take all the necessary measures to prevent causing a further deterioration to somebody's health or to the environment. The "polluters pay principle" states that the person who causes an environmental impact must pay for the preventive or remedial measures that must be taken to comply with the general rules of consideration. Finally, the "best possible technology" is a term that is used for professional operations and which applies to the technology used for both the operation itself and for the construction, operation and deactivation of the plant[45].

2.3 Decarbonization of Other Energy Sources

2.3.1 Emissions Regulations: The European Union Emissions Trading Scheme

The main general policy instruments to tackle climate change are energy and carbon dioxide taxes, emissions trading and green electricity certificates[46]. Emissions trading means releasing allowances or permits to emit a certain quantity of greenhouse gases over a certain period of time[47]. The main climate policy that affects the

[43] Rudberg, Peter M. 2013."Sweden's Evolving Hydropower Sector: Renovation, Restoration and Concession Change." *Stockholm Environment Institute, Project Report 2013-01*

[44] Environmental Code Education Commission. 1999. "The Swedish Environmental Code: A résumé of the text of the Code and related Ordinances."

[45] Environmental Code Education Commission. 1999; Rudberg, Peter M. 2013.

[46] Teir, Sebastian et al. 2010."Potential for carbon capture and storage (CCS) in the Nordic region." *Research Notes 1556*

[47] Owen, Anthony D. and Hanley, Nick. 2004. "The Economics of Climate Change." *Routledge, London and New York, Chapter*

industry in Sweden is the European Union Emissions Trading Scheme (EU ETS), which puts a restriction on emissions for the EU industry and power sectors[48]. This system was introduced by the EU to reach its present and future objectives of reducing greenhouse gases emissions and it places a cap on the maximum amount of emissions and permits to the trading of EU emission allowances. The cap makes sure that emissions are kept under control and at the same time companies receive or buy emission allowances which they can trade with one another as needed[49]**.** Since its introduction in 2005, the price for emission rights have risen up to 30 EUR/tonCO2 before the financial crisis and has since then been stable at around 6 to 10 EUR/tonCO2. The problem right now is that the cap in the EU ETS system is regulated until 2025 with an objective of -1,74% a year that doesn't match the EU target by 2050, which is of -85%. The price of the system does not represent the costs of a decarbonization strategy that is intended for the long-run. The EU ETS targets the biggest corporations within countries, such as the pulp and paper industries, iron and steel industries, non-metallic mineral products industry and the alluminium one. Furthermore, all the combustion factories that produce a power greater than 20MW are included in the policy, independently of which industry they belong to[50].

2.3.2 Carbon Capture and Storage

Sweden is thinking about introducing carbon capture and storage (CCS) systems both at a national level and in cooperation with the other Nordic and Baltic countries. For this reason, it is actively participating in international technology research on CCS in collaboration with other countries[51].

The carbon capture and storage (CCS) of emitted CO2 is seen as the best technique to reduce emissions in the long-run. These systems are currently operating in industrial applications like gas desulphurization and they capture between 85 and 90% of the CO2 in diluted gases[52]. CCS technologies work really well in decreasing CO2 emissions from combustion but they also increase the production costs for power and require more fuel to supply the necessary energy for the capture procedure. The process works by trapping the CO2 that is contained in a gas pipe and it usually does this through absorption by either using a solvent or an agent with a strong connection to the CO2. In order to use it again in a recurrent manner, the CO2 must be removed while the agent recovers its connecting capacity. The separation work is very difficult and it

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6: p. 115

[48] Åhman, Max et al. 2012. "Decarbonising industry in Sweden - an assessment of possibilities and policy needs." *Lund University , Department of Technology and Society. Report No. 77*

[49] Bagchi, Chandreyee and Velten, Eike Karola. 2017."The EU Emissions Trading System: an Introduction." *Climate Policy Info Hub*

[50] Swedish Energy Agency. 2015. "Energy in Sweden 2015."

[51]International Energy Agency. 2013. "Energy Policies of IEA Countries: Sweden."

[52] Åhman, Max et al. 2012. "Decarbonising industry in Sweden - an assessment of possibilities and policy needs." *Lund University, Department of Technology and Society. Report No. 77*

depends on the concentration of carbon dioxide in the gas: the lower it is, the harder it is to separate it. In order to create CCS for power plants, three technological methods are being developed: the first is post-combustion capture, the second pre-combustion capture, and the third oxy-fuel combustion capture. The intermediate step is the transportation of the carbon dioxide that has been captured from a power plant to a storage site. CO2 is usually transported by pipelines, but it can also be stored in tankers which are being carried by ship or rail (if the CO2 is liquefied). At the end of the CCS chain, carbon dioxide must be stored safely for a long time. Nowadays, the only way that has proved efficient is the storage of CO2 in underground geological formations, which are located either onshore or offshore around the globe and have specific characteristics that make it possible for the CO2 to be trapped underground. To minimize the risks of CO2 leakage, the reservoir needs to be monitored for a long period of time. However, until policies and regulatory frameworks are established and introduced among leading nations, it will be unlikely that CCS will be utilized as a compulsory measure[53].

2.3.3 Carbon Tax

A carbon tax is a tax imposed on the total amount of greenhouse gases emitted. If, for example, a tax rate of 50 Cents per tonne of carbon emitted is imposed, and a company emits 40 tonnes of carbon per year, then the annual carbon tax that the company has to pay will amount to 200 Euros. These types of taxes are usually limited to CO2 emissions, but they can also be applied to other kinds of greenhouse gases such as methane or nitrous oxide[54]. In addition to the EU ETS, energy and carbon taxes are the most effective policy measures in the industrial and transport sector. They gradually increase the taxes on electricity and fossil fuels, making the cost of oil rise rapidly. The industries that are already subject to the EU ETS are exempted from the carbon dioxide tax, while for those industries who are not subject to the EU ETS the carbon tax has been increased so that they pay 60% of the general carbon dioxide tax[55]. The carbon tax is one of the instruments that lead the way to the large increase in the use of biofuels in Sweden. Introduced in 1991, it has been applied to the industry sector, the service sector and to private households. This tax has increased the cost of fossil fuels and it has made renewables more competitive. Over the years the tax was increased to the point where the price of heating oil doubled, making it unprofitable and eliminating it from the heating market in both industrial plants and home boilers. During the 1970s heating oil had made up 90% of the fuel in district heating plants, while by 2010 it was only 2% of the total fuel use. In the 1990s heat and power plants received investment grants to use biomass in the production of electricity, and in 2010 biomass

[53] Teir, Sebastian et al. 2010. “Potential for carbon capture and storage (CCS) in the Nordic region.” *Research Notes 1556*

[54] Owen, Anthony D. and Hanley, Nick. (2004) “The Economics of Climate Change.” *Routledge, London and New York, Chapter 6: p. 115*

[55] Swedish Energy Agency. 2015. “Energy in Sweden 2015.”

constituted 70% of district heating fuel[56]. The carbon tax has helped to reduce the dependency of the country from fossil fuels and it is considered one of the cheapest ways to reduce CO2 emissions[57]. The transport sector, which is Sweden's largest source of CO2 emissions, is fully covered by the carbon tax while other sectors, such as the mining and the pulp and paper industries, are exempted from it. Efforts to determine the effectiveness of existing carbon taxes have been limited, but there have been a number of studies which evaluated carbon emissions levels in countries that instituted taxes in the early 1990s which show an overall reduction in greenhouse gases, with some as high as 15%[58].

2.4 Decarbonization of the Transportation Sector

2.4.1 Support for Purchase

A major improvement in the transportation sector has been the change, in January 2013, of the definition of environmentally-friendly cars: such vehicles must not emit more than a determined amount of carbon dioxide in relation to the vehicle's kerb weight. However, vehicles that are powered by ethanol and CNG are allowed to emit up to 150 grams of carbon dioxide since the fuel has a renewable origin. The definition now also includes camper vans, light trucks and minibuses. Since 2012, those who decide to buy “super green cars” can also apply for a bonus of maximum SEK 40,000 per car. In 2015, this amount was increased to SEK 215 million and it has been raised further during the following years. In addition to this, the government has been working on a “bonus malus system” for light vehicles, which ensures that customers who choose cars with low carbon emissions receive some sort of bonus, while vehicles with high emissions of carbon dioxide need to pay a higher tax[59]. The majority of Swedish cars used to be powered by high-blend biofuels like E85, which can contain up to 85% of ethanol and biogas, while most cities used to possess ethanol buses[60]. In 2014 there was an increase in the sales of electric cars and cars that use CNG14 and this porobably determined the decrease in the purchase of cars which run on E85[61]. The biofuels that are currently available on the market are ethanol, biogas and biodiesel. Between 2012 and 2013, the use of biofuels has increased by 21%, constituting the largest increase ever experienced[62]. This success is due to the fact that Sweden promotes an efficient fuel use and the use of vehicles which are powered by renewable energies and new technologies, such as electric vehicles and plug-in hybrids. The country also gives a number of tax incentives for the use of biogas, ethanol, hydrogenated vegetable oils (HVO) and biodiesel.

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[56] Bayar, Tildy. 2013. “Sweden's Bioenergy Success Story.” *Renewable Energy World*

[57] Sweden's Official Website. 2016. “Sweden tackles climate change.”

[58] Andersson, Julius. 2015.“Cars, carbon taxes and CO2 emissions.” *Centre for Climate Change Economics and Policy, Working Paper No. 238 - Grantham Research Institute on Climate Change and the Environment, Working Paper No. 212*

[59] Swedish Energy Agency. 2015. “Energy in Sweden 2015.”

[60] Bayar, Tildy. 2013. “Sweden's Bioenergy Success Story.” *Renewable Energy World.*

[61] Swedish Energy Agency. 2015. “Energy in Sweden 2015.”

[62] *Ibid.*

High mixtures, like E85, ED95 and biodiesel receive a full tax exemption. However, the condition is that the only biofuels which have a right to obtain state aid are those that conform to the sustainability criteria established under the Renewable Energy Directive 1009/28/EC[63].

2.4.2 R&D on Technology

In October 2012 the government has introduced the Research and Innovation Bill (2012/13:30), which provides funding for research and innovation projects, such as energy research, demonstration and deployment (RD&D). The RD&D funding has been increased from EUR 100 million per year to circa EUR 155 million annually by 2016[64]. Moreover, Vattenfall – Sweden's largest electricity company – has dedicated a lot of effort to Research and Development projects for both the short and the long term. The company counts about 130 full-time employees in its R&D sector and it places particular attention on the development of new technologies and resolutions in order to carry out its strategy and implement customer value. Vattenfall's e-mobility sector is focused primarily on making it advantageous and cheap to charge electric vehicles, independently of whether these are private cars, city buses or cargo trucks. The company has developed various innovative techniques like inductive charging and smart charging. The first permits a parked vehicle to recharge automatically without the necessity of plugging in a cable while the second, to be used in households, makes sure that the vehicle stops charging if the electricity is needed for cooking, washing or heating, restarting it automatically when the domestic burdens decrease. A further thrilling project is currently being tested in Rosersberg, Sweden, regarding the construction of electric roads which allow cargo tracks to charge as they drive. Projects like these will make it easier to adopt electric vehicles in the future and they will make the shift to a sustainable electrified transportation system quicker[65].

2.5 Findings

Since 2008, when there has been the last detailed review from the International Energy Agency, Sweden has achieved a meaningful progress towards the achievement of a more sustainable and efficient energy supply. This has been obtained thanks to the country's effort to support energy research, development and demonstration (RD&D), usually in cooperation with other European countries or with the rest of the world. Following the 2008 IEA recommendation, Sweden has adopted in 2009 a new climate and energy policy which aimed to pursue a sustainable environment, competitiveness and a long-term enactment. Looking to future improvements, the country has also decided to eliminate all fossil fuels by 2020, ensure that vehicles would be fossil fuel-free by 2030 and that by 2050 energy supply would be sustainable and efficient, with a zero emission of greenhouse gases in the atmosphere. Sweden has already made a significant progress in this

[63] International Energy Agency. 2013. “Energy Policies of IEA Countries: Sweden.”
[64] *Ibid.*
[65] Vattenfall. 2017. “Research and Development.”

direction and may exceed the targets that it has conceived for itself[66].

2.5.1 CO2 Emissions

Sweden is one of the few industrialized countries which have managed to achieve economic growth while at the same time decreasing GHG emissions, which are among the lowest in the EU and OECD countries[67]. Before 1970, when the country was rapidly industrializing, carbon emissions were growing exponentially. However, in the early 1970s they suddenly stopped, thanks to a series of energy policies that Sweden put into action following the oil shocks of that time. This was done as a matter of national security rather than for environmental reasons, but the country still managed to achieve highly successful results, since from that moment on its emissions have been steadily declining[68]. According to the Ecologic Institute Report, the emissions in Sweden between 2005 and 2011 have fallen by 10% and the latest projections show that they could further decrease by 19% by 2020. In 2011, Sweden emitted 61.4 Mt CO2 with one third of these being generated by the transportation sector. The latter has started to decrease emissions following the growth in the use of biofuels, higher fuel prices, and the use of more energy efficient cars. Emissions coming from energy supply and use have also declined between 1990 and 2011, mainly because the country decided to switch from fossil fuels to biomass in district heating. In 2014, in fact, more than 60% of Sweden's district heating was supplied by biofuels such as wood pellets[69]. Nowadays, Swedish per capita emissions are about as low as they were in the 1950s[70].

2.5.2 Renewable Energy Supply

In 1990, renewable energy sources constituted only 33% of the total final consumption of energy, while by 2011 this amount had increased to 48%. The heating and cooling sector in Sweden has a high share of renewable energies, which account for 65%, and this is mainly thanks to the use of solid biofuels and the prevalence of heatpumps in district heating. A similar scenario emerges from the almost carbon-free electricity sector, where hydropower and nuclear energy constitute the majority of production, while biofuels and onshore wind power have rapidly expanded in recent years. Among IEA members, Sweden has the second-highest share of biofuels and waste, while in the transportation sector it has reached a share of renewable energy sources which amounts to 9.8%[71]. In 2011 Sweden was the country which gave the highest contribution in total energy consumption in the EU, thanks to its large use of biomass for heating and its

[66] Vattenfall. 2017. "Research and Development."
[67] Sweden's Official Website. 2016. "Sweden tackles climate change."
[68] Pierrehumbert, Raymond. 2016. "How to decarbonize? Look to Sweden". *Bulletin of the Atomic Scientists, 72:2, 105-111*
[69] Ecologic Institute and eclareon. 2014. "Assessment of climate change policies in the context of the European Semester." *Country Report: Sweden*
[70] Pierrehumbert, Raymond. 2016. "How to decarbonize? Look to Sweden". *Bulletin of the Atomic Scientists, 72:2, 105-111*
[71] International Energy Agency. 2013. "Energy Policies of IEA Countries: Sweden."

hydroelectric power, which accounts for one third of the total energy consumption[72]. The Swedish Energy Agency's projections show that energy supply from biofuels and waste will steadily increase from 22.7% in 2011 to circa 25.3% in 2030. After 2030, most of the growth is expected to derive from wind power[73].

2.5.3 Impacts on the Economy

After assessing the success of Sweden in accomplishing decarbonization, the question of whether it negatively affects the economy arises. The answer is that it doesn't. On the contrary, Swedish per capita gross national income (GNI) has doubled since 1970, with growth being interrupted only by the global financial crisis that has affected other countries as well. It is likely that climate policies have had a positive effect on the economy of the country thanks to their reduction of the costs of energy imports, the provision of employment and the incrementation of exportable technologies. Independently of the question of what the Swedish economy would have been like without these policies, the matter of fact is that a country can grow its economy, ensure that its citizens have high living standards and at the same time considerably reduce its carbon emissions[74].

2.5.4 Challenges

Despite being the leading country in sustainability, Sweden still faces a series of challenges related to energy, the decarbonization of the transportation sector and the environment. Sweden has a strong and well-developed grid at both the transmission and the distribution levels, but as wind capacity increases there may be a future requirement to increase alternative transmission ways. The main problem facing the country's electricity system is thought to be the elimination of their four short-term nuclear reactors and the extra six long-term ones. Many people believe that when the final six nuclear plants are going to be shut down in the early 2030s, the future of the Swedish electricity system will be very uncertain. In addition to this, with respect to the transportation sector, the two main barriers to the development of electric cars are believed to be price and charging infrastructures. Although the first problem has been more or less solved thanks to the government's numerous incentives, the second one is still predominant. In fact, the “daily” charging is considered as the greatest barrier towards the purchasing of these types of vehicles, since installing charging facilities in homes, working places and apartments is complicated[75]. However, if the R&D projects are continued and improved, it is likely that these obstacles will be removed alltogether. Finally, the environment-related issues that Sweden faced in the past have mostly been resolved, but new ones have

[72] Ecologic Institute and eclareon. 2014. “Assessment of climate change policies in the context of the European Semester.” *Country Report: Sweden*

[73] International Energy Agency. 2013. “Energy Policies of IEA Countries: Sweden.”

[74] *Ibid.*

[75] Noel, Lance et al. 2016 “The status and challenges of electric vehicles in Sweden – 2016.” *Aarhus University, School of Business and Social Sciences, Department of Business Development and Technology*

arised since the mid-1980s, such as the depletion of the ozone layer, pollution, the conservation of biodiversity, eutrophication of waters and climate change. By now, improvements in pollution and the acidification of lakes and rivers have been achieved, but the country still needs to achieve the reduction of phosphorus levels in its lakes and of nitrogen in the sea, solve the eutrophication problem and protect biodiversity. The Baltic Sea, which is shared by Sweden and eight other countries, is threatened by the risk of eutrophication and the depletion of oxygen. Regarding forests, a lot of effort has been put into the protection of biodiversity but it is still not clear whether these efforts have been completely effective. The decline in biodiversity is mainly caused by pollution, intensive agriculture, forestry and fisheries, and also by hydroelectric projects. Despite its environmental legislations, the introduction of a carbon tax and the development of renewable energies, there are a few reasons why the conditions of Sweden's environment has not improved as quickly as everybody hoped. The first is that nature takes a while to readjust and respond to external changes. The second is that the Swedish environment is also largely affected by transboundary pollution. This means that the country's environmental quality can be achieved only if other countries do more to reduce pollution and protect the environment[76]. Moreover, while greenhouse gases emissions in Sweden have decreased, emissions in other countries have increased as a result of Swedish consumption. To solve these problems there needs to be an increase in international cooperation. For instance, introducing new international policy instruments, common EU policies, initiatives in other policy areas apart from environmental policy, implementation of legislation, partnership, and the backing of public agencies' for environmental action could bring about a positive change[77].

[76] Lundgren, Lars J. and Swedish Environmental Protection Agency. (2011) “Sweden's Environment Problems and Protection 1960-2010.” *CM Gruppen, Stockholm*

[77] European Environment Agency. 2015. “Sweden.”

CHAPTER THREE

CHINA

3.1 Introduction

China, with a population of 1.3 billion, is the world's most populous country and second largest economy. However, it still remains a developing country since its income per capita is lower than that of developed countries and its market reforms are incomplete. As a consequence of its economic development, the country is now facing serious challenges, such as high inequality, rapid urbanization and threats to environmental sustainability. In addition, China also faces problems regarding the aging of its population and the internal migration of labor force[78]. Due to its rapid economic growth, China's carbon emissions per capita have almost quadrupled since 1990. In 2007 the country surpassed the US as the world's largest carbon dioxide emitter, and since 2013 it has been held accountable for about 27% of the world's GHG emissions. China's government remains focused on economic growth rather than addressing climate change, and this is mainly because the country still needs to alleviate poverty and generate sufficient revenue to cover the costs of social and public security, education, medical care, environmental protection, and rural and urban infrastructure. Poor air quality constitutes a further reason for social rebellion and a threat to political stability, since it has been causing millions of deaths every year as well as being responsible for great environmental damage[79]. Until not long ago the country's situation seemed helpless, but luckily, it has recently started to change. Today, China invests more each year in wind, hydro and solar power than any other country on earth[80].

3.2 Promotion of Renewable Energies

3.2.1 Types of Renewable Energies and Target Setting

(a) Solar energy

The solar sector in China is rapidly expanding, and in fact the country had circa 3 GW of installed solar capacity by the end of 2011[81]. The Asian nation has recently underlined its role as the global leader in renewable energy by inaugurating the world's largest floating solar power plant. The project is located in the city of Huainan, in China's eastern Anhui province and it has a capacity of 40 megawatts (MW). Floating solar power plants have been utilized for a little more than ten years and they have several advantages, such as saving useful space on land and providing a cooling effect thanks to the water on which they float, increasing their efficiency. They can also help to slow the evaporation of water for drinking or irrigation

[78]The World Bank. 2017.
[79]Teng, Fei et al. 2015. "Pathways to deep decarbonization in China" *SDSN - IDDRI*
[80]Brandon, Simon. 2017. "China just switched on the world's largest floating solar power plant." *World Economic Forum*
[81]Worldview Report. 2012. "Geothermal Potential of China." *pp. 1-13*

purposes, by stopping sunlight before it hits the reservoir's surface[82]. Solar photovoltaic, in which solar light is converted into electricity thanks to a particular material made principally of silicon, is the major technology in the world. Thanks to the great demand coming from the market, China's photovoltaic industry has rapidly developed in the past years. In 2008 the country became the largest producer of solar panels in the world, with its biggest exports addressing Europe and the US. At the beginning China's domestic use of PV was very low, due to a lack of incentives from the state but starting from 2009 the government began to provide subsidies for the installation of PV, having recognized the need of the country to reduce its dependency on foreign markets. In response to these subsidies, China's PV market has experienced a constant growth, its share in the world market reaching 4.95% in 2011[83]. In August 2013, the Chinese government introduced new tariffs to increase the growth in the distribution of solar rooftop installations and provinces and cities all over China provided additional subsidies to complement the state ones. The government now grants subsidies that last for 20 years for a specific amount of kilowatts produced by various photovoltaic businesses and the owners of these projects receive a certain amount of money for any power surplus they might generate[84]. Solar photovoltaic power in China is used specifically in five sectors. The off grid solar PV are used in remote and rural areas for telecommunications, metereology, transportation, lights, chargers and other products. In addition, there are on-grid building solar PV which are made up by integrated solar PV and building attached PV, and large-scale solar PV. Before 2008 the offgrid solar panels were the most common types in the market, since they provided a cheap and sustainable way of delivering energy to remote and rural households. However, thanks to financial aids distributed by the government, on-grid solar PV has began to develop rapidly, reaching 99.2% in 2011. There are several advantages connected to the implementation of solar panels, such as the fact that they can be developed anywhere, on land or on buildings, they are modular, they can be installed close to the places where they are needed and their cost in the near future will probably equal that of fuels. Furthermore, China has perfect conditions for the development of solar panels, because its land is rich of solar energy, it has become one of the major solar PV manufacturers, and the government has finally understood the importance of making a good use of solar power in the country[85].

(b) Wind power

At the end of 2010 China surpassed Germany and the US by becoming the world's biggest wind power

[82]Brandon, Simon. 2017. "China just switched on the world's largest floating solar power plant." *World Economic Forum*

[83]Zhang and He. 2013. "Analysis on the development and policy of solar PV power in China." *Renewable and Sustainable Energy reviews 21: 393-401*

[84] RE100. 2015. "China's fast track to a renewable future."

[85]Zhang and He. 2013. "Analysis on the development and policy of solar PV power in China." *Renewable and Sustainable Energy reviews 21: 393-401*

capacity producer. The country's installed wind quantity increased from 28 MW in 1996 to 42 GW in 2010[86]. The metereological conditions in China are favourable for producing wind energy, especially in the northern part of the country and the eastern coastal areas. The first on-shore wind farm was constructed in 1988, with the funding coming from the Danish government. However, despite foreign investment the industry's development was pretty slow until the early 2000s. From 2004 on, following a series of policies that promoted them, investments have started to increase. The majority of wind power in the country comes from nine provinces in the North, which have constituted 86% of national capacity in 2008. The nine provinces have structural differences and can be divided into two sub-groups: the first comprises the inland provinces of Inner Mongolia, Liaoning, Hebei, Jiling, Heilongjiang, Gansu and the autonomous region of Xinjang Uygur, while the other consists of Jiangsu and Shandong. The first group is the one which represents the development of on-shore wind power in China, while the second group represents the potential of the off-shore one. The majority of the investments are still directed towards on-shore projects, since the off-shore ones are more costly and complex. In the past years wind power has grown from a small sector to a well established source of electricity in many countries, but its percentage of wind power to total electricity production in 2008 was still low in China when compared to other countries such as Germany, Spain and Denmark. One of the reasons for this are the issues that are still faced by the industry, such as high costs, transmission problems and the manufacturing of the equipment[87].

(c) Hydropower

China is the country with the highest installed hydropower capacity in the world and, according to the National Energy Administration (NEA), its aim is to attain 380 GW by 2020 which would mean increasing production by 16.5% on average each year[88]. Hydropower is a clean and renewable energy source, and it is the only type that can be expanded to a great extent for commercial purposes. Its main positive aspects are that it uses water, which doesn't risk being depleted during the production process, it doesn't pollute the air or produce toxic waste, and it is the most efficient way to produce electricity. China has a large quantity of rivers, more than 50.000 of which cover an area of over 100km² and the southwestern part of the country is the one that has the best potential for hydropower development. The first hydropower station was built in 1912 in Shilongba, but it was only after 1949 that the industry started to develop rapidly. In 2005 the capacity and generation of hydropower in China ranked first in the world, and the country shared 13.3% of the world's hydro production. However, hydropower constitutes only a small share in the state's total electricity production. Til 2005 the country had 21 big hydropower plants in action, which had energy production as their primary purpose and irrigation and flood protection as their secondary one. Taking into

[86]Worldview Report. 2012. “Geothermal Potential of China.” *pp. 1-13*
[87]Liu and Kokko. 2010. “Wind power in China: Policy and Development Challenges.” *Energy Policy 38: 5520-5529*
[88]Worldview Report. 2012. “Geothermal Potential of China.” *pp. 1-13*

consideration hydropower resources, construction costs and other factors, China has started to develop additional bases on the Yellow River, the Hongshuihe River, the Yangtze River and the Wujiang River. Along with the big plants, China has began to develop small hydropower ones (which have a capacity of less than 50 MW) which generated, by the end of 2005, almost 32.9% of total hydropower generation capacity that year. In 1994, the country began building the biggest hydropower project in the world, the "Three Gorges Project", which is its greatest success in developing the Yangtze River. The plant is composed of three parts: the main project, which includes the dam, the powerhouses of the hydropower plant, the ship lock and the ship lift, the reservoir project and the transmission project[89]. Even though it has contributed to reduce carbon emissions from 2003 to 2010 by 406.7 million tons, there are several serious problems connected to its construction. These include the flooding of archaelogical and cultural sites, the displacement of 1.3 million people and other ecological changes, such as increased risks of landslides, affected water quality, riverbed and soil erosion, and the reduction of the four major domestic fish species. The situation can be changed only if China is willing to make policy changes and invest in environmental programs to eliminate, or at least reduce, the environmental consequences in the regions affected by the project[90].

(d) Biomass

Biomass is an important energy source in China and in the past it used to be utilized especially in rural areas. In the year 2000 it accounted for 13% of primary energy consumption in the country. However, the combustion of woods and other agricultural leftovers used for cooking and heating in rural areas has negative aspects, especially regarding health. The burning systems that are being used create indoor air pollution, which affects especially women and children. Certain studies have demonstrated that 13 to 22% of all the deaths related to pulmonary diseases, lung cancer, pulmonary heart diseases and pneumonia are caused by it. Another negative aspect is that the task of collecting biomass fuels, which requires a great amount of time, is usually carried out by women and children making it harder for them to spend their time doing something more productive like going to school or working. In addition to indoor pollution, biomass fuel has the greatest impact on air pollution in general due to the open-field burning of crop leftovers during harvest time. In the past these residues were used for heating, cooking or other activities, but recently farmers have started to burn them in the fields, creating extreme pollution problems. Despite all these negative aspects, the benefits that the use of biomass brings are many. For instance, its utilization in rural areas could increase living standards and promote industrialization, while at the same time generating employment. Moreover, since the sustainable use of biomass doesn't generate CO2 emissions, there would

[89]Huang and Yan. 2009. "Present situation and future prospect of hydropower in China." *Renewable and Sustainable Energy Reviews, 13: 1652-1656*

[90]Xu, Xibao et al. 2013. "Environmental impact assessments of the Three Gorges Project in China: issues and interventions", *Earth-Science Reviews, 124:115-125.*

also be climate benefits arising from its use. The main resources that are used for biomass in China are residues from agricultural and forest industries, animal waste from livestock farms and municipal solid waste[91]. Since the country's energy mix today is still mainly dominated by coal, the government has decided to increase its efforts in achieving a more sustainable energy. According to the "2016-2020 biomass energy development plan", biomass energy will be more marketed and industrialized by 2020. China already produces a great amount of biomass, equal to almost 460 million tons of coal annually, but the majority of it is not exploited because of the lack of proper technologies. The government is currently encouraging the use of non-fossil energies, such as biomass, to contribute to its economy in a cleaner and more efficient way and it aims to increase the use of non-fossil energy in the energy mix from 11% to 20% by 2030[92].

(e) Geothermal Energy

China's geothermal power has not received the same attention or expansion as other renewable energy sources, such as hydro and wind. The country is rich of geothermal resources and it is the world's leader in their global usage. Most of China's geothermal power is used as direct heat because of the low temperature of the source. Resources with high temperature are located in the regions of Tibet and Yunnan, which are the areas with the greatest capacity for the production of geothermal power. China began developing geothermal energy in the 1970s during the global oil crisis. Nine small hydrothermal plants were installed in the country, but their inefficiency and lower temperatures brought to the closure of seven of them. In 1977 a high temperature hydrothermal plant was build in Yangbajing, Tibet, close to the Tibetan capital Lhasa. Between the years 1977 and 1991, 25MW of capacity was installed in Tibet, producing roughly 88% of China's total geothermal power production capability. Since then, there haven't been major improvements in geothermal power development in the country, apart from the expansion of medium and low source temperature geothermal resources. In fact, the country is the world leader in geothermal direct use in agriculture, spas and residential and commercial buildings. The Ground Source Heat Pump (GHP) industry has increased rapidly in China since its first establishment in the 1990s. Between the years 2004 and 2009, the installed capacity has increased from 383 to 5210, constituting an increment of 1263% . During the past 10 years the Ground Source Heat Pump industry has expanded to over 200 Chinese businesses. The potential of the country's geothermal resources is great, since its twelve major basins could produce up to 7 billion GWh of electricity. However, the country still faces major technological problems related to the development of geothermal energy, as well as a lack of knowledge of its resources, which makes it harder for the market to attract financing for further investment[93].

[91] Jingjing, Li et al. 2001. "Biomass energy in China and its potential." *Energy for Sustainable Development, Volume 5 No. 4: 66-68*

[92] China Daily. 2016."China to boost biomass energy development in 2016-2020."

[93] Worldview Report. 2012. "Geothermal Potential of China." *pp. 1-13*

3.2.2 Financial Support

Public funds for renewable energy development existed long before the introduction of the Renewable Energy Law, which is the country's first legislation encouraging the expansion of alternative energy sources. In 1999 the State Council established an innovation fund of 1 billion RMB for small and medium-sized businesses to finance renewable energy and energy effectiveness. About 1000 projects were financed from this fund, which consisted of grants and loans. Apart from this, some local Governments have also decided to support the expansion of alternative sources of energy such as the Inner Mongolia Autonomous Region, which has used income tax revenues to support the research and development of renewables. The NDRC published in 2006 "Guidelines for Using the Public Fund for Renewable Energy Development", which outlines three priorities. The first is to support the production of renewable electricity sources, such as wind, solar and ocean. The other two priorities are to research other alternative energy sources which could substitute oil and to support the use of renewables for buildings' heating and cooling systems. The public fund can be used in two ways. The first, as a grant and those who obtain it can use it to research and develop new renewable energies. The second way is to subsidize loan interests so projects which are eligible can obtain public funds to pay parts of the loan interests[94]. The only existing tax policy that encourages the production of renewable energy is the "Administrative Order No. 2001-198", issued by the Ministry of Finance (MOF) and the State Administration Taxation in December 2001, before the REL was put into place. This order implied that the value-added tax to use municipal solid waste to produce power would be first collected and then refunded. For instance, the tax rate for wind power was reduced from 17% to 8.5%. However, this taxation policy has not proved to be enough with regards to renewable electricity generation, since wind power capacity has not changed until the introduction of the Renewable Energy Law. Another measure is the reduction or exemption of customs duty to any imported machinery which produces renewable energy and to elements that are considered high-tech. In the 1980s and 1990s, the reduction or exemption of customs duties on the main parts of imported wind turbines, or the turbines themselves, and on photovoltaic pieces were all approved and this made sure that the duties paid were pretty low. However, the downside to this measure is that there is no official governmental report that imposes these duty benefits in detail, which means that they are conceded on a case-by-case basis. The subsequent problem is that, being there a great need to develop domestic wind technology, these customs duty benefits will probably disappear[95].

[94] Wang, Feng; Yin, Haitao and Li, Shoude. 2010."China's renewable energy policy : Commitments and challenges." *Energy Policy 38: 1872–1878*

[95] *Ibid.*

3.2.3 Policies

(a) Renewable Energy Law

The Renewable Energy Law, adopted on 28 February 2005 and enforced from 1 January 2006[96], represents the beginning of a new epoch regarding the promotion of renewable energies in China. This has not been the first program regarding renewable energies in the country, but it has been the major step ahead towards this direction. First of all it has created a national system for the development of alternative energies, targets for these energies in the market and a pricing mechanism, and secondly it has encouraged the construction of renewable energy power facilities. Article 2 of the REL defines alternative energies like hydropower, wind power, solar energy, geothermal energy and marine energy as acceptable, but does not do the same for nuclear power which has been developed following other laws. Article 4 declares renewable energy as the most important area for development, while Article 8 requires the National Development and Reform Commission (NDRC) to adopt a national plan concerning renewables and their goals, which calls for the development of more precise implementation plans by the local planning agencies. Article 14 makes it compulsory for China's electricity grid companies to buy all the electricity produced by approved renewable energy structures located in their areas of operation while article 19, which regards pricing, did not determine detailed criteria to establish grid purchase prices. Moreover, the Renewable Energy Law institutes a national fund to promote the production of renewable energies and provides tax incentives for renewable energy projects[97]. Article 24, for instance, determines a public fund financed by general tax revenues for the development of renewable energy[98]. In 2009 some amendments were made to the Renewable Energy Law. The three major ones were concerned with having more control over renewable energy projects at the national level, a requirement that the State Council and other governmental agencies promote a code to specify the right amount of electricity to be bought by grid companies and modifications to the national fund for research and development[99].

(b) *The 13th Five-Year Plan*

The 13th Five-Year Plan – to be implemented between the years 2016 and 2020 – follows the 11th and 12th Five-Year Plans and its main objective is to focus on China's "unbalanced, uncoordinated, and unsustainable growth". The Plan aims to readjust the economy by making it independent from exports and directing it

[96] Wang, Feng; Yin, Haitao and Li, Shoude. 2010."China's renewable energy policy : Commitments and challenges." *Energy Policy 38: 1872–1878*

[97] Eisen, Joel B. 2010. "China's Renewable Energy Law: A Platform for Green Leadership?" *Wm. & Mary Envtl. L. & Pol'y Rev. Vol. 35:1, pp: 25-26 and 31-32*

[98] Wang, Feng; Yin, Haitao and Li, Shoude. 2010."China's renewable energy policy : Commitments and challenges." *Energy Policy 38: 1872–1878*

[99] Eisen, Joel B. 2010. "China's Renewable Energy Law: A Platform for Green Leadership?" *Wm. & Mary Envtl. L. & Pol'y Rev. Vol. 35:1, pp: 25-26 and 31-32*

towards a type of growth that has a higher value and is led by consumption. Furthermore, it aims to increase the quality of life of China's population, through the implementation of environmental protection and social welfare programs. The last FYP contains 25 targets, among which 13 are binding, and it is the most eco-friendly plan so far, since 10 of the 25 main targets and 10 of the 13 binding ones are related to the environment. Apart from the 25 targets, the 13th FYP insists on the Chinese's government engagement to double China's 2010 GDP and the average disposable income level by 2021. The government's aim is to achieve a 6.5% average annual growth to obtain a "moderately prosperous society" by 2020. However, the FYP also focuses on "green growth", which means shifting towards a more sustainable economic model in order to alleviate the environmental degradation brought by the country's previous growth strategy. Official reports have found out that 20% of China's cultivable land and 33% of its surface water are polluted, while more than 80% of its underground water – which is used by farms, factories, and households – is too polluted to utilize or drink. In 2016 Premier Li declared that China would enforce strict environmental codes including a punishment method for wrongdoers and, in fact, the Chinese government has increased its efforts in enforcing environmental laws with the help of monitoring systems and inspections in 15 provinces. These inspections have brought to the closure of around 200 polluting factories and the punishment of more than 1,000 government officials and company chiefs. The main objectives of the plan regarding the environment include expanding monitoring and evaluation methods on a national level, setting energy and carbon emissions reductions, improving air, soil and water quality, and supporting domestic green businesses. Regarding this last point, the government plans to support the expansion of energy efficient and environmentally friendly industries until they become competitive firms worldwide. The two favorite types of companies are those that produce new energy vehicles and energy-saving technologies. Moreover, the country has established energy and carbon dioxide emissions reduction targets and an energy cap in order to obtain energy efficiency, lower emissions, and China's shift away from the heavy industry and towards the service sector[100].

(c) Environmental Protection Law

The Environmental Protection Law, approved on 24 April 2014, represents the latest progress in China's environmental legislation. It is the most strict environmental protection law in existence in China, and it has two main reasons for its implementation. The first is air pollution, which is an issue that has caused a large reaction among citizens regarding environmental protection. The other motive is that China's leaders have started paying more attention to environmental protection issues, making it easier to create new laws and shift away from the older, more rigid ones. To get more into detail, there have been three kinds of changes: the first regarding the legislative concept, the second the administrative mechanism and the third the legal

[100] Koleski, Katherine. 2017. "The 13th Five-Year Plan." *U.S – China Economic and Security Review Commission; pp: 3-22*

approaches. With respect to the first concept, the new law is considered as fundamental with regard to environmental protection, making it different compared to other laws. The new legislation is centered on the concepts of sustainable development, eco-friendly buildings and environmental protection. Its main principle is the "Priority of Environmental Protection", which requires that economic development and environmental protection are considered as coordinated and not as opposing concepts. Regarding the innovation of administrative mechanisms, the new law focuses on collective governance, meaning that the responsibility of protecting the environment should not only be assigned to the government but also to businesses and citizens. Moreover, citizens have the right to be informed, to participate and to supervise environmental issues. In this new law, there has been a further increase of the judiciary's power to imprison and fine wrongdoers. Concerning the innovation of legal approaches, existing elements have been modified and new ones have been added, such as the total quantity control of pollutants, the acceptance of pollutant payment, the prevention of district pollution and other important resolutions. In particular, the role of the government as responsible organ for environmental protection has been highlighted and from now on it will be supervised regularly. Environmental quality is of great importance to the public interest, so this revision is looking to be approved by all the society. The rights of public participation play a central role in the revised version of the law and opinions and suggestions are easier to be adopted than before[101].

3.3 Decarbonization of Other Energy Sources

3.3.1 Emissions Regulations: The Emissions Trading Scheme

China announced seven pilot ETS schemes in 2011. The country had previous experience with CDM (clean development mechanism) and this is why the biggest industries managed to influence the NDRC's decision regarding the establishment of the seven pilots and the subsequent formulation of the Chinese Certified Emissions Reductions (CCER) program. In the five cities and two provinces where the pilots have taken place, 57 million tonnes of carbon, prized US $308 million, were traded until 31 July 2015. The ETS were designed at the local level and as a result they each covered different sectors and had distinct thresholds. These pilots were in force during the 2013-2015 period, and they became part of a national ETS under the 13th Five-Year Plan. They all include financial penalties, which stretch from €1,500 to €7,000 per violation, for those who do not comply with them. For those who need to pay for violating the schemes, other penalties that are unique to China can be applied to them. The seven pilots have produced seven different carbon prices in the country, which have been fluctuating between €1.75 to €7 per tonne, rising to over €15 in the Shenzhen pilot. Between 2013 and 2014, there have been moments when the carbon prices in China's ETS pilots increased to higher levels than the EU ETS ones. The reasons for these price fluctuations are an over allocation of grants, policy mistrust held by ETS participants, lack of transparent market information and

[101] Mu, Zhilin; Bu, Shuchun and Xue, Bing. 2014. "Environmental Legislation in China: Achievements, Challenges and Trends." *Sustainability 6: 8967-8979*

concern over the transition to the national ETS. The national ETS now covers companies from eight different sectors and 18 sub-sectors, which consume the equivalent of more than 10,000 tonnes of coal per year. These sectors and sub-sectors include power generation, heat power generation and grid operators; petrochemicals; iron and steal; metals other than iron; building production and materials; pulp and paper; and aviation. The NDRC will be responsible with deciding the total amount of allowances to be given to each executive. Under the national ETS, companies can trade allowances that are not used in the open market on specific exchange platforms, which have been accepted by the government. The NDRC is expected to decide various markets for trading, and make information about trading publicly available. Furthermore, the NDRC will appoint verifiers and will make sure that the companies covered by the ETS will report their annual emissions to their local Development Reform Commissions[102].

3.3.2 Carbon Capture and Storage

CCS activity in China is currently focused on developing a series of small and independent demonstration projects to test the different characteristics of the technology, focusing in particular on pre-combustion (IGCC) opportunities. This has been developed by a cooperation between eight Chinese energy industries and a US business. They tried to develop and experiment a system that combined the different processes of coal gasification, hydrogen production, hydrogen power generation and CO2 detachment. The project, carried out in Tianjin, had three different phases with the final aim of constructing a 400 MW CCS demonstration plant to be operative by 2015. A further project has been developed, this time regarding post-combustion, in a collaboration with Australia under the Asia Pacific Partnership for Climate and Development. This partnership has resulted in the construction of a post-combustion research pilot plant at the Huaneng Beijing Cogeneration plant. The project was approved in 2008 and its aim is to capture about 3,000 tonnes of CO2 per year to be used in the soft drinks industry. Further partnerships have been developed between China and the European Union, like the COACH (COoperation Action within CCS China-EU), the NZEC (Near Zero Emissions Coal), Geo-Capacity and STRACO2 (Support to Regulatory Activities for Carbon Capture and Storage). For future development, China needs to adopt regulations to cover all aspects of CCS and keep cooperating with other countries in order to improve the functioning of these systems[103].

[102] Swartz, Jeff. 2016. “China's National Emissions Trading System: Implications for Carbon Markets and Trade.” *International Emissions Trading Association (IETA), Issue Paper No. 6*

[103] Findlay, Matthew; Mabey, Nick; Marsh, Russell; Ng, Shinwei and Tomlinson, Shane. 2009. “Carbon Capture and Storage in China.” *Germanwatch e.V*

3.3.3 Carbon Tax

Currently, China doesn't have a carbon tax. However, a study by Zhang Zhixin and Li Ya, has analyzed the impact that an eventual carbon tax would have on the country's economic growth. The results show that energy consumption and carbon dioxide emissions are different in the various Chinese regions, because of distinct economic structures. Accordingly, also the effects of carbon taxes on local economies would vary: poor regions with a great number of natural resources produce primary goods with a high carbon usage. Therefore, implementing a carbon tax would not be advantageous for them. On the other hand, provinces in eastern regions have a number of high-tech industries with a lower carbon dioxide emissions, and they would be less affected by the introduction of a carbon tax. However, if managed correctly, a carbon tax could promote local economic development even in those regions which are more disadvantaged. This would require the government's intervention by investing the profits coming from the new carbon tax in the rural areas, give funds to local companies and establish policies and financial support for the regional low-carbon businesses[104].

3.4 Decarbonization of the Transportation Sector

3.4.1 Support for Purchase

Chinese leaders have recently began to develop New Energy Vehicles (NEV) which are powered by renewable energy and can eliminate the negative aspects, such as pollution, coming from fossil fuel cars. Following this trend, various automobile producers in the Chinese market have began developing electric vehicle models. The sales of these types of cars have increased by 324% in 2014 when compared to the previous year, while production has arrived at 78,499 units increasing 4.5 times compared to that year's amount. Thanks to subsidies, car manufacturers have produced a total of 48,000 electric cars and 30,000 plug-in hybrids. In addition to incentives granted by the government, many big Chinese cities enhance the production and commerce of electric and hybrid vehicles in their localities. Usually, tax incentives are given to local car producers, which carry out their activity either in the city itself or in its district.

The Beijing Administration has decided to increase the recharging stations in the city from 20 to 100, in order to give customers more possibilities to recharge their electric cars[105]. Furthermore, the government has declared that it will exempt electric cars and other typologies of "new energy" vehicles from the acquisition tax, which is 10% of the final value of the vehicle. It also offers subsidies for electric car buyers, which last year increased from $5,700 to $9,800, while local incentives could further reduce the prices[106].

[104] Zhixin, Zhang and Ya, Li. 2011. "The Impact of Carbon Tax on Economic Growth in China." *Energy Procedia 5:1757–1761*

[105] Masiero, Gilmar et al. 2016. "Electric vehicles in China: BYD strategies and government subsidies." *Revista de Administração e Inovação, Volume 13, Issue 1: Pages 3–11*

[106] The Guardian. 2014. "China makes new electric cars tax-free."

3.4.2 R&D on Technology

By 2004, about 3,000 engineers were occupied in research and development among the Chinese state-owned companies and the shared enterprises which included foreign OEMs. Before the reform period and the subsequent expansion of the economy, R&D programs were limited by central planning. Because of the lack of competition and of incentives regarding the development of new vehicles or the improvement of existing ones, Chinese engineers didn't have any real opportunity to acquire R&D practice. In recent years, however, the vast majority of R&D financing are employed for the fabrication and the development of the products. To compete with producers from the rest of the world, the Chinese automobile industry must be ready to frequently make investments. It is thanks to investments made by representatives of the car industry worldwide that technology keeps improving and new products are appearing almost every day. China has undertaken steps to support some of its long-term technological research, by introducing a RMB880 million (over $100 million), five-year program to support research on fuel cells, hybrid vehicles, and electric vehicles[107].

3.5 Findings

Despite it being the world's largest emitter, China has put in a lot of effort, especially in the past years, into the development of renewable energies and the reduction of carbon emissions. In fact, carbon emissions did slow down and coal consumption has decreased by about 1% every year on average since 2013. The leader in non-fossil energy sources is hydropower, followed by nuclear, solar, and wind power. Nonetheless, renewable energy sources have not grown enough to replace coal, but energy consumption has slowly decreased and this has made sure that non-fossil sources could provide a larger share of the growth. China has promised to reduce its CO2 emissions intensity to 60-65% below the 2005 levels by 2030, increase the share of renewables to 20% of total energy consumption in 2030 and peak its carbon dioxide emissions before 2030. For the emissions in China to peak earlier, economic growth should be slower or the emission intensity has to decrease faster than expected. To keep the global average temperatures below 2ºC above preindustrial levels, Chinese emissions should decrease as fast as they went up[108]. This is why the country has decide to stop fossil fuel consumption. In January this year, the country's energy regulator has brought to an end more than 100 coal-fuelled plants which were under construction across the country, with a combined output of 100 gigawatts (GW)[109]. Moreover, the country is also experimenting new decarbonization methods such as emissions trading and carbon capture and storage, while, in the transportation sector, it is making many improvements regarding the development of electric cars.

[107] National Research Council and National Academy of Engineering. 2003. “Personal Cars and China.” *Washington, DC: The National Academies, Chapter 3*

[108] Peters, Glen. 2017.“Have Chinese CO2 emissions really peaked?” *Climate change news*

[109] Brandon, Simon. 2017. “China just switched on the world's largest floating solar power plant.” *World Economic Forum*

3.5.1 CO2 Emissions

The majority of data available regarding carbon emissions comes from the 1997-2009 period. During these years, total carbon emissions have remained constant between 1997 and 2001, rapidly increased from 2001 to 2005 and slowed down after 2005. During the period from 1997 to 2001, the increase in total carbon emissions was limited, while between 2002 and 2005 all Chinese provinces caused a big increase in total carbon emission and in the following years, these emissions kept increasing because of the raise of the economic rate. However, when the emission intensity started decreasing, the economic structure of the country still relied on heavy industry. Together with the decline in emissions intensity, growth also decreased by at least half compared to the preceding five years. The main obstacle to CO2 reduction is the inequity in technology between different regions: those with higher total carbon emissions have a higher number of manufacturing and mining industries, such as Hebei, Shandong, Shanxi and Inner Mongolia. Because of a lack of advanced technologies, machinery and handling knowledge, energy efficiency is harder to achieve in these regions compared to more developed ones. Moreover, the phenomena of urbanization and increasing quality of life in urban areas are responsible for higher emissions, since they require more living space, more vehicles, and a greater use of home electronic equipment[110]. On a more positive note, recent studies show that China's total energy consumption grew 1.4% in 2016 while its CO2 emissions remained low, partly thanks to a 12% increase in clean energy development. After almost twenty years of steady increases, China's CO2 emissions appear to have remained stable since 2013. The country has also declared that its emissions in 2017 will decrease by 1% compared to 2016, which means that it will be the fourth year in a row of either zero growth or a decline in emissions[111].

3.5.2 Renewable Energy Supply

When we compare it with the year 2008, we can see that the percentage of renewable energy over total consumption in 2009 increased from 8.4% to 9.9%[112]. China's wind power installation more than doubled every year between 2006 and 2008, and in 2008 its total wind capacity reached 12 GW, taking the lead in Asia. However, according to Audit Reports on Implementation of Policies Regarding Renewable Electricity Pricing and Sales, published by the SERC in 2008, renewable electricity capacity considered as a share of total capacity decreased by 1.37% and renewable electricity as a share of total electricity production decreased by 1.23%. This decrease was caused by the fact that despite the development of renewable electricity from sources such as wind power, the increase in other types of renewable energy sources, like

[110] Liu, Zhu. 2016. “China's Carbon Emissions Report 2016: Regional Carbon Emissions and the Implication for China's Low Carbon Development.” *Belfer Center for Science and International Affairs, Cambridge, Mass: Harvard University*
[111] McKenna, Phil. 2017. “China's Carbon Emissions Falling, While Trump Points U.S. in Opposite Direction.” *Inside Climate News*
[112] *Ibid.*

hydropower, was much slower than the production of traditional fossil fuel electricity generation[113]. In recent years, however, this trend has started to change and China is now considered a global leader in the production of renewable energies.

3.5.3 Impacts on the Economy

Many countries believe that the improvement in energy efficiency and the development of renewable energy are two of the most effective methods for solving environmental and climate challenges. Improved energy efficiency can help reduce total energy consumption, emissions of greenhouse gases and air pollutants, while at the same time increasing economic growth. Meanwhile, the shift from fossil fuels to renewable energy can make sure that there is a cleaner and low-carbon energy structure. China has relied a lot on energy for its economic growth, but environmental damages and the limited availability of fossil fuels now poses a greater threat on the country. This is why the international opinion is pressuring it to keep its GHG emissions under control. A series of preconditions need to be fulfilled for the country to achieve a high share of renewable energies in its future energy mix: the first, would be the restructuring of the industry toward a low-carbon economy with an efficient energy use; the second, would be to install power generation capacity on a huge scale, especially for wind and solar PV power; and finally, there would be a need of a great investment in renewable energy development. Investments in renewable energies would have positive impacts on the economy of the country, such as stimulating industries which produce machinery and electronic devices as well as R&D sectors. Studies have shown that the development of renewable energies on a large scale could increase output worth of $1.18 trillion from other renewable energy related industries and generate 4.12 million jobs by 2050[114].

3.5.4 Challenges

As has already been mentioned, China put a lot of effort into the development of renewable energies, and it also has a great potential for their expansion thanks to its diverse natural resources. However, the country still faces a lot of challenges regarding both the progress in renewables and the effectiveness of its environmental policies. These mainly regard grid infrastructure and the interconnection of small power producers, deficiencies in environmental legislation and the lack of an environmental tax system. To begin with, the country has a problem of geography since, given its massive size, the long-distance power transmission becomes a challenge. While China's coal, hydro and wind energy resources are mainly based in the west, the principal load centres are in the east[115]. For example, the windiest areas in the country are often

[113] Wang, Feng; Yin, Haitao and Li, Shoude. 2010.“China’s renewable energy policy : Commitments and challenges.” *Energy Policy 38: 1872–1878*

[114] Dai, Hancheng; Xie, Xuxuan; Xie, Yang; Liu, Jian and Masui, Toshihiko. (2016) “Green growth: The economic impacts of large-scale renewable energy development in China.” *Applied Energy, Volume 162, pp. 435-449*

[115] Worldview Report. 2012. “Geothermal Potential of China.” *pp. 1-13*

located far away from densely populated areas and from the power grid, and this requires major investments and expenditures in transmission lines to bring power to the grid[116]. The main problem of the country is its lack of a unified national electricity grid: at the moment its grid system is fragmented into six regional power grid clusters, which operate quite independently from one another[117]. Another major problem is constituted by the lack of basic infrastructure and by the inadequacy of the capacity and knowledge about how to handle the electricity produced from renewable energies[118]. Because of this, grid companies are now looking to enhance the interconnections between regional grids and build more transmission lines to cope with larger quantities of electricity from various sources. They want to build a grid system with an ultra-high-voltage (UHV) network which would stretch over the entire country[119], connecting Xiangyang, in China's northwest, to the country's eastern cities[120]. Further challenges are related to China's environmental laws, which have played an important role in the country's environmental protection efforts but which still have many defects and flaws. For instance, the shortcomings in environmental legislations could explain why pollution controls have proved ineffective in the country, at least until a few years ago. The reasons are various: firstly, the country's environmental legislation has not yet adopted the concept of sustainable development, which could be an important leading principle. Secondly, there are many gaps in the environmental legislation and it is evident that laws and regulations are not coordinated. Thirdly, there are problems related to unclear responsibility, the composition of the system, inequality in rights and obligations, and a lack of performance regarding the legal content. Many environmental laws used to assert that the responsibility for local environment protection should be attributed to the local government, but this rule was not implemented very well since there was a lack of control mechanisms. Fourthly, since China's environmental legislation has been affected by the economy for a long time, it paid more attention to governmental control duties rather than using market economic instruments. Finally, it is clear that legislation is being led by the government and this makes it harder for the citizens to participate in the legislative process[121]. However, in the past years, these last points have been addressed by the 13th Five-Year Plan which has introduced monitoring systems and punishment mechanisms for wrongdoers and by the "Environmental Protection Law" which gives the right to citizens to be informed, participate and supervise environmental issues. The last challenge that we are going to talk about is related to the lack of environment-targeted taxes such as energy taxes, sulphur taxes or carbon taxes. This means that the influence of pricing is not effective in improving energy efficiency

[116] Eisen, Joel B. 2010. "China's Renewable Energy Law: A Platform for Green Leadership?" *Wm. & Mary Envtl. L. & Pol'y Rev. Vol. 35:1, pp: 25-26 and 31-32*
[117] Worldview Report. 2012. "Geothermal Potential of China." *pp. 1-13*
[118] Eisen, Joel B. 2010. "China's Renewable Energy Law: A Platform for Green Leadership?" *Wm. & Mary Envtl. L. & Pol'y Rev. Vol. 35:1, pp: 25-26 and 31-32*
[119] Worldview Report. 2012. "Geothermal Potential of China." *pp. 1-13*
[120] Eisen, Joel B. 2010. "China's Renewable Energy Law: A Platform for Green Leadership?" *Wm. & Mary Envtl. L. & Pol'y Rev. Vol. 35:1, pp: 25-26 and 31-32*
[121] Mu, Zhilin; Bu, Shuchun and Xue, Bing. 2014. "Environmental Legislation in China: Achievements, Challenges and Trends." *Sustainability 6: 8967-8979*

and the elimination of pollution. Since there isn't a specific environment-related tax system in the country, the current tax scheme cannot address the issues related to energy and the environment. Moreover, the financial difficulties experienced in certain provinces of China can be partially attributed to the tax sharing system, which leads to a sort of protectionism towards local polluting companies and those who do not comply with environmental standards. However, during the past twenty years OECD and EU countries have proved how effective environmental taxes can be. For instance, the majority of these taxes have helped to increase energy efficiency and reduce pollution. These international experiences demonstrate that environmental taxes, especially carbon taxes, are invaluable in reducing pollution and cutting CO2 emissions. All the countries which have adopted a carbon tax have experienced an increase in the use of bio-fuels and a decline in fossil fuels consumption, while, at the same time, reducing CO2 emissions. Introducing an environmental tax would be a very successful method for both the environment and the economy since these tax reforms in OECD countries haven't brought any negative impacts on their economic growth but, in certain cases, they actually had extremely positive effects. Along with economic benefits, the introduction of environmental taxes also helped to create new job opportunities[122].

[122] CCICED. 2009. "Economic Instruments for Energy Efficiency and the Environment." *Policy Research Report*

CHAPTER FOUR

ETHIOPIA

4.1 Introduction

Ethiopia is a landlocked country, located in Eastern Africa, whose land stretches over more than 1.1 million square kilometers and presents a big display of climate zones and soil conditions. With more than 80 million inhabitants, it is the most populous country in Eastern Africa and the second-most populous in Africa after Nigeria. Despite it being one of the world's poorest countries, Ethiopia has good chances for growth. In fact, between the years 2005 and 2010, the country's real GDP grew by 11% thanks to a 15% expansion of agricultural land and a 40% yield increase in the agricultural sector. During the same time period, Ethiopia has been able to improve its infrastructure, double its electric power generation capacity, increase the extension of the telecommunication network from 0.5 million users to 25 million, construct new roads and add more than 11,000 kilometeres of road to the system already in place. The country relies on foreign investment, which has increased in the past years, and on imports of primary goods. Thanks to its recent positive development, Ethiopia now wants to reach middle-income status within 15 years by enhancing its agricultural productivity and incrementing its industrial capacity. However, if it were to do so by using a conventional economic development path, GHG emissions would more than double and they would reach 400 Mt CO2 in 2030. Luckily, the country has decided to implement a 'green development', by trying to achieve economic growth while at the same time limiting greenhouse gases emissions[123]. Despite being in the middle of a state of emergency, caused by almost a year of often violent anti-government demonstrations[124], Ethiopia's renewable energy sector continues to grow rapidly. The country was among the boldest parties that signed the Paris Agreement on climate change, committing to cut carbon emissions by 64% by 2030. It now wants to further its development plans along with the expansion of renewable energies, which are the centre of its project[125]. This is because, even though the country isn't itself a big emitter, it is suffering a lot from the consequences of climate change and it faces worsening natural phenomena, like stronger droughts and more unpredictable planting seasons[126].

4.2 Promotion of Renewable Energies

4.2.1 Types of Renewable Energies and Target Setting

(a) Biomass

The energy system in Ethiopia is constituted mainly by the use of biomass fuels which account for 89% of

[123] Federal Democratic Republic of Ethiopia. 2011. "Ethiopia's Climate-Resilient Green Economy: Green Economy Strategy"
[124] Al Jazeera. 2017. "Ethiopia extends state of emergency by four months."
[125] Monks, Kieron. 2017. "Riders on the storm: Ethiopia bids to become wind capital of Africa." *CNN*
[126] Woldegebriel, E.G. 2015. "How Ethiopia plans to become a clean energy exporter." *World Economic Forum*

the total national energy consumption. Households are those which make the greatest use of biomass fuels, since they are the most accessible and cheap sources of energy. The household sector consumes about 85% of total biomass, while the industrial and commercial service sectors use about 6% and 5%. Rural households depend almost completely on biomass as a source of cooking energy. 8.2 and 5.5 million tonnes of biomass are obtained from trees and dead wood, while crop residues and manure constitute about 5 and 7 million tonnes respectively to the total national energy consumption. Solid biomass is the most used source, especially for cooking, and it accounts for 80% of the national energy consumption. It is followed by liquid biomass, bioethanol and biodiesel. The first has expanded as a substitute of imported petroleum fuel and kerosene as cooking fuel. The second is being produced from molasses, a derivative of sugar production, by a public sugar farm. Since the end of 2008, there has been the introduction of the five percent ethanol blending in gasoline (E-5), and an NGO is currently trying to promote ethanol fuel for household cooking. Finally, there are now over 50 developers which are cultivating energy crops for the production of biodiesel, 15 of which have already begun operations. The Government of Ethiopia supports foreign and local investment in the development and use of biomass energy resource. The Biofuels Development and Utilisation Strategy encourages the expansion of market while at the same time deterring the use of food crops as feedstock for production[127].

(b) Hydropower

Ethiopia is well-known for its abundance of water sources, and this is why many call it "the water tower of Africa." The country has 12 river basins, 22 lakes and it has about 2.6 billion cubic meters of ground water resource. According to the Ethiopian Electric Power Cooperation, hydropower is the main source of power in the country, producing about 88% of the total electricity. However, it could generate even more, since it is estimated that water resources have the potential to generate as much as 30,000 MW of power. About ten years ago the demand for electricity, especially from rural areas, was very low. The main grid was not connected to these parts of the country, mostly because the costs of power transmission were extremely high. This is why the government, to meet the electricity demand of the rural areas, has began to build independent electricity supply infrastructures like small hydropower plants, wind turbines and diesel generators. Micro and pico-hydropower plants (which generate less than 5kW) are beneficial for rural areas in developing countries, since they are able to provide energy in an eco-friendly and affordable way, leading at the same time to an increase in employment, economic development, the improvement of the environment, the mitigation of poverty and the increase in the levels of cultural and living standards. Thus, building stand-alone electricity supply infrastructures for rural regions seems to be the most sustainable way to concentrate on the demand for energy in remote areas.The second main reason why Ethiopia has started to

[127] Shanko, Melessaw. 2009. "Ethiopia's Bioenergy Market." *Target Market Analysis, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)*

focus on developing its water potential is the protection of the environment, especially its forests resources, since the majority of the population uses them as a source of biomass production. Hydropower projects are usually criticized because their reservoirs cover large amounts of space and they displace many communities from their homes and these problems could be even worse in a developing country like Ethiopia, which lacks the financial resources to resettle the population. However, the state has many areas which could create storage reservoirs without causing social disruption, so if the hydropower projects are developed there, these issues can be avoided all at once. Moreover, hydroelectric power projects provide many services such as recreational uses, navigation and flood control, as well as irrigation for agricultural purposes. Since the majority of the population lives in rural areas and depends on agriculture for its livelihood, hydroelectric sources would constitute a reliable source of water, helping it to avoid droughts and other challenges[128]. The most famous and ambitious hydropower project in the country is the Grand Renaissance Dam, the constructions of which began nearly six years ago. The dam, which is located on the Blue Nile close to the border between Ethiopia and Sudan, will begin to produce electricity sometime in 2017. When in use, the project will produce around 6,000 megawatts of electricity. The electricity in excess will be exported to other African countries and even to Europe, making Ethiopia the largest electricity exporter in Africa. Other positive aspects are that it could bring a steadier flow of water during the dry season and less flooding in the rainy season[129]. The most astonishing aspect of this expensive project, which cost $5 billion, is that it is entirely funded by Ethiopia without any foreign investment. If the Grand Renaissance Dam and other hydroelectric projects, such as the Gibe III dam on the Omo river, are finished on time, the World Bank has estimated that Ethiopia could earn $1 billion a year from electricity exports[130].

(c) Wind power

Currently, electricity generation in the country is dominated by hydropower but the increase in demand, which is expected to increase at about 10% every year, calls for the development of new sources of renewable energy, such as wind power, solar power, geothermal and biomass. The “Accelerating Wind Power Generation in Ethiopia” (AWPG) is a program developed by the Ethiopian and the Danish governments, in a partnership which aims to respond to climate change by improving the management of natural resources. The two countries thought that wind power could help to grow and diversify the power generation capacity in Ethiopia and it could provide the supply required to cover the expanding demand for electricity, both in the country and abroad. In addition to this, wind power contributes to the reduction of CO2 emissions, since it produces energy in a clean way[131]. Ethiopia's commitment to decarbonization

[128] Degefu, Dagmawi Mulugeta et al. 2015. “Hydropower for sustainable water and energy development in Ethiopia.” *Sustainainable Water Resource Management, Springer International Publishing*
[129] Kumagai, Jean. 2016. “The Grand Ethiopian Renaissance Dam Gets Set to Open.” *IEEE Spectrum*
[130] Veselinovic, Milena. 2015. “Ethiopia's $5bn project that could turn it into Africa's water powerhouse.” *CNN*
[131] Ministry of Foreign Affairs of Denmark. 2016. “Accelerating Wind Power Generation in Ethiopia.” *F2 Case Number: 2016-*

pushed it on the path of becoming the wind power capital of Africa. Its largest wind farm, the Ashedoga plant, was inaugurated in 2013 and it produces 120-megawatt (MW). It is located in a deserted area outside Mekelle in Tigray region, which is only 475 miles distant from the capital Addis Ababa. The farm was built thanks to the supervision of the German company Lahmeyer International and financed by France's Vergnet[132]. This project was followed in 2015 by an even larger one, the 153 MW Adama II facility. Despite these innovations, by the end of 2015 hydropower still constituted the main energy supply, with wind power accounting for just 324 MW of Ethiopia's total output of 4,180 MW. For this reason the government has now decided to build at least five additional wind farms, with the aim of producing a minimum of 5,200 megawatts from wind power in the next four years. The main difficulty remains that of connecting the greater amount of plants possible to the national grid, since it is very important to have different energy sources to obtain a reliable system. The three main reasons why the country is investing so much in wind power are the devastating effects of droughts – which have decreased the value of hydropower energy, – the diminishing cost of wind power technology and the awareness that Ethiopia has a lot of sites with huge wind energy potential. Moreover, it is believed that wind power could bring benefits to poor communities by offering training and job opportunities in the new farms. At the same time, the plants could improve the country's position in the region thanks to trade. Ethiopia is already exporting energy to neighbourring countries like Sudan and Kenya, and wind power could offer a further market opportunity[133].

(d) Solar Power

Ethiopia has plenty solar energy resources, with an annual average irradiance of 5.2 kWh/m²/day. The country's solar energy market is relatively new, since when it started in the early 1990s annual sales growth was under 5%. However, in the last years a growth in sales of about 15%-20 % on average has been reported. The market for PV systems is slowly increasing, especially thanks to the help of NGOs and the Rural Electrification Fund (REF) for provincial schools and health institutions. Following the growth in rural income, there has been an increase in the demand for solar PV coming principally from the need for lighting, powering TVs and charging mobile phones. Off-grid solar PV market for households and commercial enterprises in Ethiopia started around mid 1990s and the demand was below 5kWp per year, which was very discouraging for suppliers. For the latter, solar PV constituted only less than 5% of their annual productivity. However, since then there has been a relative growth in the photovoltaic sector, thanks to a series of factors. Firstly, there have been a series of projects funded by international donors aimed to create awareness and competence since the year 2000. Secondly, the improving rural income in many parts of the country created a higher demand for electronics. Thirdly, the expansion of telecommunicasions into rural areas created new

9613

[132] Smith, David. 2013. “Ethiopia opens Africa's biggest windfarm.” *The Guardian*

[133] Monks, Kieron. 2017. “Riders on the storm: Ethiopia bids to become wind capital of Africa.” *CNN*

demand for small systems, such as a single light bulb and a mobile phone charger. Fourthly, the Rural Electrification Fund (REF) created awareness about PV as an alternative power supply mechanism. Finally, the chance to acquire solar PV systems through regional energy agencies to be re-sold at subsidized prices to rural households and businesses has stimulated the market. Off-grid community systems are aimed for health institutions, schools, religious institutions and water supply systems. The total installed solar PV capacity in these kinds of systems is around 500 kWp, but it has been estimated that this number will increase thanks to the support of NGOs and the REF. The telecommunications sector is one of the fastest-growing in Ethiopia, and the Ethiopian Telecommunication Corporation (ETC) aims to achieve universal (100%) telecommunication access in the country by connecting all rural villages and make sure that the inhabitants will have telephone access within a 5km extent. In off-grid locations the ETC activates its rural headquarters and wireless telephones with either solar PV or generator sets[134]. In conclusion, for the millions of people living in remote rural areas of Ethiopia who don't have access to the power grid or cannot afford electricity, solar energy constitutes an important tool. They can now turn to off-grid solar to light up their homes, have telephone access, watch television and charge their mobile devices, instead of relying on fossil-fuel based sources of power[135].

(e) Geothermal energy

Ethiopia began researching geothermal resource areas in 1969. Due to a series of factors, a detailed exploration work was started in the Lakes area of the rift system during the 1970s. During the thirty years in which geothermal resource explorations were conducted in the country, there has been a growth in the amount of information, exploration capacity and infrastructure. The first exploration drillings have been carried out in the Aluto-Langano and Tendaho geothermal fields. The former was explored in the late 1970s and early 1980s and, following detailed surveys, two wells were drilled on the Aluto volcano which produced 36 and 45 t.p.h. geothermal fluid at more than 300ºC. Two further wells were drilled as counterbalances to the west and east of this area, which respectively produced 100 and 50 t.p.h fluid with lower temperatures. Four other wells were drilled, with one of them being abandoned because of a fishing problem. A 7.3 MWe geothermal plant was built in 1999 using these exploration wells, but due to a lack of practical knowledge it hasn't been completely usable until recently. The second geothermal research was completed between 1979 and 1980, in the Tendaho area with the financial and technical help of Italy. From 1993 to 1998, three deep and three shallow wells were drilled, which provided a temperature of over 250ºC. In the following years, zones of tectonic and magmatic activity have been explored, the most important of which are Abaya, Corbetti, Tulu Moye, Dofan and Fantale. These six geothermal project areas have been

[134] Shanko, Melessaw. 2009. "Ethiopia's Solar Energy Market." *Target Market Analysis, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)*

[135] The World Bank. 2016. "Off-Grid Solar Lighting Up Ethiopia"

chosen because they were close to areas of economic activity and to the national power grid. However, further work has demonstrated that there are many other tempting opportunities that are ideal to seek in the long run, such as the Dallol, Kone, Meteka, Teo, Danab and Lake Abe areas, which are located between the southern and northern Afar geological provinces. The most recent operations are a three year project named Strategic Geothermal Resource Assessment in the Ethiopian Rift Valley, started in 2009, which aims to locate and identify areas for deep drilling and the memorandum of understanding signed by Ethiopia and Japan in June 2009 to achieve scientific and engineering data for the growth and development of the Aluto Langano geothermal field. The main challenges to the expansion of geothermal resources in Ethiopia are related to prioritization, lack of financial support and institutional organization. But it is important to keep developing this type of energy resource since, because of Ethiopia's disposition to droughts, there is a need for a mixed energy supply apart from hydropower. Moreover, geothermal power is the second cheapest renewable resource in the country[136].

4.2.2 Financial Support

The Development Bank of Ethiopia (DBE) and the International Development Association (IDA), the World Bank's fund for the poorest countries, are currently giving loans to the solar energy producers as well as credits to households so that they can afford to buy solar lanterns and Solar Home Systems (SHS) through a $20 million credit line under the Electricity Network Reinforcement and Expansion Project (ENREP). A further $20 million credit line was favored by the World Bank Board of Directors in May 2016, which was part of a bigger sum of $200 million of additional payment to the ENREP[137]. Another incentive is the Rural Electrification Fund (REF), which provides loans for the expansion of off-grid electrification projects. The Fund gives 85% loan with a 7.5% interest rate for diesel projects and a 95% loan with a 0% interest rate for renewable energy projects. Every type of renewable energy technology, like solar PV, mini and micro hydropower, and biomass, can receive backing from this program. The grant contributes 20-30% aid money of the investment cost to the planners of the project and it helps renewable energy project developers to assess the cheapest options in areas which lack hydro resources[138]. To further increase Ethiopia's advancement towards its goals of acquiring renewable energy and energy accessibility, the Ethiopian government is devolving $50 million of financing from the Scaling Up Renewable Energy in Low Income Countries Program (SREP) for the investment in wind, geothermal and SME renewable energy expansion. The funding, provided by the SREP to 75MW geothermal and 100 MW wind power, will contribute to the expansion of energy supply at cheap prices and will have a low environmental impact. SREP support will

[136] Kebede, Solomon. 2009. "Status of Geothermal Exploration and Development in Ethiopia." *Geological Survey of Ethiopia*
[137] The World Bank. 2016. "Off-Grid Solar Lighting Up Ethiopia"
[138] Shanko, Melessaw. 2009. "Ethiopia's Bioenergy Market." *Target Market Analysis, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)*

also ensure that a renewable energy SME financing facility will be established in order to let the population have access to renewable energy technologies. Ethiopia's Scaling Up Renewable Energy Plan was established under the government's authority in collaboration with the African Development Bank, members of the World Bank Group, other development partners and important Ethiopian stakeholders[139].

4.2.3 Policies

(a) The Environmental Policy

The Environmental Policy, introduced in 1997, is the main policy regarding the environment and the management of natural resources in Ethiopia. The overall goal of this policy is to improve the health conditions and the quality of life of all citizens, while encouraging sustainable social and economic development and the protection of the environment. The Policy aims to make sure that sustainable and eco-friendly processes are implemented, organic diversification is protected and renewable resources are used. Secondly, it wants to make sure that the benefits coming from the exploitation of non-renewable resources will be enjoyed by future generations as well, and that the negative impacts coming from the depletion of natural resources and the environment are going to be minimized. Thirdly, it wants to identify those natural resources which are now not being utilized, find new types of technology and increase the uses which have not yet been applied. Fourthly, it wants to add economic, social and environmental costs and benefits to the natural resource development by evaluating the environment and the services it provides. In the fifth and sixth points, the policy reports that it wants to improve the environment to make sure that all the needs of its citizens are met and it wants to avoid the pollution of land, air and water in the most cost-effective way possible. Seventh, it wants to develop and support Ethiopia's cultural heritage in a sustainable way; eighth it wants to ensure that all people and their organizations can take part to the environmental management activities. Finally, it wants to raise public awareness regarding the fundamental connection between environment and development. It then sets out precise policy directives for different sectors regarding the environment and the management of natural resources. For example, sections 3.1 and 3.2 refer to policies concerned with agriculture and forestry, while section 3.4 covers water resources. The Environmental Policy basically encompasses every sector that has to do with the environment such as natural, mineral and energy resources, human beings, urban development and health, atmospheric pollution and climate change, cultural and natural heritage and a number of cross-sectoral environment policies which have to do with the mix of the previously mentioned policy sectors. It also mentions social and gender issues, land use plan, environmental economics, information system, impact assessment and research, as well as environmental education and assessment[140].

[139] Climate Investment Funds. 2012. “Ethiopia.”
[140] The REDD Desk. 2016. “The Environmental Policy of Ethiopia.”

(b) Ethiopia's Programme of Adaptation to Climate Change (EPACC)

Ethiopia's Programme of Adaptation to Climate Change is a programme of action which is meant to build a climate resilient economy by learning how to adapt at sectoral, regional and local community levels. The EPACC replaces the National Adaptation Programme of Action (NAPA) which was developed in 2007 and sent to the UNFCCC Secretariat. It draws its contents from the NAPA, but in a more detailed way. The Programme has 29 points which include preventing land degradation and thus reduce soil loss, reducing the loss of biodiversity, managing water effectively, reducing the impacts of severe droughts, shifting from fossil fuels to renewable energies and so on. The Programme will be implemented from the federal level through all the levels of government, until it reaches the local communities in each regional state. Each local district has the right to choose its own work programmes and laws to regulate the actions of its citizens in achieving greater climate resilience. The second aspect of EPACC is to stretch over different government sectors to guarantee that the established aspects of climate change are ingrained in the governmental policies and strategies. For the correct implementation of the Programme everyone is asked to participate, from civil society, religious organizations and local communities to all levels of government administration. This is necessary to obtain a fair and equal response to climate change and to create the correct knowledge, competences and responses which will lead to the correct implementation of the Programme. The EPACC will be systematically monitored, reported on and verified. The first three-year phase (2011-2014) has been funded by US $10 million, by US $6.5 million coming from the government of Japan and from a further US $2.6 million from the United Nations Development Programme[141].

4.3 Decarbonization of other energy sources

Ethiopia doesn't have a national emissions trading scheme, a carbon tax or carbon capture and storage systems, but it has nonetheless set a goal to reduce its emissions of greenhouse gases by 64% by 2030, which is the most determined plan ever presented to the United Nations Climate Change Conference. The country plans to do so by cutting emissions coming from agriculture, manufacture and transport by adopting cleaner practices and decreasing deforestation[142]. The country has implemented the Climate Resilient Green Economy Strategy (CRGE), which plans to foster a resilient economic development pathway while decreasing per capita emissions by 64% or more, and the Second Growth and Transformation Plan which is closely linked to the CRGE.

4.3.1 The Growth and Transformation Plans

The first Growth and Transformation Plan (GTP), is a five-year plan that lead Ethiopia's development path

[141] CRGE Vision. 2010. “Ethiopia's Vision for a Climate Resilient Green Economy.”
[142] Daily Mail. 2015. “Ethiopia to cut carbon emissions by two-thirds by 2030.”

from the years 2010 to 2015 introduced by the Ministry of Finance and Economic Development[143]. Apart from achieving the Millennium Development Goals in the social sector and creating proper conditions for the construction of a sustainable nation, the main aim of the Plan is to maintain at least an average real GDP growth rate of 11%. The GDP growth in the plan is expected to help create employment and obtain an increase in income, contributing to poverty eradication[144]. However, the Plan doesn't only focus on the increase in the growth rate and the eradication of poverty: it also sets some targets for the generation of an additional 8,000 MW of electricity from renewable energies, for the increase in electricity customers from 41% to 75%, and for the expansion of the transportation system. It also outlines certain goals regarding biofuels, in order to diminish the gap between supply and demand by increasing the production of bio-ethanol to 194.9m litres and the use of biodiesel to 1.6bn litres, while expanding the number of ethanol mixing infrastructures to 8 and those of biodiesel to 72. The Growth and Transformation Plan makes an explicit reference to the sustainability of growth, stating that "environmental conservation plays a vital role in sustainable development." Building a 'green economy' and implementing environmental laws are among the main decisive aspects to be followed during the plan period[145]. Following the GTP I there has been the implementation of a second GTP, which is supposed to be in force for the 2015-2020 period. The Second Growth and Transformation Plan has been built on regional policies, strategies, programs and lessons learned from the performance of the first GTP and the post-2015 sustainable development goals (SDGs). It has also taken into consideration the global and regional economic situations which directly or indirectly affect the Ethiopian economy. The main objective of the GTP II is to fulfill Ethiopia's aim of becoming a middle income country by 2025 by obtaining an annual average real GDP growth rate of 11%, while at the same time pursuing a rapid industrialization and transformation. The important aspect to underline is that, among the list of main strategies to be used to achieve these objectives, there is always a mention to the construction of a climate resilient green economy[146].

4.3.2 Climate Resilient Green Economy Strategy

Ethiopia promulgated the Climate Resilient Green Economy Strategy (CRGE) to mitigate the problems related to environmental degradation and pollution which could result from the country's rapid economic growth. This procedure should guide it towards a sustainable development path in a number of sectors, especially the energy one, and it was implemented in response to the country's aspiration to become an

[143] Jones, Lindsey and Carabine, Elizabeth. 2013. "Exploring Political and Socio-Economic Drivers of Transformational Climate Policy: Early Insights from the Design of Ethiopia's Climate Resilient Green Economy Strategy." *Overseas Development Institute, Working Paper*

[144] Engida, Ermias et al. 2011. "Ethiopia's Growth and Transformation Plan: A Computable General Equilibrium Analysis of Alternative Financing Options." *Ethiopia Strategy Support Program II (ESSP II), Working Paper 30*

[145] LSE and Grantham Research Institute on Climate Change and the Environment. 2010. "The Growth and Transformation Plan (GTP)"

[146] National Planning Commission. 2015. "The Second Growth and Transformation Plan (GTP II) 2015/16-2019/20" *The Federal Democratic Republic of Ethiopia*

emission-free economy by 2025. The strategy's aim is to achieve a zero net carbon emission economy and it identified hydropower as the most reasonable option to make this a reality, considering the large number of water resources that the country has and its many different purposes[147]. Implemented in 2011, the Climate Resilient Green Economy (CRGE) Strategy has three main objectives: the first is promoting economic development and growth; the second is ensuring the decrease and prevention of future emissions; and the third is improving resilience to climate change. The strategy is closely linked to the Growth and Transformation Plan, since the implementation of the CRGE contributes to the achievement of the goals set under the GTP. The CRGE Strategy has three further objectives: attracting international climate investment, supporting modernization on the latest production programs and creating a profit in exploiting the use and productivity of the country's resources in a sustainable way. The Climate Resilient Green Economy Strategy is comprised of two main parts: the Green Economy Strategy and the Climate Resilient Strategy. The first revolves around four main targets: increasing sustainable agricultural production and food security; protecting forests; increasing power generation from renewable energies to become self-sufficient and to be able to export to neighbouring countries; and supporting modern energy-efficient technologies in the transport, industry and construction sectors. The second is focused on two main aspects: encouraging the introduction of the decrease and control of disaster-related risks into the CRGE's main objectives; and helping to include resilience and adaptation objectives into local and regional plans. Since Ethiopia depends heavily on natural resources, the Climate Resilient Strategy has a particular focus on agriculture, land-use and forestry[148].

4.4. Decarbonization of the Transportation Sector

Ethiopia's experience with decarbonizing the transportation sector has began in 2010, with the launch of the first electric cars, despite the problems connected to power shortages. The Solaris Elettra vehicles had to be sold in the country and exported to other nations in Africa and Europe. Many believe that the country is not ready for electric cars because of its poor infrastructure, uncertain power supplies and low levels of wealth. For instance, taxes on cars in Ethiopia can amount to more than 100% and many Ethiopians with low incomes would struggle to afford an electric car[149]. In March 2013, the Ethiopian Federal Environmental Protection Authority (EPA) and dVentus Wind Technologies PLC inaugurated the Electronic Vehicles pilot Project, thanks to the support of the UNDP. The project introduced 12 e-taxis to be used in the cities of Adama, Mekele, Sekota and Debremarkos. The benefits brought by e-taxis are many: they help decrease air

[147] Degefu, Dagmawi Mulugeta et al. 2015. "Hydropower for sustainable water and energy development in Ethiopia." *Sustainainable Water Resource Management, Springer International Publishing*

[148] Jones, Lindsey and Carabine, Elizabeth. 2013. "Exploring Political and Socio-Economic Drivers of Transformational Climate Policy: Early Insights from the Design of Ethiopia's Climate Resilient Green Economy Strategy." *Overseas Development Institute, Working Paper*

[149] BBC News. 2010. "Ethiopia launches electric car despite power shortages."

pollution, they reduce the amount of money spent on fossil fuels and they create new job opportunities for Ethiopians[150]. In 2015, Global Electric Transportation (GET), a US company, announced that it would build an electric car manufacturing industry in Ethiopia, with a production capacity of 4000 units per month. The project has been developed in response to the country's efforts to become a "green economy" and reduce its carbon emissions[151]. Despite these first attempts, Ethiopia still doesn't have a big market for electric vehicles at the moment, nor does it have research and development programs. It first needs to address a series of problems, like the transmission of electricity to the rural parts of the country and the frequent blackouts, before introducing environmentally-friendly cars. In the future, the country could also look towards the development of biofuels to be used in the transportation sector. The latter is the one which consumes the majority of imported petroleum and caused a great number of CO2 emissions in the country.
Since the nation's economy is increasing, it is likely that the demand for petroleum will also increase, threating the country's sustainable development. Thus, it would be profitable for Ethiopians to look for other available alternatives, such as biofuels. With respect to this, the government has already began to blend gasoline and currently the ethanol to gasoline ratio is 10:90. If the government keeps following this method, then the ratio is expected to increase by 25%[152].

4.5 Findings

In 2010 the Prime Minister of Ethiopia Meles Zenawi declared that he had two goals for the country: for it to become a middle income nation by 2025 and to do this by 2030 without an increase in Greenhouse Gas emissions (GHGs). This was thought to be completely impossible, especially since Ethiopia is a poor country with a population which is living on less than $1.25 a day. However, data from the 1999-2012 period, shows otherwise. The country has demonstrated a population increase of 43%, an increase in National Affluence (GNI) of 242% and a decrease in greenhouse gases emissions of 15%. It has obtained this outstanding result by making its institutions ready for change and investing in "green growth" initiatives. If growth can indeed be green and the results of growth can be shared in an equal way to reduce poverty, then the case of Ethiopia could be used as a model of sustainable growth for other developing countries[153].

4.5.1 CO2 Emissions

Ethiopia's emissions grew by 86% between 1993 and 2011. During these years GDP increased faster than

[150] UNDP. 2013. "Ethiopia Pilots Electric Vehicles."
[151] Construction Review Online. 2015. "Ethiopia to get electric cars assembly plant."
[152] Birhanu, Abadi and Ayalew, Shimels. 2017. "A Review on Potential and Status of Biofuel Production in Ethiopia." *Journal of Plant Sciences, Vol. 5, No. 2: pp. 82-89*
[153] Baines, Steve. 2017."Can economic growth really be decoupled from increased carbon emissions in Least Developed Countries? Ethiopia's Story." *From Poverty to Power*

total GHG emissions, which shows that the carbon intensity of the economy in 2011 had decreased compared to 1991[154]. The total GHG emissions of Ethiopia in 2010 were 150 Mt CO2 and they derived mainly from live stocks, the agricultural sector, deforestation, electric power generation and from the transport, industrial and building sectors, which added 3% each. Despite several years of economic growth, the country's emissions are very low. Ethiopia emits 2 t CO2 compared to an average of more than 10 t per capita in the EU and more than 20 t per capita in the US and Australia. When looking at emissions at a global level, the country's total emissions constitute only 0.3%[155].

4.5.2 Renewable Energy Supply

The total supply of primary energy more than doubled between 1990 and 2012, with biofuels and waste constituting 93% in 2012, followed by fossil fuels which accounted for 6% and 1% coming from renewables. The national electric grid is constituted principally by renewables, the majority of which comes from hydropower, followed by wind and geothermal. Ethiopia's Intended Nationally Determined Contribution (INDC) has underlined, however, that 77% of the population doesn't have access to modern energy sources and still relies on wood for fuel. In rural households families use fuel wood since they have no access to electricity, so the government has decided to expand biogas to make sure that there is a reduction in the demand for fuel wood in favour of that for efficient cook stoves[156].

4.5.3 Impacts on the economy

The implementation of the GTP, the CRGE and the use of renewable energies have all proved beneficial to Ethiopia's economy. For instance, the Ethiopian Minister of Water, Irrigation & Energy has declared that the implementation of the GTP has brought about a continuous economic development that has enabled Ethiopia to become one of the fastest developing economies not only in Africa, but also in the world. The country's GDP has been growing at a rate higher than 10% annually for the past years, leading to an increase in demand for energy which has increased to 25% a year. In response to the negative effects of GHG emissions on the climate, the Ethiopian government has decided to implement the Climate Resilient Green Economy Strategy, which ensures that the country follows a sustainable economic development and protects itself and the environment from the effects of climate change. One of the main elements of the country's green economy are renewable energies since it is blessed with huge capacity in hydropower, wind, solar, geothermal and bionenergy resources. This capacity, combined with the government's commitment to its exploitation and the country's strategic location makes it a renewable energy hub in Africa, providing the region with clean and cheap energy which can replace traditional electricity. Moreover, the export of

[154] USAID. 2011. “Greenhouse Gas Emissions in Ethiopia.”
[155] Federal Democratic Republic of Ethiopia. 2011. “Ethiopia's Climate-Resilient Green Economy: Green Economy Strategy”
[156] USAID. 2011. “Greenhouse Gas Emissions in Ethiopia.”

renewable energy to neighbouring countries could bring further economic benefits to the country[157].

4.5.4 Challenges

Despite Ethiopia's outstanding progress in its sustainable economic development, the country still faces major challenges. To begin with, 70% of its population doesn't have access to electricity, especially in the rural areas where most people live. Even in regions where there is grid coverage there are frequent power shortages and blackouts, including the capital Addis Ababa, impacting on the fast-developing economy in a negative way. Moreover, studies show that in a few years the national demand for electricity will exceed the supply of the installed hydropower capacity, which will also affect the demand for power exports to neighboring countries[158]. Poverty and illiteracy are other major problems in the country: 49% of the population can't read or write, which is also caused by the fact that children are often forced to leave school because of poverty and hunger. If the country's leaders do not start addressing these problems, then it is unlikely that the country will lift itself out of extreme poverty levels. Environmental issues, such as water pollution and land degradation, which often leads to desertification, add up to this[159]. Ethiopia's reliance on charcoal and fuel wood is partly responsible for the massive land degradation that is happening, making the bare soil more exposed to corrosive rainfall and waterways' erosion. The main cause remains that of climate change since it can lead to phenomena which can affect not only the economy but also the population's possibility of feeding itself, given the fact that the country relies principally on agriculture for its sustenance[160]. Natural causes like droughts and floodings can put the economy in a bad shape and leave many starving[161] while variations in rainfall, temperature and evaporation can affect hydropower generation negatively. For example, droughts cause reduced power production, which leads to a worse economic performance. In 2002-2003 because of drought, the supply of power was lost one day a week for four months[162].

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CHAPTER FIVE
Conclusion

The thesis was concerned with the decarbonization of the economy, which means the ways in which countries can decrease their greenhouse gases emissions in order to comply with the Paris Agreement. The Paris Agreement is the most recent arrangement regarding the issue of climate change and it is very important since it aims to reduce the global temperatures rise by keeping them under 2 degrees Celsius above pre-industrial levels. If this target will not be met, the implications for our Planet will be unpredictable. In the past years, we have already experienced how the rise in temperatures can cause severe droughts, the rise in sea levels, the melting of the ice caps, floods, and other extreme weather conditions. If the goals set by the Paris Agreement are not met, these phenomena will worsen threatening all humankind. This is why it is so important that every country in the world revises its policies and environmental legislations and begins to utilize carbon-free energy sources, in order to contrast climate change. To see how different countries around the world are responding to climate change we have analyzed the situations in Sweden, China and Ethiopia. We have used as a model the "Climate change mitigation Policy Progression Indicator" (CPPI), which utilizes a series of Action Indicators and Outcome Indicators to determine the progress of different countries. We have managed to collect findings for almost every indicator, but for all three countries we failed to find data regarding the intensity targets on power plants and the preferential treatments given to carbon-free cars. In addition to these indicators we have also added the policies and environmental legislations introduced in the countries, because we think that these are fundamental instruments in response to climate change. In the findings, apart from the Outcome Indicators we have also made predictions on the effect that applying these measures has had or could have on the country's economy and the challenges that still need to be solved regarding the decarbonization process and the protection of the environment. Sweden represents the optimal way to achieve decarbonization while at the same time obtaining economic growth, and in fact the country has been defined as the "leading power in sustainability." The country can be used as a model to follow by other developed countries which need to reduce their emissions in order to fulfill the Paris Agreement targets since it has "scored" well in almost every Action Indicator. In 2015, 57% of the country's energy was produced by renewable energies while, at the same time, it has managed to increase its GDP by almost 60% in the past 25 years. The country's success can be explained by its extensive Research and Development Programmes regarding alternative energy sources, and its high number of environmental policies, government incentives and disincentives. The country has also been successful in decarbonizing the transportation sector, thanks to its incentives for the purchase of environmentally-friendly cars and the extensive research and development programmes on new

technologies. All these measures have made sure that emissions in the country have fallen while the production of renewable energies has increased. Thus, the Swedish example shows that a combination of well-formulated public policies and private ability can lead to a low-carbon and flourishing future. Of course not every country can copy the exact measures that proved successful in Sweden. For instance, Sweden has an extremely great amount of hydropower and biomass relative to its population, so the exact compound of policies and energy sources needed to solve the problem will be different in every country. Some may have more wind, solar and nuclear energies in the mix compared to Sweden, while other countries which are rich in fossil fuels may find it more convenient to employ carbon capture and storage techniques together with a greater use of natural gas[163]. If Sweden constitutes the perfect example to follow for developed countries which want to decarbonize their economies, China and Ethiopia are two examples of developing countries which need to achieve economic growth while decreasing their emissions. Although China is the world's second largest economy, it is still considered a developing country since its income per capita is lower than that of developed countries and its market reforms are incomplete. China is the world's largest emitter and until not long ago, it was thought as the country displaying the most unsustainable example of growth. In fact, it still has a lot of problems related to pollution, poverty, social and public security, education, medical care and rural and urban infrastructure. However, the reality is that in a short time China has undertaken the path of becoming the world's leader in renewable energies. In the analysis of the country we have used the same indicators as for Sweden, and these have showed us that the country is indeed making an improvement in its development of renewable energy sources and the decarbonization of other energy sectors, even though coal remains its primary energy source. China's renewable energies include solar, wind power, hydropower, biomass and geothermal. Regarding environmental policies, China has implemented a number of them in the past years, such as the 13th Five-Year Plan, the Environmental Protection Law and the Renewable Energy Law. With respect to the transportation sector, it has started to build eco-friendly cars and is investing a lot of money in research and development programmes responsible for the production of these types of vehicles. China has achieved a 1% decrease in coal consumption every year since 2013 and between 2008 and 2009 the share of renewable energies has increased from 8.4% to 9.9%, but this development was still slower than that of fossil fuels. In order to meet the Paris Agreement targets sooner, China should start to implement a series of policy changes, invest in environmental programs and renewable energies development and it should introduce environmental monitoring systems. Finally, our last case study is constituted by Ethiopia, which many would consider an extremely poor country with the only goal of lifting itself out of poverty. However, this is only a misconception since Ethiopia has been expanding not only its economy in the last years but also its renewable energies. The country has in fact decided to follow a “green growth” path in response to the severe climatic impacts that it has experienced in the past years, such as severe droughts, soil

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degradation and subsequent famines. The country's energy mix is constituted almost entirely by renewable energies, with 89% coming from biomass alone in 2010. Hydropower is the largest source of electricity producer in the country, but climatic problems like droughts have made it indispensable for Ethiopia to start developing new sources of energies to complement it. This is why the government has put a lot of effort into the expansion of wind power, solar power, and geothermal power as well. To make this process easier, the country has implemented a series of policies and legislations which aim at increasing renewable energy production and creating a climate resilient economy. In other energy sectors and the transportation sectors, Ethiopia hasn't achieved significant results yet. For instance it didn't implement an emissions trading scheme, a carbon tax or carbon capture and storage systems. In the transportation sector, it has tried to introduce electric vehicles but their expansion is not big yet, since the country still needs to face problems related to electricity transmission and power shortages especially in its rural areas. However, the fact that Ethiopia, which isn't in itself a big emitter, put in so much effort into becoming a sustainable economy should be taken as an example by many other developing countries. The country is responsible for only about 0.3% of total global emissions, but this didn't stop it from developing new renewable energy technologies and implementing a number of environmental legislations. Furthermore, the Ethiopian government believes that an increase in energy coming from renewables could be beneficial for the country, since the exceeding power could be sold to neighbouring countries.

In conclusion, there is no right or wrong way of decarbonizing the industry, because every country has different natural resources, economic situations and emission sources. However, the three case studies show how every type of country, from the wealthiest one to the poorest, can put in its best efforts to counter the negative aspects of climate change, by balancing its strengths and weaknesses. Sweden, for instance, has achieved an almost total decarbonization of its economy thanks to its combined use of renewable energies, policies, taxes and nuclear power. It has managed to exploit its natural resources in a beneficial way, investing in Research and Development Programmes from the very beginning. China, which still relies heavily on coal for its energy, has become in recent years a major leader in renewable energy production. If it were to stop using fossil fuels alltogether and start investing more into renewable energies, it could gain major benefits not only in economic terms, but also in environmental ones, responding for instance to its big pollution problem. Ethiopia, on the other hand, didn't let its weak economy stop it from investing in a series of grand renewable energy projects. With the help of foreign aid the country is hoping to become a renewable energy hub in Africa. This is to show that change, even if slow, can be obtained by every country in the world. The important thing is that everyone, from businesses to private individuals, puts in their best efforts since climate change is a problem that affects us all and there is no time to determine who should be held responsible anymore.

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Riassunto in Italiano

La tesi tratta la questione della decarbonizzazione, includendo il tema delle energie rinnovabili, delle politiche ambientali e degli incentivi che vengono usati per diminuire le emissioni di CO2.
L'argomento del riscaldamento climatico è stato ampiamente discusso negli ultimi anni, ma è divenuto ancora più popolare in quest'ultimo anno in seguito all' accordo di Parigi sul clima e alla successiva uscita degli Stati Uniti da esso. Mai come ora è importante sottolineare l'importanza di fare qualcosa per rispondere al cambiamento climatico. Negli ultimi anni si sono cominciati a manifestare gli effetti negativi di questo riscaldamento globale, quali l'aumento delle temperature, lo scioglimento dei ghiacci e di conseguenza l'innalzamento del livello dei mari, siccità e altri fenomeni estremi. Gli scienziati concordano nel dire che il riscaldamento climatico è causato per la maggior parte da fenomeni umani, ed è quindi compito di tutti cercare di diminuire questi effetti catastrofici. L'accordo di Parigi sul clima è il più recente tentativo da parte dei leader mondiali di arginare il problema. Esso definisce un piano di azione globale che intende indirizzare il mondo sulla buona strada per evitare cambiamenti climatici pericolosi limitando il riscaldamento globale al di sotto di 2ºC rispetto ai livelli preindustriali. Addirittura, si auspica di limitare l'aumento a 1.5ºC, cosa che ridurrebbe i rischi maggiormente. I paesi che hanno aderito all'accordo hanno dovuto presentare dei piani nazionali di azione per il clima e dovranno riferire i progressi raggiunti verso l'obiettivo a lungo termine. Per vedere quali sono effettivamente i mezzi per diminuire le emissioni di CO2, che sono la causa principale del riscaldamento della temperatura mondiale, abbiamo deciso di analizzare tre diversi paesi che hanno preso parte all'accordo di Parigi. Questi sono la Svezia, la Cina e l'Etiopia e sono stati scelti in quanto rappresentano, per così dire, l'assetto odierno del mondo. Il primo è infatti un paese sviluppato e benestante, il secondo è un paese in via di sviluppo (nonostante abbia la seconda economia più grande al mondo) e il terzo è un paese povero e per molti versi sottosviluppato. Nonostante queste tre nazioni siano diverse in quanto a sviluppo economico, posizione geografica e provenienza delle emissioni, hanno tutte come obiettivo comune quello di mantenere le temperature al di sotto dei 2ºC e per questo motivo devono implementare delle misure specifiche all'interno dei propri paesi. Per monitorare il progresso che questi tre paesi stanno facendo, abbiamo deciso di usare come modello il "Climate change mitigation Policy Progression Indicator" (CPPI), ovvero l'indicatore del progresso delle politiche relative all'attenuazione del cambiamento climatico. Questo sistema utilizza due diversi tipi di indicatori: indicatori di azione e indicatori di risultato. I primi servono a valutare quali azioni vengono svolte effettivamente per diminuire le emissioni e si occupa di tre ambiti: la promozione delle energie rinnovabili, la decarbonizzazione di altre fonti di energia e la decarbonizzazione del settore dei trasporti. Gli indicatori dei risultati invece si occupano delle emissioni di CO2 e della produzione delle energie rinnovabili. Noi abbiamo seguito, dove possibile, la struttura del CPPI ma abbiamo aggiunto alcune cose che ci sembravano rilevanti. Per esempio abbiamo deciso di descrivere brevemente le varie leggi e le politiche relative alla protezione dell'ambiente e allo

sviluppo sostenibile, e nei risultati abbiamo cercato di individuare quali sono gli effetti che queste hanno sull'economia e le sfide che devono ancora essere affrontate.

La Svezia rappresenta il modello quasi perfetto di decarbonizzazione e dovrebbe essere presa come esempio dagli altri paesi sviluppati che vogliono diminuire le proprie emissioni di anidride carbonica. Il paese scandinavo infatti è stato definito “leader della sostenibilità” in quanto è riuscito ad ottenere allo stesso tempo una buona decarbonizzazione e una buona crescita economica. Nella nostra analisi ha ottenuto dei buoni risultati per quasi tutti gli indicatori di azione. Nel 2015 il 57% dell'energia del paese è stata prodotta da energie rinnovabili. Allo stesso tempo, la Svezia è riuscita ad aumentare il suo GDP di quasi il 60% negli ultimi 25 anni, diminuendo l'uso di carbon fossili di un quinto. Il successo del paese può essere spiegato dal suo impegno nell'ambito della ricerca e dello sviluppo riguardante non solo le energie alternative ma anche il settore automobilistico, e il suo grande numero di leggi e politiche ambientali, incentivi statali e tasse sul carbone. La principale fonte rinnovabile di energia è costituita dalle biomasse, che hanno permesso al paese di raggiungere una diminuzione del 9% nei gas serra e un incremento del 50% del prodotto nazionale lordo. La Svezia è inoltre la più grande produttrice di energia idroelettrica nell'Unione Europea e la decima a livello mondiale. Negli ultimi anni ha anche cominciato a sviluppare il settore dell'energia eolica, il quale ha di recente acquisito un ruolo maggiore. Nonostante la mancanza delle condizioni geologiche necessarie per l'esplorazione geotermica profonda, la Svezia è riuscita a diventare il terzo paese leader nell'uso di energia geotermica grazie al suo sviluppo delle pompe di calore. Infine, il settore dell'energia solare non è molto sfruttato nel paese, a causa della mancanza del supporto del governo e dei suoi alti costi, ma i pannelli solari vengono comunque utilizzati da singole famiglie nelle proprie case. L'ampio successo delle energie rinnovabili deve essere attribuito agli incentivi del governo e all'introduzione di certe politiche, come il sistema basato sul certificato verde del 2003, che sostiene e incoraggia la produzione di energie alternative. Per diminuire la presenza di CO_2 nell'aria la Svezia ha anche incominciato a sviluppare dei sistemi di cattura e stoccaggio del carbonio, i quali sono considerati i metodi migliori per ridurre le emissioni a lungo termine. La nazione scandinava ha inoltre implementato varie politiche e leggi volte alla protezione dell'ambiente, come il Codice Ambientale del 1999, la prima serie di leggi riguardanti lo sviluppo sostenibile. Per de carbonizzare altri settori di energia ha introdotto una tassa sul carbonio già nel 1991 e nel 2005 ha cominciato ad essere soggetta allo scambio di quote di emissioni dell'Unione Europea. Nel 2009 ha aggiunto un'altra politica riguardante il clima e l'energia, il cui obiettivo è quello di diminuire le emissioni e aumentare il numero di energie rinnovabili usate nel settore dei trasporti e nel consumo totale finale di energia. Grazie ai numerosi incentivi per l'acquisto di macchine ecologiche e ai programmi di ricerca e sviluppo di nuove tecnologie, il paese è riuscito a decarbonizzare anche il settore dei trasporti.
Dunque il caso della Svezia dimostra come una combinazione di politiche pubbliche ben formulate e una

certa dose di capacità individuale, possano portare ad un futuro prosperoso e caratterizzato da emissioni molto basse. Ovviamente non tutti i paesi possono replicare le stesse misure che hanno avuto successo in Svezia. La nazione, ad esempio, ha una grande quantità di energia idroelettrica e di biomasse in confronto al numero della popolazione, quindi l'esatta misura di politiche e fonti di energia che servono a risolvere la situazione variano di paese in paese. Alcuni possono avere più energia eolica, solare o nucleare nel mix energetico in confronto alla Svezia, mentre altri, ricchi di combustibili fossili, potrebbero trovare più conveniente usare sistemi di cattura e conservazione dell'anidride carbonica insieme all'uso di gas naturale.

Se la Svezia rappresenta l'esempio perfetto da seguire per le nazioni sviluppate che devono decarbonizzare le proprie economie, la Cina e l'Etiopia sono gli esempi di come due paesi in via di sviluppo possano ottenere una crescita economica senza aumentare le emissioni di anidride carbonica. La Cina è la più grande responsabile dei gas a effetto serra nel mondo e, fino a non molto tempo fa, era considerato il paese con la crescita più insostenibile. Infatti, essa ha un gran numero di problemi legati all'inquinamento, la povertà, la sicurezza pubblica e sociale, l'educazione, l'assistenza sanitaria e le infrastrutture rurali ed urbane. Nonostante ciò, la realtà dei fatti è che in poco tempo la Cina è riuscita a diventare una leader mondiale nelle energie rinnovabili. Per analizzare la nazione abbiamo usato gli stessi indicatori della Svezia, e tramite questi abbiamo notato che essa sta effettivamente facendo enormi progressi nello sviluppo di energie alternative e nella decarbonizzazione di altri settori di energia, anche se il carbone rimane comunque la fonte più utilizzata. Le energie rinnovabili in Cina sono costituite dall'energia solare, idroelettrica, eolica, geotermica e dalle biomasse. Nel 2008 la nazione è diventata la più grande produttrice di pannelli fotovoltaici al mondo, e di recente ha costruito il più grande impianto fluttuante di pannelli solari mai esistito. Nel 2010 è diventata anche la più grande produttrice di energia eolica a livello globale, e in effetti la Cina si è impegnata molto a sviluppare questo tipo di energia. Nonostante i suoi sforzi, sussistono molti problemi relativi alla trasmissione dell'elettricità derivante dalle energie rinnovabili a causa di una mancanza di esperienza. L'energia idroelettrica è un altro settore che potrebbe rivelarsi positivo per il paese, dato che quest'ultimo ha la più grande capacità idroelettrica installata al mondo. Il paese ha anche inaugurato il più grande progetto idroelettrico mondiale, denominato “Diga delle Tre Gole”, ma esso ha suscitato vari problemi che l'hanno reso controverso. Infatti la sua costruzione ha causato lo spostamento di 1.3 milioni di persone, l'inondazione di siti archeologici e culturali e rischi ecologici, quali un incremento di frane, il deterioramento della qualità dell'acqua, l’erosione del suolo e del letto del fiume, e la scomparsa di una delle quattro maggiori specie di pesce. In più, l'energia idroelettrica costituisce solo una piccola parte della rete elettrica totale. Le biomasse facevano parte del 13% del consumo finale di energia nel paese nel 2000, e per questo motivo il governo ha deciso di stabilire un programma per il loro sviluppo per il periodo 2016-2020, che intende industrializzare e commercializzare l'energia da biomassa. Infine, il paese ha un grande potenziale per quanto riguarda lo

sviluppo dell'energia geotermica, ma quest'ultima non ha ricevuto la stessa attenzione e la stessa crescita degli altri tipi di energia, compromettendone il successo. La Cina ha implementato parecchie politiche e programmi ambientali negli ultimi anni: il più recente è stato il tredicesimo piano quinquennale, che si occupa di aumentare la qualità della vita dei cittadini, proteggere l'ambiente e introdurre programmi di previdenza sociale. Un aspetto positivo del piano è che di 13 obiettivi vincolanti, 10 riguardano l'ambiente. Ciononostante, il principale obiettivo della nazione rimane quello di ottenere una crescita economica. La legge sulla protezione ambientale del 2014 e quella riguardante le energie rinnovabili del 2005 promuovono lo sviluppo sostenibile, la protezione dell'ambiente e lo sviluppo di energie alternative nel paese. Negli ultimi anni, la Cina si è imbarcata in una serie di progetti riguardanti la cattura e lo stoccaggio del carbonio e lo scambio di quote di emissioni, e sta prendendo in considerazione l'introduzione di una tassa sul carbonio. Riguardo al settore dei trasporti, essa ha cominciato a costruire macchine ecologiche e ad investire in progetti di ricerca e sviluppo responsabili per la produzione di questo tipo di veicoli. La Cina ha ottenuto un calo dell'1% nel consumo di carbone ogni anno a partire dal 2013, e tra il 2008 e il 2009 la percentuale di energie rinnovabili utilizzate è aumentata dall' 8.4% al 9.9%. Per ottenere gli obiettivi posti dall'accordo di Parigi più velocemente, il paese dovrebbe cominciare a cambiare ulteriormente le sue politiche, investire in programmi ambientali e nello sviluppo di energie rinnovabili, e inserire dei meccanismi per monitorare l'ambiente.

L'ultimo caso da noi studiato è stato l'Etiopia, che molti considerano un paese estremamente povero con l'unico obiettivo di sollevarsi dalla propria condizione di povertà. Tuttavia, questa è un'idea errata in quanto, negli ultimi anni, il paese ha sviluppato non solo la propria economia ma anche le energie rinnovabili. L'Etiopia ha infatti deciso di intraprendere una crescita ecologica per reagire ai cambiamenti climatici che l'hanno colpita negli ultimi anni, quali siccità, degradazione del suolo e le conseguenti carestie. Il mix energetico del paese è costituito quasi principalmente da energie rinnovabili, con l'89% derivante solamente dalle biomasse nel 2010. L'energia idroelettrica è la principale fonte di elettricità nel paese, ma problemi ambientali quali la siccità hanno reso indispensabile per l'Etiopia lo sviluppo di ulteriori risorse. Per questo motivo il governo si è impegnato nella realizzazione e crescita di energie quali quella eolica, solare e geotermica. Il governo etiope in collaborazione con quello danese ha introdotto un programma per accelerare la produzione di energia eolica nel paese, ritenendo che quest'ultima possa servire a diversificare la capacità di produrre energia del paese e a coprire la fornitura di elettricità derivante dall'aumento delle richieste. Il mercato di pannelli solari sta lentamente crescendo negli ultimi anni, in seguito all'aumento dei salari e al successivo aumento della domanda per l'elettricità. Sistemi di pannelli fotovoltaici non connessi alla rete nazionale servono soprattutto nelle comunità rurali per fornire energia ad ospedali, scuole e chiese. Lo sviluppo dell'energia geotermica in Etiopia è ostacolato da una mancanza di fondi e di organizzazione, ma

nonostante tutto essa è stata abbastanza analizzata negli ultimi anni. Se questo settore venisse esteso ulteriormente, potrebbe portare numerosi vantaggi alla nazione, la quale ha bisogno di fonti di energia diversificate. Per rendere il processo di crescita ecologica più facile, il paese ha introdotto due piani di crescita e trasformazione, il primo dei quali era in funzione tra il 2010 e il 2015, mentre il secondo è entrato in vigore per il periodo 2015-2020. Entrambi i piani hanno come scopo quello di eliminare la povertà ed ottenere un aumento dell'11% del PIL, attraverso una crescita eco-sostenibile. Questo significa aggiungere 8.000MW alla quantità di elettricità prodotta dalle energie rinnovabili, aumentare la produzione di biocombustibili e creare un'economia resistente al clima. Quest'ultimo obiettivo è stato ripreso nella strategia per lo sviluppo di un'economia eco-sostenibile e resistente al clima, introdotta nel 2011, la quale ha come scopo quello di far sì che l'Etiopia diventi un'economia a emissioni zero entro il 2025. Il programma di adattamento al cambiamento climatico è stato creato nel 2011, per creare un'economia resistente al clima grazie all'apprendimento di come adattarsi sia a livello regionale che locale della comunità. Infine, la politica più vecchia riguardante l'ambiente è la politica sull'ambiente del 1997, che ambisce a migliorare le condizioni di salute e la qualità della vita dei cittadini, incoraggiando allo stesso tempo uno sviluppo sostenibile grazie all'uso di risorse naturali, culturali e create dall'uomo e alla protezione dell'ambiente. Negli altri settori energetici e nel settore dei trasporti, l'Etiopia non ha ancora ottenuto risultati rilevanti. Essa non ha infatti né uno schema di scambio di quote di emissioni, né una tassa sul carbonio o uno schema di cattura e stoccaggio del carbonio. Nel settore automobilistico essa ha provato ad introdurre veicoli elettrici ma la loro espansione non è ancora grande, in quanto il paese deve ancora affrontare una serie di problemi legati alla trasmissione e all'approvvigionamento di energia elettrica, soprattutto nelle zone rurali. Ciononostante, il solo fatto che l'Etiopia, la quale non è una di per sé una grande responsabile di emissioni di CO_2, abbia dimostrato un considerevole impegno nel diventare un'economia sostenibile dovrebbe essere preso come esempio da altri paesi in via di sviluppo. Il paese è responsabile di solo 0.3% delle emissioni globali, ma questo non l'ha fermato dallo sviluppare nuove fonti di tecnologie rinnovabili e implementare numerose politiche ambientali. Inoltre, il governo etiope crede che un aumento di energia proveniente da fonti rinnovabili possa essere vantaggioso per il paese, dato che l'energia in eccesso può essere venduta ai paesi limitrofi.

La conclusione della tesi è che non esiste un modo giusto o sbagliato per decarbonizzare l'economia di un paese, poichè ognuno ha risorse naturali, situazioni economiche e fonti di emissioni diverse. I casi analizzati ci hanno dimostrato come ogni tipo di nazione, dalla più ricca alla più povera, possa impegnarsi al massimo per contrastare il cambiamento climatico, cercando di bilanciare le sue forze e le sue debolezze e facendo in modo che ogni livello della società collabori per raggiungere questo obiettivo comune.