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The impact of investing in renewable energy on the economic growth and CO_2 emissions of EU countries

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ABSTRACT

This work studies the effects of investments in renewable energies on economic growth rates and CO_2 emissions for 26 countries of the European Union, between the years 1990 and 2010, using a fixed effects panel data analysis. Two different econometric models are evaluated, the first one aims at finding a correlation between the investment on RE and economic growth, while the second analyzes its correlation with carbon dioxide emissions. The models show remarkable results as the impact of renewable energy investments is mostly positive, in fact it reduces emissions in the long run, while it does not affect economic growth of any country. These results suggest that European policy makers should adhere to cleaner energy solutions and policies, incentivizing the production of renewable energy. In this way, by promoting an energetic transition towards lower CO_2 emissions and a sustainable economic growth, governments will be able to give up fossil fuels and rely on a cleaner and safer energy, improving the quality of life of the entire continent.

INTRODUCTION

The world we live in has radically changed compared to the beginning of last century. Thanks to discoveries and innovations in the medicine, industrial and electronic field, our world has become more interconnected than ever before. On one hand, globalization has brought us closer, mixing our cultures and preferences, enhanced by the longest period of peace the world has ever seen (at least for the majority of the nations), but on the other, we are exposed to the same risks, and in this situation we need to find common solutions. The reason why I chose to deal with the subject of renewable energies is that it is related to a current problem, which is represented by different factors, such as pollution, climate change and innovation. I have always been fascinated by new inventions, in particular those who could 'save the world', in this case from the greed of politics and selfishness. For this reason, I took the chance to analyze this subject to study which are its actual effects on the real world. The subject of renewable energy is dealt by the three main chapters of this study and each of them from a different point of view. In the first one, a definition of the characteristics of each type of renewable resource is laid down, describing what they are, their ability to produce electricity and their main general aspects. The first chapter also deals with the recent energetic transition, mentioning the importance of tackling climate change and the main actions taken by the European Union (which will be the sample of the empirical analysis in chapter 3) to promote renewable energies and reduce pollution, the main incentives, but also the greatest barriers in switching from polluting resources to renewable ones. The second chapter is characterized by a more economic approach, in fact an economic analysis outlines the effects of renewable energy investments on different macro areas of the economy, such as global trade, economic growth and employment. Finally, in the third chapter, an econometric model describes the impact of RE investments on two different variables, which are economic growth and CO_2 emissions.

CHAPTER 1 Pathways to a green economy

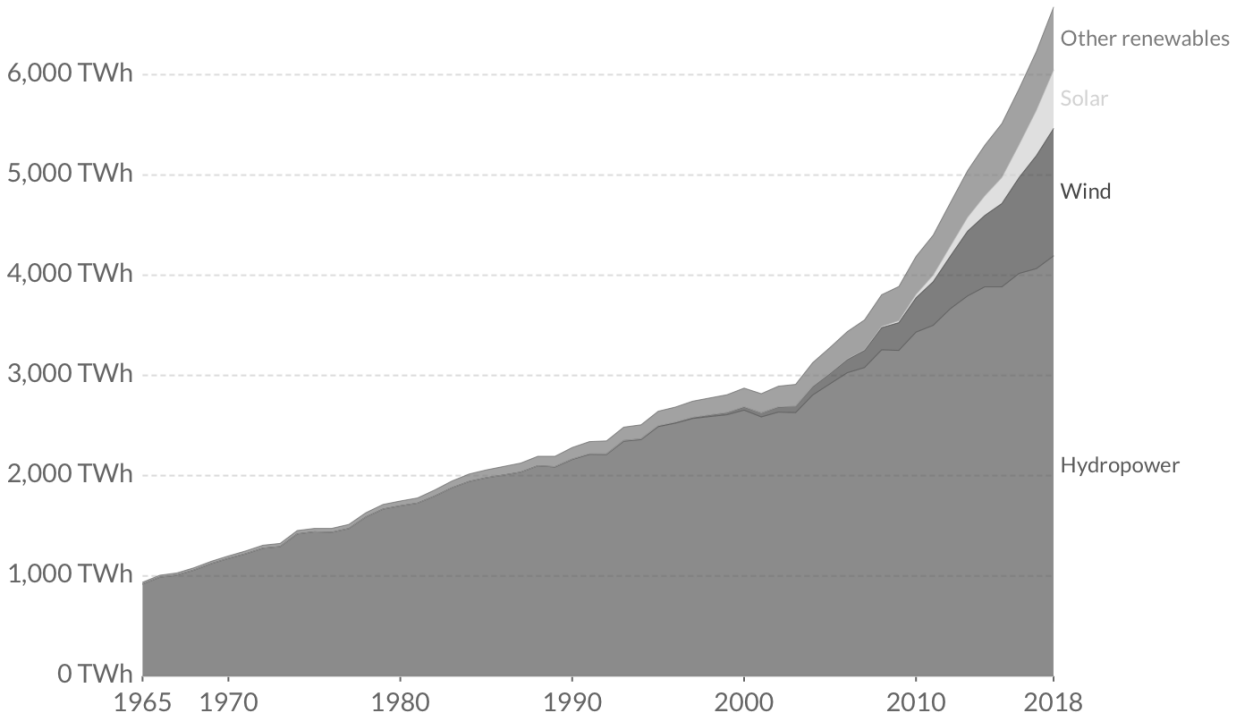
1.1 Renewable resources and their characteristics

Most of the activities that we carry out during the day involve the use of energy, from a phone call to watching a movie, from baking food in the oven to driving a car. This energy is obtained through renewable and non-renewable sources, and while the former represents a more clean and sustainable way to provide energy, the latter has proven to have a negative impact on the environment and public health. Renewable resources are a well-studied and researched topic in modern literature, and their definition is broad. Twidell and Weir (2015) define Renewable Energies as "*energy obtained from the continuing or repetitive currents of energy occurring in the natural environment*" (Twidell & Weir, 2015), pointing out the natural origin of these resources. Because of their natural characteristics, as stated by the research of Twidell and Weir (2015), renewable resources renew over time on a human timescale making themselves almost inexhaustible. This means that as humans invest more on renewable energies the impact on the environment will always be positive, as these resources are constantly replenished. This characteristic is what makes them environmentally desirable, and economically sustainable, which is crucial in scenarios such as growing economies, where the growing populations in countries as India or China has led to higher demand of electricity consumption. In fact, as expressed by Dincer and Acar (2015) "*one of the biggest challenges in the world is to meet the growing energy demands in an environmentally-benign and sustainable manner, especially in rapidly developing countries with their rising populations and standards of living*" (Dincer & Acar, 2015). What makes them even more desirable is the fact that they are considered to be the key factor in reducing fossil-fuel emission and tackling climate change, as stated by Nada Kh. M. A. Alrikabi (2014), countries will never face the problem of running out of renewable resources,

as these are evenly distributed around the world. This problem arises with other resources, for example oil and gas. In addition, renewable resources renew through natural process yielding no pollution or other waste in the environment. These resources are available throughout the year and in the long-run investing in this industry is more profitable even though it may have higher initial costs. Being widely available in many countries also results in energy security, which means that countries can rely on their own supply of energy and have lower competition over energy resources, and higher public health, reducing pollution in congested cities and enhancing 'green' transportation. Moreover, there have been improvements in the quality of life in those countries that started investing on green resources, which has also led to waste minimization in the industry sector. It is also helpful when trying to reach more remote territories and to solve problems of local energy shortage, that for example rely on fuel supplies.

The graph of figure 1.1, shows the global energy production of renewable resources in terms of Terawatt per hour (Twh) between 1965 and 2018. The production curve has been increasing since 1965, reaching its peak in

Figure 1.1 Global Renewable Energy Generation



the 2000s, period in which investments have increased in other resources besides hydropower, that as can be easily inferred, is the most prevalent throughout the entire sample period (Statistical Review of World Energy, 2019). Renewable Energies can be divided into different categories based on their use or purpose, in fact they can be seen as "*any energy source that is naturally regenerated over a short time scale and either derived directly from solar energy (solar thermal, photochemical, and photo- electric), indirectly from the sun (wind, hydropower, and photo- synthetic energy stored in biomass), or from other natural energy flows (geothermal, tidal, wave, and current energy)*" (Cleveland & Morris, 2005).

1.1.2 Solar Power

The energy coming from the sun is the main resource of renewable energy that is available everywhere on the planet, and for this reason it is considered the most convenient and reliable. Solar energy has many uses, in fact, it is collected and used through different technologies, mainly in the form of thermal and thermodynamic for domestic use, but it is also harvested through Photovoltaics cells, versatile devices commonly installed on roofs, ground or on poles. In the last decade the investments on solar panels have increased by 30%, especially in the agricultural sector, where there is a considerable interest to prevent waste. Other uses are water heating, battery charging or street lighting, which is very helpful in more remote and inaccessible areas. Despite being very popular its cost is still high with respect to other substitutes in fact "*only 0.04% of the basic power used by humans comes directly from solar sources because using a photovoltaic (PV) panel costs more than burning fossil fuels*" (Mohtasham, 2015). Nevertheless, as the above cited study continues, the price of solar panels is dropping as of 2019 and they come with many advantages, as "*solar energy is non-polluting, does not create greenhouse gases, such as oil-based energy does, nor does it create waste that must be stored, such as nuclear energy*" (Mohtasham, 2015).

1.1.3 Wind Power

Wind power is one of the most dynamic among these resources. Ever since the middle ages windmills and wind pumps were very common in Europe and helped shaping the agricultural sector. Nowadays the main use of wind around the world is to provide electricity through the construction of wind turbines, which are based on the exploitation of wind energy that originates from the earth's thermal asymmetries, and therefore can be defined as a solar energy. First developed in the late nineteenth century, wind farms have changed throughout the years and represent a source of renewable energy, with a very low impact on the environment. Both onshore and offshore wind turbines are built on rural and coastal areas where they are spread over a wide territory, often affecting animal ecosystems and modifying countryside landscapes. Especially in developing countries, wind power represents a solid alternative source to fossil fuels, as it maintains a stable price and constitutes an inexhaustible resource. In addition, the energy coming from wind turbines is not available on demand as the direction and strength of winds changes, but over a year the yield of energy is constant, varying in different months. Thanks to its characteristics "*wind technology is simple, and it is mature in developed countries. Although wind energy is a small industry, it is competitive*" (Dincer & Acar, 2015). As Dincer and Acar (2015) affirm, wind energy is growing in popularity and investments, but it is still a small industry when compared to other renewable energies such as solar or hydroelectric. Wind power plants in Europe are mainly located in the north, where in countries such as Denmark the energy coming from wind turbines amounts to 12.5% of total energy production, but also in southern countries such as Spain it represents a significant source of energy.

1.1.4 Biomass Energy

Biomass energy is a renewable source that consists in the exploitation of animal or vegetal substances, such as food waste, wood residues or other organic materials, in order to produce heat and electricity. Biomass energy has been used for more than one could imagine, thanks to its versatile characteristics, as discovered by the previous cited article of Javid Mohtasham (2015), "*the use of biomass energy has the potential to greatly reduce greenhouse gas emissions, dependence on foreign oil, landfills, and finally supports local agricultural and forest-product industries*". It has many benefits; biomass industries generally dedicate entire acres of fast-growing trees such as bamboo as feedstocks instead of supporting intensive food-crops. It can also be converted into different materials and fuels for transportation, or even to produce electricity, in fact the energy contained in plant biomass can be converted using thermochemical, biological or physical processes. The outcome is a high energy density product, which can be used more easily and flexibly in subsequent energy conversion devices. Nevertheless, the impact on the environment may be high in some situations due to land erosion or transportation emissions.

1.1.5 Geothermal Energy

This type of energy takes advantage of the heat under the earth's crust, together with water trapped under the surface, in order to produce electric power or more commonly to provide energy for heating systems. The closer to the earth's nucleus the higher will be the temperature because of its nuclear reactions that generate heat. Part of that energy goes up to the surface where it meets water and creates a source of steam, used in the turbines to produce electricity. To build a geothermal plant is needed an underground inspection of the territory where a dwell is dug down, a process that can be very expensive. Obviously, the areas more suitable for this exploitation are the ones close to volcanoes or geysers. Intuitively, the

energy coming from eruptions of magma or air, is not always available, but what makes it a renewable source is the internal heat of the earth which instead is inexhaustible and has a low impact on the environment, where no fuel is ever used in the process. The main disadvantage is that there are a limited number of areas where geothermal plants can be built and there is also the threat of volcanoes and earthquakes to take into account, occurring more frequently in those territories. As John W. Lund, Derek H. Freestone and Tonya L. Boyd (2005) denote in their study, geothermal energy has many uses; from space heating to agricultural crop drying, with the former being the most widespread across EU countries. Especially in Iceland, the energy consumption coming from geothermal sources is over a half of the overall energy supply (W.Lund, H.Freeston, & L.Boyd, 2005).

1.1.6 Hydroelectricity

Among the natural resources that today we exploit to produce electricity, water is the one that has always been present in many sectors across centuries. It has maintained a primary role in feeding crops and livestock and for other different uses, such as in mills in wheat production. Today, water resources offer more than 17% of global electricity consumption, and the greater part of their potential has still to be exploited, especially in Africa, Asia and South America. Countries such as India or China, and other developing economies where more than two billion of people currently live, are planning to build hydroelectric plants on a large-scale as they consider this energy as fundamental for their economic growth. Hydroelectricity has unique advantages unlike other resources like fossil fuels, for its impact on the environment. For example, a dam is able to provide a stable supply of water to households and to the agricultural sector, but also a better control of navigation and floods. On the other hand, the main environmental concern is related to the construction of water tanks and water dams that provoke social and natural changes but nonetheless it represents a safe

technology whose costs are lower compared to other renewable resources, and its facilities can be used for a long time.

1.2 Energetic transition and global concern

Fossil fuels such as petroleum, coal or natural gas have represented the main source of energy for many nations around the world for decades. The amount of these resources though is not infinite, and they are compromising the environment; they are not available everywhere and at any time and have a serious impact on global ecosystems. Around the 1970s scientists started studying the effects pollution had on human health, and ever since, world leaders have gathered to find a common solution to prevent a global cataclysm. People have become aware of the health-related problems caused by the emission of carbon dioxide in the atmosphere, which represent a real threat to humans, but more generally to every species. The main problem related to pollution is that the enormous quantity of carbon dioxide released in the air is one of the causes for global warming and climate change, to which renewable energies represent a solution, capable of reducing pollution and mitigate climate problems. In order to promote investments in this sector, incentives have proven to be necessary, even though many barriers still exist.

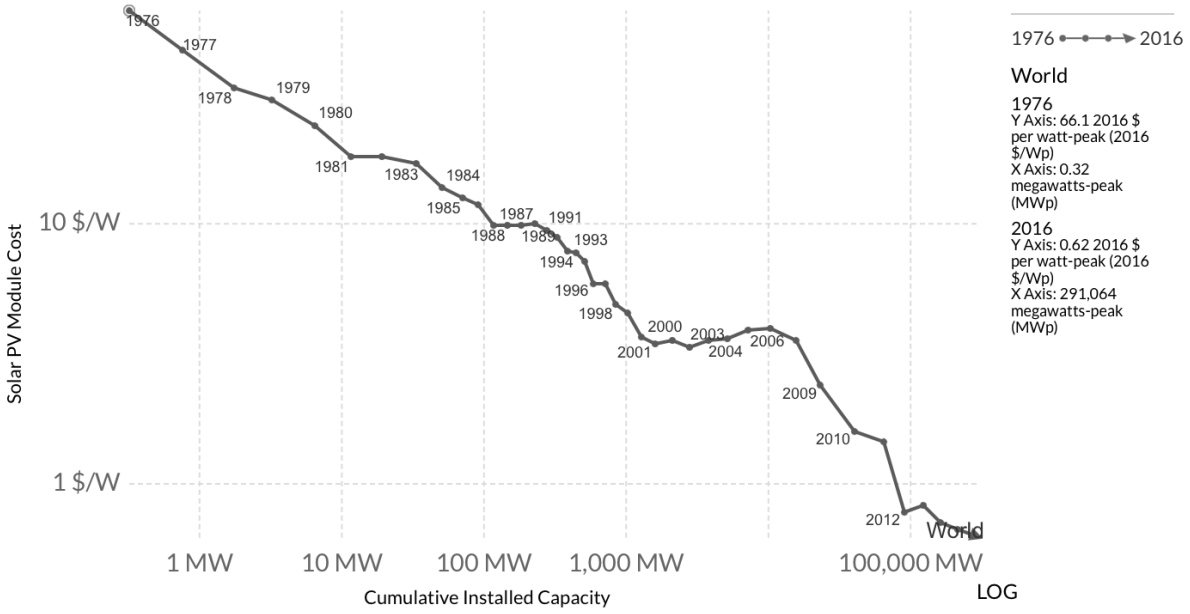
1.2.1 Switching costs, barriers and incentives

The term 'energetic transition' refers to a long-term change, switching from one way of producing energy to another. In the recent times there have been many instances in which an energetic transition has taken place, from the industrial revolution, between the seventeenth and eighteenth century, to the use of the oil, and finally to renewable resources. It is determined by technological and political factors, and its impact is hard to foresee, in fact an energetic transition is a long and slow phenomenon. The energy sector is mainly influenced by the set of new policies and directions that are being adopted by governments across the world in response to climate change on

one hand, and on the other by the new technologies that are employed, both varying according to each country's available resources. The need for policies and incentives is justified by the existence of many barriers in the energy sector that prevent investors to exploit its opportunities. Such barriers are reflected in "*subsidies for conventional forms of energy, high initial capital costs coupled with lack of fuel-price risk assessment, imperfect capital markets, lack of skills or information, poor market acceptance, technology prejudice, financing risks and uncertainties, high transactions costs, and a variety of regulatory and institutional factors*" (Beck & Martinot, 2004). As the research done by Fred Beck and Eric Martinot (2004) suggests, there are many factors that may prevent investors from entering the renewable energy business. As the above cited work goes on, the authors mention the main costs and restrictions in the renewables market, in particular the initial costs, which are very high when compared to alternative fossil fuels. This results in less installed potential and higher financing for the same amount of output, making renewable energies projects riskier. When considering instead the 'lifecycle' costs, that include also future price fluctuations, conventional resources appear to bear more risk as future fuel price fluctuations would represent a burden and uncertainty. In addition, the real costs of fossil fuels are born by society, in terms of health-related issues and economic problems (e.g. loss of forests and polluted waters). From a legal point of view, the research above mentioned continues, addressing the practical issues that may represent an obstacle for the renewable energy manufacturing; facilities, plants, PV installation or wind turbines could face restrictions due to their noise, height or safety, or due to environmental concerns regarding for instance wild animals' habitats that would be violated. On the other hand, many nations such as the United States, Japan, or countries in Europe have implemented incentives and cost reduction policies to stimulate investments in clean energies. Subsidy programs and tax relief, as well as tax incentives and investment tax credits have become popular, in order to promote renewable energy investments. Low rate loans and grants programs have offered

many opportunities and have permitted a better access to this new technology, in addition to green certificates, that started to be employed predominantly in Europe but later widespread globally. Green certificates are a new tradable commodity valid for three years that is proportional to the clean energy provided. They distinguish themselves on the type of renewable energy source and size of plant and can be sold providing an additional profit to the owner besides the renewable energy produced.

Figure 1.2 Solar Photovoltaic module prices vs. Cumulative capacity, from 1976 to 2016



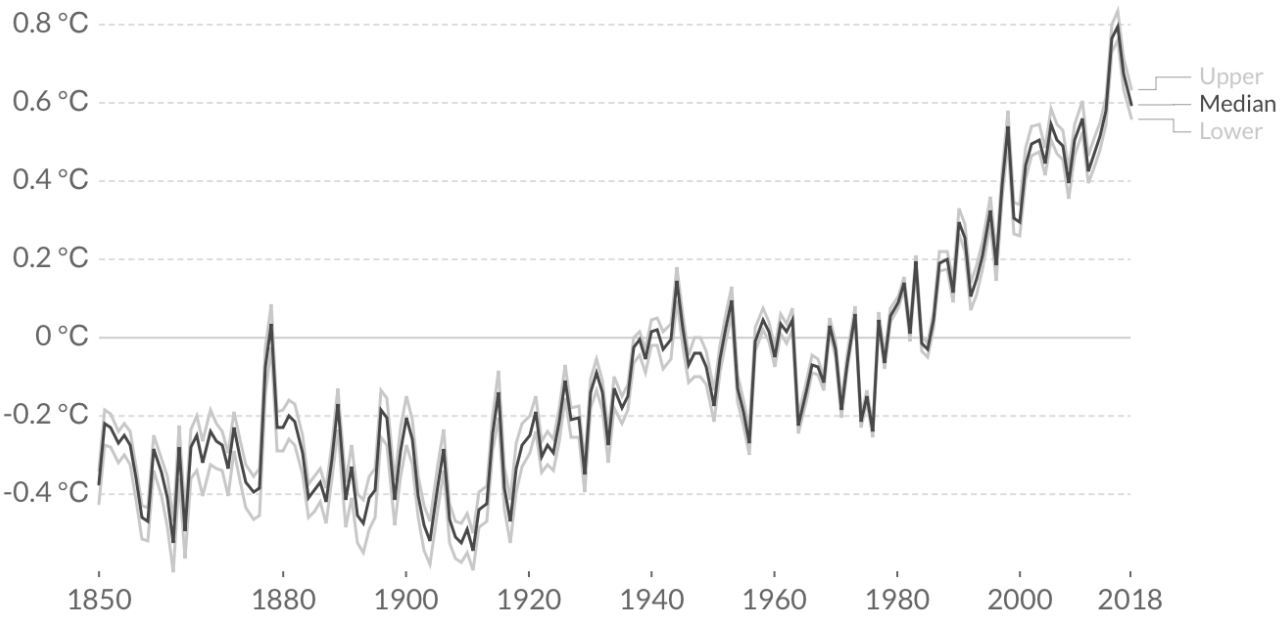
Although renewable energy costs appeared very high when these new technologies were first introduced in the economy, their prices have been decreasing ever since, as it is showed in figure 1.2 in the case of PV with respect to their cumulative capacity (François, et al., 2018). Nevertheless, the actions taken by government to encourage companies to invest in green energy will be needed in the future, as fossil fuels and other polluting resources will always represent a valid investment.

1.2.2 Climate threats and solutions

Climate changes have always occurred throughout history, but only since the modern era we have been able to quantify weather mutations, thanks to new technologies such as the introduction of meteorological instruments. In particular, a global and reliable analysis of climate changes was only achievable from the mid-nineteenth century. Since that period, we have been able to study climatic events and severe weather phenomena like excessive precipitations or tropical cyclones that have enabled us to make predictions about future patterns and possible threats. What has mostly concerned scientists though, have been the rising temperatures around the globe. Since the 1990s global warming has become a main environmental concern, mainly because of related natural disasters, air and sea pollution and health-related diseases. The presence density in the atmosphere of greenhouse gases such as carbon dioxide and chlorofluorocarbons, which is much higher than pre-industrial levels, has led to the increase of the average global temperatures as affirmed by Prajit K. Dutta and Roy Radner (2004), "*there is a growing scientific consensus that global warming and related climate changes have been occurring during the past three centuries, that a significant factor in this trend is the accumulation of atmospheric greenhouse gases (GHGs), and that human activity is largely responsible for this increased concentration*" (Dutta & Radner, 2004). The level of emissions of CO_2 is expected to increase in the future, unless there are drastic changes regarding pollution policies and renewable technologies are introduced in the economy. To address the climate issues and to provide the community with scientific information regarding climate change risks, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) founded in 1988 the Intergovernmental Panel on Climate Change (IPCC), which has provided since then five assessment reports that offer a general review of the latest climate change improvements. It has been estimated by the IPCC that the terrestrial

temperature has increased by 0.5 C° since 1975 and in the next century the increment will more than double. In particular in the last thirty years the

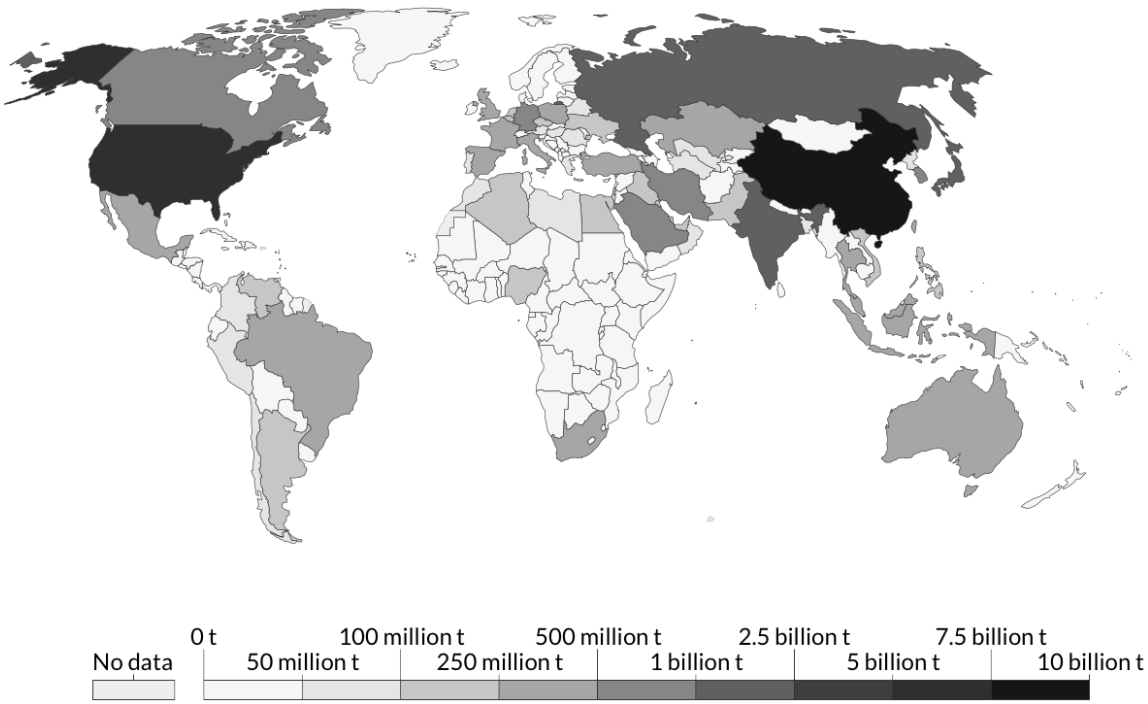
Figure 1.3 Global Average Temperature Anomaly



average annual temperature has risen in a more acute way with respect to the beginning of the century, in fact it led to the warmest decade between 1995 and 2005, where every year consecutively has been registered as the hottest year ever recorded since 1861. As shown by the graph above in figure 1.3, the average global temperature has maintained a rising trend since the beginning of the twentieth century, reaching a record high in the 2010s (Morice, 2016). Some scientists have thought of this period as a natural climate transition that is said to occur eventually, but the truth is that a more significant climate mutation is taking place, which has been enlarged and altered by human activities. If no action is taken to slow down the process, the outcome would be catastrophic, and every sector of the economy would be hit. From agriculture, that would be strongly damaged by events as drought and floods, to tourism, which will decrease in winter due to lower snowfall and in summer due to coastal erosion. A series of non-reversable events would begin that will permanently affect the environment, the melting of the icecaps at the north pole and consequently the rising of sea levels could change the planet as we know it. The evidence

of climate change has not been equally addressed by world leaders, but according to the study conducted by Ole Røgeberg, Steinar Andresen and Bjart Holtsmark (2010), the issue of climate change began to gain attention among governments by the 1970s, when at the World Meteorological Conference the dangers of climate change became subject of scrutiny and discussion by the international community, and later on in the late 1980s the UN General Assembly decided to gather a climate convention, at a time where climate change was merely a hypothesis based on scientific data. The UNFCCC (United Nations Framework Convention on Climate Change), environmental treaty that was later adopted in the Rio 1992 'earth summit', on the basis of the IPCC 1990 supplementary report that addressed the possible links between human activities and climate change, had as primary goal to keep stable the greenhouse gases concentration in the atmosphere. The summit is considered the first international non-binding treaty where industrialized countries were asked for the first time to stabilize emissions by the 2000s, to prevent further damages to environment, in particular the most industrialized and polluting countries were called to take the greater part of responsibility and to equally share the efforts. Figure 1.4 describes

Figure 1.4 Annual CO_2 Emissions, 2017



the actual situation of annual CO_2 emissions in 2017, where countries such as China, United States, India and Russia, account for the greatest part of global pollution (Quéré & al., 2018). Following the 1992 summit, every year starting from the mid-1990s, specifically in 1995 in Berlin, an international conference is held, called the conference of the parties (COP), which is meant to address the global improvements in fighting climate change and outline what actions are needed to be taken. One of the most important among these meetings has been the COP 3 in Kyoto, Japan, in 1997, where the 193 nations adopted the Kyoto Protocol, which came into force in 2005. In this case the treaty represented an obligation that required the nations that adhered to it to reduce emissions of CO_2 and other greenhouse gases, that from the beginning appeared to be difficult negotiations. Another remarkable and historical agreement was reached in 2015 at the 21st COP in Paris, later known as the Paris Agreement whose basis is represented by the fourth report of the IPCC, and whose main objective is to prevent the average global temperatures to rise above 2 C^{O}. The nations also agreed on reducing emissions by 2050, and for the first time, developing countries participated to the conference as an independent group. In spite of everything, treaties are based on each country's commitment to pursue the same path of change and unity and represent the first step towards this common goal, calling for every nation to take part, as Albert Einstein once said, "*the world will not be destroyed by those who do evil, but by those who watch them without doing anything*".

CHAPTER 2 *Clean energy investments: an economic analysis*

2.1 Economic benefits from investing in renewable energies

As mentioned in the previous chapter, renewable energies represent a valid choice of investment for many reasons, which go from environmental concerns, such as reducing greenhouse gases emissions, to economic motivations, as these resources not only have enabled countries to eliminate wastes and improve the quality of life of the population, but they have also boosted economic growth and innovation. From a macroeconomic point of view, understanding the consequences and advantages this transition would bring is crucial and has become a matter of global consideration. As the world's population is dramatically increasing, especially in underdeveloped countries such as in Africa, where "*the continent's current population of about one billion is projected to rise to between 3.1 and 5.7 billion with probability 95% by the end of the century*" (Gerland, et al., 2014), the energy demand is growing every year and nations are becoming more involved and interested in investing in renewable energies potential, without mentioning the climate change concerns that are pushing governments to take action. In this scenario the adoption of a renewable system has proven to be significant in shaping the socio-economic aspects of our society and creating new opportunities. According to the study of Rabia Ferroukhi et al. (2016), in fact, global GDP will rise by more than one trillion dollars in response to the energetic transition, but also employment and human well-being will improve in the future as the investments in this sector will follow a positive trend, each depending on economic factors at national level, such as technological development, costs and available infrastructures (Ferroukhi, et al., 2016). As the article goes on, other changes are mentioned that will be brought to the world economy modifying entire sectors, as for instance the increase in

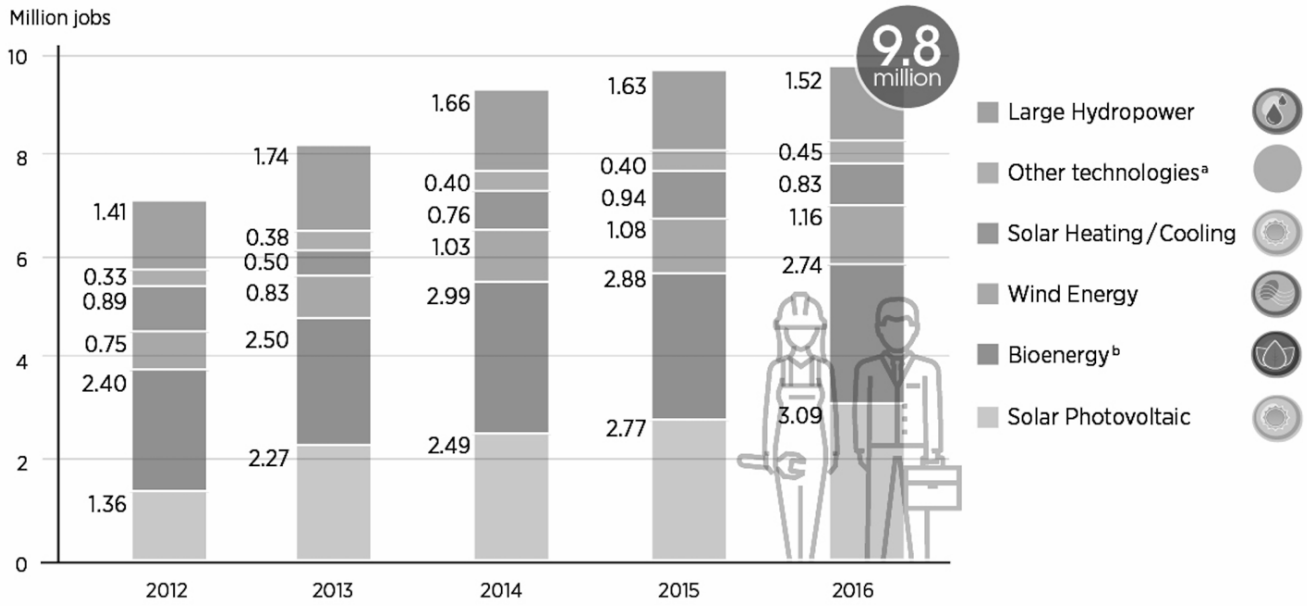
the share of energy coming from renewable resources will create new markets and disrupt others. The consumption of fossil fuels and its production will decrease and will have implications for global trade, more countries will rely on their own production of energy without having to pay high tariffs on imports and depend on foreign countries. The number of people employed will greatly increase due to the construction of new facilities and plants and will be covering the losses in jobs in the fossil fuel industry, as job creation is the main positive consequence of the transition (Ferroukhi, et al., 2016).

2.1.1 The impact on Employment

The employment rate is one of the most important macroeconomic variables in the economy and represents the key to economic development in a country, as explained by Lawrence H. Summers, policymakers are aware of its importance and must keep this rate under a certain threshold (Summers, 1981). The creation of jobs is determinant in order to achieve welfare sustainability and it is the primary goal of every government that aims at guaranteeing growth and social stability. The energy industry represents a stable source of employment as electricity is constantly required by households, and keeps on growing, as stated by the 2019 edition of the EurObsverv'ER, "*around 1.51 million persons are directly or indirectly employed in the European Union renewable energy sector*", with Germany, Spain and France leading in employment rate, followed by UK and Italy, totaling a "*growth of 67 000 jobs (+4.6%) between 2017 and 2018*" (Lescot & Tuillé, 2019). These figures are comforting in the light of the global recession that has damaged the world economy the last decade, in fact, as the above mentioned research done by Rabia Ferroukhi et al. (2016) affirms, after the 2008 crisis the energy industry was particularly hit, registering substantial losses in employment, as many other businesses. Part of the recovery is accounted by a constant growth in the renewable

sector that over the last years has represented a relief for the economy. Proof is given by employment rates, varying across the globe, with the largest employers being China, in addition to many other Asian countries, providing more than 3 million jobs, and Brazil "*the second largest employer, has almost 1 million employed",* and a future outlook for this sector that is even more encouraging, as the author continues, employment will reach around 14 million workers by 2030 as doubling the investments in renewable energies will sharply increase the number of people employed directly and indirectly (Ferroukhi, et al., 2016). In particular developing countries as India, China or Mexico will thrive in this energy development, where the manufacturing of equipment and the availability of working

Figure 2.1 Number of workers employed in the renewable energy sector from 2012 to 2016



capital will represent a primary resource that will allow them to become the principal employers in the world. This trend can be explained by the exponential growth of some regions such as southern Asia, and central America, by new investments, moved by the aspiration to become world leaders, especially in India where, as the study proceeds, "*meeting its 2022 target of 100 GW of solar alone is expected to create 1.1 million jobs*" (Ferroukhi, et al., 2016). On the y-axis of figure 2.1 we can notice the increasing number of jobs in millions across different renewable energy sectors, while on the x-axis the years from 2012 to 2016, describing a

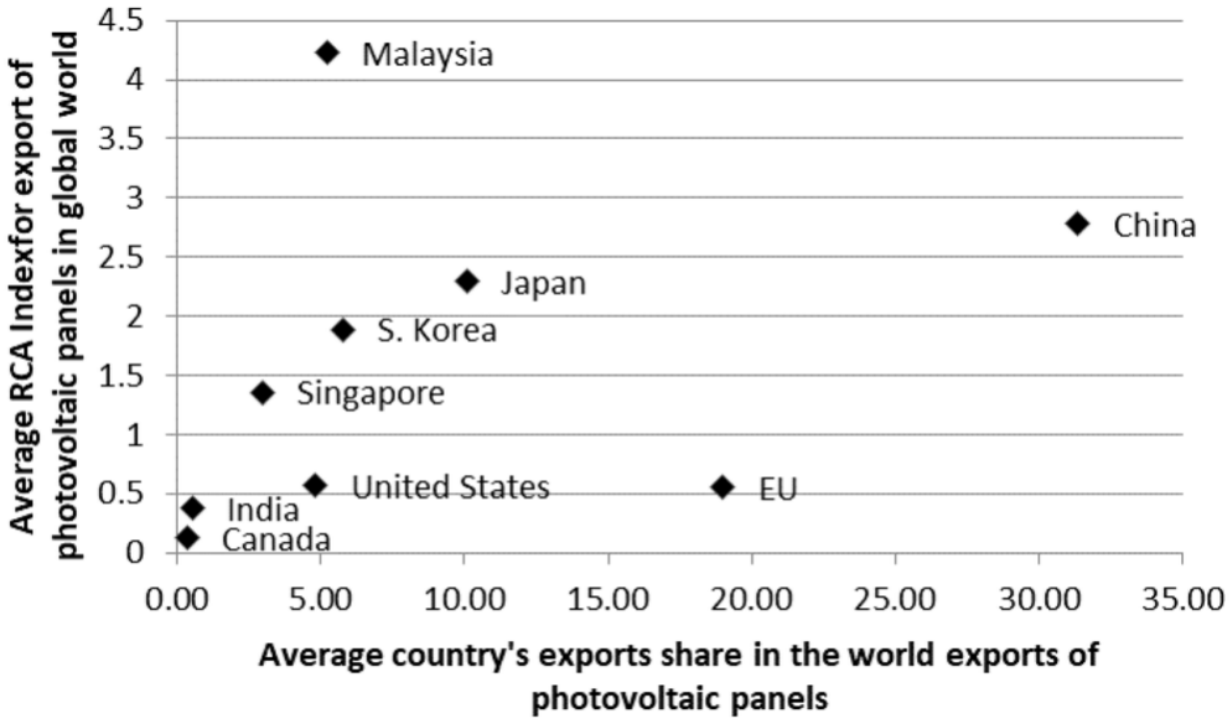
positive trend especially in the solar photovoltaic and bioenergy sectors (Ferroukhi, Khalid, García-Baños, & Renner, 2017). Investing in these resources does not only involve an economic transition due to the growing employment in the construction, installation and maintenance industries, but also an increase in jobs in sectors such as tourism and environmental protection. Traditionally, employment and environmental protection policies have been viewed separately and never as integrated and often also in a conflictual way. With the sustainable development strategy, on the other hand, closer integration between sector policies must be promoted, which will have a positive impact on tourism. The well-preserved environment is the source of growing tourist demand. Today this demand is growing all over the world and in Europe in particular. At the basis of these economic changes, which will upset global balances, there is the will of the international community to undertake a path of sustainable development to generate wealth without destroying the environment and without increasing the gap between wealth and poverty. Sustainable development is based on a wise use of natural resources, in particular, it is based on the most efficient use of energy, in order to respect natural cycles and the carrying capacity of ecosystems on extending the benefits of development to as many subjects as possible. It is therefore an economic, environmental and social development.

2.1.2 The consequences for global trade

In recent centuries, industrial development and economic globalization (the creation of a single global market), have favored the transfer of goods and services across international borders. Never as in the twenty-first century have the countries around the globe been able to exchange goods as fast and easy, representing an opportunity for them to exploit their competitive advantage, especially for those who already have invested in renewables, and enrich their economies. This aspect is a key characteristic of well-functioning economies, in fact, having access to international markets is an

important source of income and allows to be connected to enormous exchange networks. In the past thirty years the value of goods traded globally has more than quadrupled in terms of trillion of dollars, especially with regards to the fuel market, representing the majority of all goods traded, mainly coming from a small group of exporters. On one hand, imports of fuels could be particularly reduced by the introduction of renewable energies, benefitting small economies that depend on foreign goods. On the other, economies that rely on exports could thrive as well differentiating the energy production and reducing the environmental impact. The overall impact on global trade will be positive, as Rabia

Figure 2.2 World exporters of Photovoltaic Panels



Ferroukhi et al. (2016) assert, the volume of trade in the future decade will be greater than it has ever been, considering the reduced fossil fuel production which will be offset by the growing supply of renewable energy (Ferroukhi, et al., 2016). In particular this energy transition from polluting to non-polluting resources stems from a decreased demand for exports and imports of fuels and the increase of 'green' investments, leading to a shock for fuel exporting economies for the fact that a lower volume of trade will also impact their overall demand for goods and services, thus reducing the

gross domestic product. For the greatest part of importers instead, as the study above cited states, the "*switch to a greater share of renewables has potentially favorable trade implications. Reducing fuel imports can improve trade balance and improve GDP*", meaning that doubling the share of renewable energy production could bring major economic benefits, together with reduced risk due to fluctuation in oil prices and improved energy security (Ferroukhi, et al., 2016). There is a vast range of opportunities brought by renewable energies, in particular for developing countries that lead in exports, such as China, which in addition to being the largest employers is also the main exporters of renewable energy, as studied by the EurObsverv'ER (2019) (Lescot & Tuillé, 2019). The research analyzes the volume of trade in the recent years, showing that the observed countries in the sample, varying from Asian to European economies, all register an increment in trade, describing Germany, The Netherlands, and Denmark, as the greatest traders after China, whose main strengths, as outlined by the report, come particularly from its concentration in Photovoltaic installations, that were built on a large scale through the use of the latest technologies (Lescot & Tuillé, 2019). This characteristic is also showed in figure 2.2, that depicts the largest exporters of Photovoltaic Panels, pointing out the major world trader as China (Agnieszka & Bożena, 2020). For what concerns the trade of single renewable energies the strongest increase is registered in Germany with regard to wind energy, followed by Denmark and Spain, as The State of Renewable Energies in Europe (2019) outlines, "*these three countries in sum generate a worldwide export share of 98%*" (Lescot & Tuillé, 2019). In the hydroelectricity market instead, there is an overall balance where China is still owning the largest share competing with the major European economies. The United States are the primary producer of Biofuels, keeping its position below the other economies in the other renewable energies' fields (Lescot & Tuillé, 2019).

2.1.3 Repercussions on economic growth

The term economic growth refers to a macroeconomic phenomenon which is characterized by a long-term development of the economy as a whole, more specifically as "*an increase in the production of goods and services over a specific period*" at a national level (Amadeo K. , 2019). It represents a determinant factor that has proven to be influential for many economic decisions, as declared by Roy Thurik and Sander Wennekers (1999), "*economic growth is a key issue both in economic policy making and in economic research*" (Thurik & Wennekers, 1999). Economic growth is in turn characterized by different elements that the researchers Giulio Cainelli, Rinaldo Evangelista, and Maria Savona (2004) have researched in their study, outlining that "*It is widely acknowledged that technological change and innovation are major drivers of economic growth and lie at the very heart of the competitive process*" (Cainelli, Evangelista, & Savona, 2004), showing that these variables, when introduced in the economy have a significant impact, as they enable firms to out-perform others in the market. These two factors enable businesses to reach higher productivity while lowering the costs of production. In fact, the introduction of new technologies and ideas leads a country to be more productive and to supply more goods and services, hence directing the economy to a constant growth, a process that is advantageous for both producers and consumers as it creates jobs and improves welfare. To estimate the impact of these variables on economic performance and production, the most widely adopted measures are GDP (Gross Domestic Product) and GNP (Gross National Product) and while the former takes into account the value of all final goods and services produces within a country in a specific time period (Amadeo K. , 2020), the latter "*includes income earned by citizens and companies abroad, but does not include income earned by foreigners within the country*" (Merriam-Webster, 2020). These analytical tools allow policymakers and investors to determine whether the economy is about to undergo a recession or expanding, but also the effect of taxes or other fiscal plans on the economy, as stated by Diane Coyle (2014), in relation to the

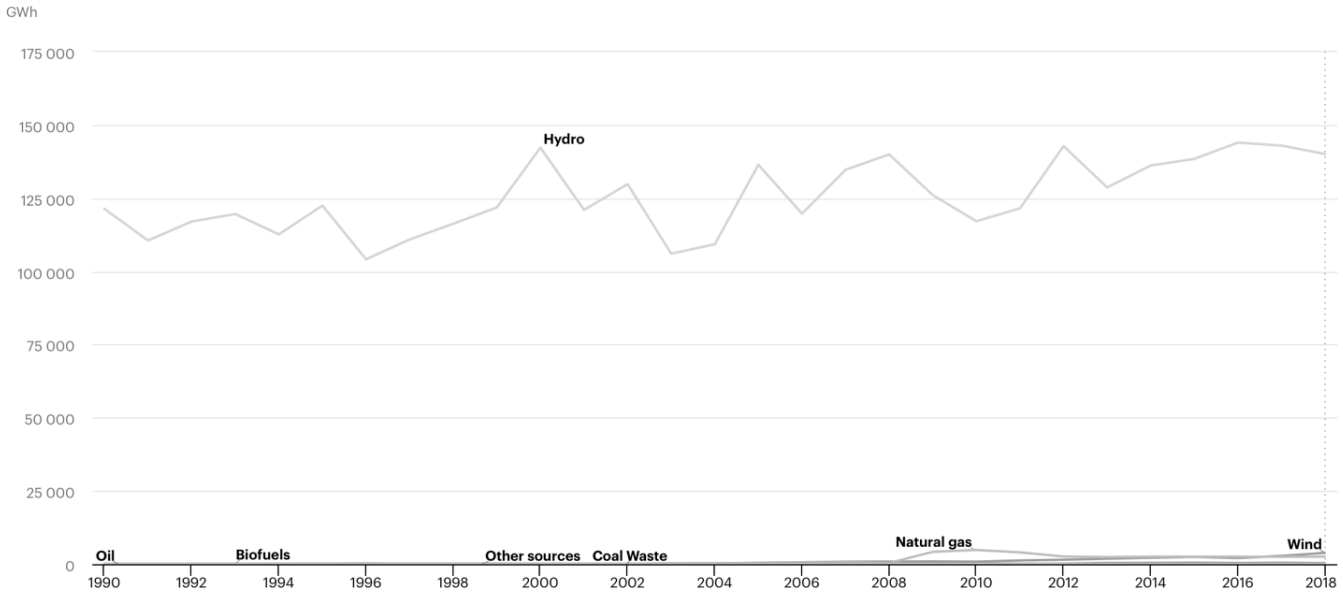
utility of measures such as GDP, "*we have been taking the growth of GDP as our measure of whether we are growing more prosperous, or better off in a wider sense*" (Coyle, 2014). Hence, positive and negative GDP can be used to assess the health of an economy, and it is correlated to other variables such as unemployment rate, which will be low in case of an economic growth and vice versa in case of recession, but also investments and stock prices. As previously stated, the introduction of innovative technologies can have an impact on GDP and the growth of a nation. This is also the case for renewable energies, as forecasted by the aforementioned study of the International Renewable Energy Agency (2016), doubling the production of renewable energies would increase global GDP by an amount "*between USD 706 billion and USD 1.3 trillion" in 2030.* (Ferroukhi, et al., 2016)*.* Besides aiming at enhancing global welfare, these investments also aim at improving global health conditions through the reduction of emissions in the atmosphere, as studied by the research of Susana Silva, Isabel Soares and Carlos Pinho (2011), that analyzed the impact of increasing investments on renewable energy on economic growth and how it affects GDP and also on emissions (Silva, Pinho, & Soares, The impact of renewable energy sources on economic growth and CO2 emissions- a SVAR approach, 2011). Their study has found that economic growth may initially be hurt by the introduction of these technologies, explained by the high initial costs and that this "*economic cost may disappear as these sources become economically competitive*". The study also shows a positive effect on emissions (Silva, Pinho, & Soares, The impact of renewable energy sources on economic growth and CO2 emissions- a SVAR approach, 2011). In modern literature this is a topic dealt with extensively and finds many interpretations. It has been the subject of many studies that have revealed its importance to the global economy, particularly that of Roula Inglesi-Lotz (2016) has in addition revealed that *"a 1 % increase of renewable energy consumption will increase GDP by 0.105% and GDP per capita by 0.100% while a 1 % increase of the share of renewable energy to the energy mix of the countries*

will increase GDP by 0.089% and GDP per capita by 0.090%" , stating that the final benefits of this transition are remarkable (Inglesi-Lotz, The impact of renewable energy consumption to economic growth: A panel data application, 2016).

2.2 100% green potential: the case of Norway

The European plan to reduce emissions of greenhouse gases by 2050 is mainly based on increasing the production and consumption of renewable energy and consequently reduce the supply of fossil fuels, as suggested by Sophia Ruester et al. (2014) "*the overarching long-term EU climate policy goal is to reduce greenhouse gas (GHG) emissions within the EU by at least 80% below 1990 levels by 2050*" (Ruester, Schwenen, Finger, & Glachant, 2014). As claimed by Vicki Duscha et al. (2016) in their work, the increasing investment in clean energy will improve the energy security in Europe, and help fighting climate changes (VickiDuscha, et al., 2016). This is true for all the economies that are trying to switch from fossil fuels to renewable

Figure 2.3 total electricity supply by source, Norway 1990-2018



sources, a process that relies on many factors and will take several years, as the aforementioned research by Sophia Ruester et al.(2014) "*the EU commitment to achieve an almost entirely decarbonized European energy*

system by 2050 requires a stable long-term policy framework" (Ruester, Schwenen, Finger, & Glachant, 2014). The benefits illustrated in paragraph 2.1 come from early investments in these technologies, but what happens when an economy is able to supply 100% clean energy? There are few examples in Europe, mostly coming from the northern region, where nations have turned green their entire electricity supply. This is the case for Iceland that in fact "*generates 100% of its electricity with renewables: 75% of that from large hydro, and 25% from geothermal*" (Gipe, 2012), but also *"other countries that have electric grids with high fractions of renewables based on hydropower include Norway (97%), Costa Rica (93%), Brazil (76%), and Canada (62%)"* (Kroposki, et al., 2017). In particular the situation in Norway is similar to the one of Iceland. The country is about to become 100% green going from a country that relied on oil to the adoption of renewable resources, as "*Norway's $1tn oil fund, the world's largest sovereign wealth fund, is to plunge billions of dollars into wind and solar power projects"* (Carrington, 2019). Its electricity production has historically been based on the exploitation of the territories' lakes and rivers to produce hydroelectric power. As shown in figure 2.3 (Electricity Information, 2019), the main resource from which Norway produces energy is hydroelectricity, as also affirmed by Audun Ruud et al. (2011) "*nearly 100 % of electricity consumption in Norway stems from hydropower*" (Ruud, Egeland, Jacobsen, Knudsen, & Lafferty, 2011). Norway is also investing in the electric car markets, another source of clean energy in order to reduce cars' emissions in congested cities, in fact "*the Norwegian government set a target to get 50,000 electric vehicles on its roads by 2017 – something it managed to do more than two years earlier than expected*" (Norway's leading the charge on a sustainable electric future, 2019). A total reliability on renewable energy has long-term effects, as the study Brian Vad Mathiesen et al. (2010) on the effects of renewable systems claims, the emission of greenhouse gases would be largely reduced, without

mentioning the economic benefits as lower costs and increased savings, or the reduction in health-related diseases due to a cleaner environment (VadMathiesen, Lund, & Karlsson, 2011). As paragraph 2.2 pointed out, the long-term benefits are also related to an increase in employment rate and overall welfare.

CHAPTER 3 *Consequences of renewable energy investments on economic growth and CO_2 emissions*

3.1 Impact of renewable energy investments on growth and emissions: literature review

In the last few decades the relationship between investments on renewable energy and economic growth and carbon dioxide emissions has been subject to attention and research, but many governments are still very skeptical about their economic impact. The previous chapters have shed a light on the main characteristics and consequences of these modern technologies, pointing out a positive correlation between renewable sources and economic development. Nevertheless, when a new technology or innovation is introduced in the economy many individuals, communities, and governments are scared by the possibility that risky investment might have negative repercussions. In spite of this, there is empirical evidence that shows the importance of an energetic transition from polluting resources to 'green' investments, in fact, many studies have focused on explaining how an increase of renewable energy production can improve one country's wealth and reduce pollution, and their findings have sometimes resulted contradictory, but showed the increasing recognition that these resources are receiving and their potential to make a remarkable change to society as we know it. Some scientists and researchers have investigated how renewable energy consumption could be linked to economic growth, Stamatios Ntanos et al. (2018) have found that in high GDP countries, such as Germany, France or Italy, the impact was higher than in low GDP countries, but still significant. They concluded by underlying the importance of policy-makers decisions regarding investment choices in this sector, stating that 'green' incentives and large-scale investments have a key role in the energetic transition (Ntanos, et al., 2018). From a different

point of view, Taeyoung Jin and Jinsoo Kim (2018), have researched the impact of coal production on economic growth. Their findings confirm the theory that clean energy is a sustainable choice, with respect to polluting resources as coal. In fact, as it is claimed in their work "*our empirical analysis showed that coal consumption adversely affects economic growth in the long run. Therefore, policymakers should consider reducing coal dependency in the long run through alternative energy sources, while maintaining current levels of coal consumption*" (Jin & Kim, 2018). They admit that in the short-run coal might represent the cheapest investment for policy-makers, especially in developing countries, which are the ones that in the past decades have been responsible for the highest carbon emissions, but in the future coal consumption might not represent the best investment choice. The above cited article also addresses the environmental problems caused by polluting resources, "*furthermore, economically developed countries may restrain coal usage to prevent environmental degradation (carbon emissions)*" (Jin & Kim, 2018). Mita Bhattacharya, Sudharshan Reddy Paramati, Ilhan Ozturk and Sankar Bhattacharya (2016), have found that in the areas of the world where renewable energy is being produced, "deployment of renewables is creating jobs in the economy", especially in nations as China, Bulgaria, Denmark and Greece (Bhattacharya, Paramati, Ozturk, & Bhattacharya, 2016).

3.2 Data description and Empirical Methodology

As mentioned in the literature review, the impacts of renewable energy production on the economy are many and affect various sectors. Renewable technologies represent a modern invention, and from the beginning of this century we are experiencing its effects, and throughout different analysis we can affirm that the consequences of the energetic transition affect multiple sides of the economy. For this reason, this research focuses on studying and estimating the relationship between renewable energy investments on economic growth of European countries and their CO_2

emissions. The data for the empirical analysis was retrieved from World Bank database and Penn world Table, as described in table 3.4. The research is divided in two parts, the first one deals with analyzing the effects of an increased share of renewable energy on total electricity output, which is expressed by the variable ren_share, on economic growth (growth), that has been calculated as a real GDP growth rate. The second model studies the impact on carbon dioxide emissions, described as Co2_1_gdp, which is a measure of CO_2 emissions per GDP. These two dependent variables were chosen in order to capture the impact of renewable energies, since their major aim is to reduce world pollution offering an alternative resource of electricity, and at the same time, improve the economies' quality of life and development. The two linear regressions to be estimated are expressed in exhibits 3.1, 3.2:

(3.1)

$$growth_{it} = \beta_1 rgdpch\_1_{it} + \beta_2 ren\_share_{it} + \beta_3 yr\_sch\_ter_{it} + \beta_4 openk_{it} + \beta_5 ki_{it} + \beta_6 kg_{it} + c_i + \lambda_i + \varepsilon_{it}$$

(3.2)

$$Co2_{1_{gdp}} = \gamma_1 rgdpch\_1_{it} + \gamma_2 ren\_share_{it} + c_i + \lambda_i + \varepsilon_{it}$$

Where i represents the cross-section dimension and t the time dimension, while c_i and λ_i represent the country and fixed effects and ε_{it} is the random error. Table 3.4 describes the regressors used in the two models. In particular in the first one are included a number of variables that characterize the economy in the long run. They are the openness of a country, openk, representing "*the degree to which nondomestic transactions (imports and exports) take place and affect the size and growth of a national economy*" (Keman), and other two variables kg and ki, that are respectively government spending and investment shares of Real GDP, together make up the majority of the Gross Domestic Product of a country. Finally, yr_sch_ter, captures the effect of an increased level of education

(average years of tertiary education) on economic growth. Regarding the other linear regression, an indicator of CO_2 emissions is used (Co2_1_gdp) to represent the amount of carbon dioxide released, and how it changes based on the ren_share produced. The sample was selected in order to offer a heterogeneous group of countries. It includes 26 out of 27 countries that are part of the European Union, from the most developed, which according to the Human Development Index measure (Human Development Index (HDI), 2019) are Ireland, Germany and Sweden, to the least developed as Croatia and Bulgaria (table 3.3). The analysis takes into consideration 20 years of observation, from 1990 to 2010, starting from the period when renewable technologies were not yet introduced into the economy, but were about to gain popularity, until the decade of the early 2000s where they established themselves as essential alternative energies. The majority of the countries included in the study has implemented policies in order to promote access to renewable technologies. Lena Kitzing, Catherine Mitchell and Poul Erik Morthorst (2012), have found in their study that there is evidence supporting the fact that most EU countries' policies are converging in order to support an implementation of RES in Europe (Kitzing, Mitchell, & Morthorst, 2012). This helps explain the increasing amount of investments in the sample period, especially, as before mentioned, in the 2000s. In particular, the most important policies implemented by EU countries, as cited by Lena Kitzing et al., are investment grants, which represent "*financial supports granted by governmental (and European) institutions to investors in renewable energy projects in the form of non-reimbursable payments*" and other fiscal measures as "*indirect tax incentives, such as eco-taxes on fossil fuels or CO_2*" (Kitzing, Mitchell, & Morthorst, 2012).

Table 3.3 Sample description

country	mean Real Gdp	mean co2 emissions
Austria	22092,4	0,197125
Belgium	21061,6	0,2813
Bulgaria	5740,35	1,43056
Croatia	10022,1	0,399141
Cyprus	11988,5	0,361553
Czech Republic	16184,1	0,769323
Denmark	21715,9	0,194185
Estonia		1,16636
Finland	18703,9	0,290257
France	20098,1	0,163431
Germany	23287,4	0,273806
Greece	16007,1	0,343398
Hungary	11281,9	0,537122
Ireland	17574,2	0,260327
Italy	19199,3	0,219133
Latvia		0,43914
Lithuania		0,505456
Luxembourg	37973,2	0,26069
Malta	12436,4	0,368287
Netherlands	22385,8	0,253463
Poland	8660,74	1,0817
Portugal		0,266539
Slovak Republic		0,67773
Slovenia	18183,8	0,404377
Spain	16862,2	0,245661
Sweden	20939,9	0,135856
Total	17687,2	0,454812

***Note**: This table was derived from the study conducted by G. Vallanti (2020)*

Table 3.4 Variables description

Variable	*Symbol*	*Description*	*Source*
Economic growth	growth	Real GDP growth rate	Penn World Table
Real Gdp per capita	rgdpch_1	Real GDP per capita expressed in 2005 constant US$	Penn World Table
Renewable Energy share	ren_share	Renewable electricity share of total electricity output (%)	World Bank Data
Education	yr_sch_ter	Average years of tertiary education	Penn World Table
Openness	openk	Sum of Exports and Imports divided by Real GDP in constant prices	Penn World Table
Government spending	kg	Governement share of Real GDP per capita in constant 2005 US$ (%)	Penn World Table
Investment	ki	Investment Share of Real GDP per capita (%)	Penn World Table
CO_2 emissions	Co2_1_gdp	CO_2 emissions expressed in kilotons per GDP	World Bank Data

***Source**: World Bank and Penn Table Database*

3.2.1 Results and interpretation

On the basis of the arguments of the previous chapters, the aim of this work was to create a standard growth model in order to analyze the impact of renewable energies on the rate of growth of the economy and on CO_2 emissions, and to understand if there exists environmental and economic benefits that would suggest a need to increase investments on these resources, or if they exist at the expense of a possible economic development. The model was studied to include and control for more indicators related to economic growth, such as human capital (yr_sch_ter), in terms of years of school, openness degree of an economy (openk), share of investment (ki) and government spending (kg), which reflects public spending and efficiency regarding policy-makers actions to stimulate growth. Based on the assumptions and hypothesis made, the coefficient kg can be positive or negative, but there is no clear theory about its real impact on the economy since it is strictly related to the efficiency of government intervention. The indicator of investment, ki, is instead intended as a proxy for capital stock growth. As shown in table 3.5, openk, ki and kg occur to have a positive impact on the dependent variable, while it is shown a negative effect for the variable ren_share. At first sight this result might appear to be contradictory with the premise of a positive impact of RE sources on economic growth. Nevertheless, it is not statistically significant, meaning that is very unlikely from a statistical point of view and that there is no evidence that investing in RE resources has a negative impact on growth. This outcome is crucial in determining if it is worth investing in these resources, but as it is demonstrated, we cannot establish that it would preclude economic growth in the long run. The R-squared is higher in the second model (0,9460), which means that the model explains most of the variability of the data around its mean. Among the scholars who have studied this relationship, Sakiru Adebola Solarin, Usama Al-Mulali and Ilhan Ozturk (2017), have also found that there exists a link between hydroelectricity production and economic development in two developing

countries such as India and China. Their analysis concludes that "*energy plays an essential part in stimulating economic growth, which means that decreasing energy use arbitrarily may have an adverse influence on the countries' economic development*" (Solarin, Al-Mulali, & Ozturk, 2017).

Table 3.5 Results of regression on economic growth (3.1)

Variable	growth
rgdpch_1	-0,19413*** (0,02471)
ren_share	-0,05457 (0,03803)
yr_sch_ter	-0,01416 (0,02258)
openk	0,00035** (0,00016)
Ki	0,00464*** (0,00059)
Kg	0,00432*** (0,00146)
	R^2 = 0,5762 N = 393

***Note**: Robust standard errors in parenthesis ***significant at 1%, **significant at 5%, *significant at 10%. Country FE and year FE are included.*

Findings of Roula Inglesi-Lotz's panel data application (2016), also suggest a positive correlation between the establishment of renewable energy markets and increase in real GDP, that, as the author affirms, are able to offer many advantages to public policy problems, such as improved environmental conditions and welfare (Inglesi-Lotz, The Impact of Renewable Energy Consumption to Economic Growth: A Panel Data Application , 2016). Using the same methodology that has been used to calculate the impact of renewable energy on economic growth, it was calculated its impact on CO_2 emissions. Results are reported in table 3.6 and show a remarkable outcome that was

Table 3.6 Results of regression on CO_2 emissions (3.2)

Variable	Co2_1_gdp
rgdpch_1	-1,59324 (2,52290)
ren_share	-5,82572*** (2,05773)
	R^2 = 0,9460
	N = 389

***Note**: Robust standard errors in parenthesis ***significant at 1%, **significant at 5%, *significant at 10%. Country FE and year FE are included*

anticipated before in the previous chapters, that is the effect of ren_share on Co2_1_gdp. It shows a negative impact, which is statistically significant, meaning that investments in renewable energies reduce CO_2 emissions in the long run. This demonstrates, together with the fact there is no negative impact on the rate of growth of the economy, from table 3.5, that the importance of introducing and investing in these technologies is greater than we policy makers might think. This relationship was the subject of other studies in the past, as in the previously mentioned article by Susana Silva, Isabel Soares and Carlos Pinho (2011), a SVAR methodology has been used to explain how the implementation of renewable energy resources would reduce carbon emissions, using a sample of 44 countries (Silva, Pinho, & Soares, The impact of renewable energies on economic growth and CO2 emissions, 2011). The authors proved that a reduction in CO_2 emissions is explained by an increase in renewable energies output, and that achieving an environmental solution is possible giving the opportunity to governments to save capital and invest it in other projects (Silva, Pinho, & Soares, The impact of renewable energies on economic growth and CO2 emissions, 2011). Sakiru Adebola Solarin, Usama Al-Mulali and Ilhan Ozturk (2017) in their previously mentioned study, pay attention also to the link between emissions and renewable electricity consumption, in particular the implementation of hydroelectricity in India and China between the years 1965 and 2013. Their results confirm what has been found in this study, in terms of efficiency of renewable energies. In fact, as they admit, "*with the use of more hydro- electricity in the energy mix, the utilization of fossil fuels, which are responsible for most of the CO_2 emission, is likely to decrease*", meaning that more hydroelectricity, which is one of the most important renewable energies (as stated in chapter 1 'pathways to a green economy'), the lower will be carbon dioxide emissions released (Solarin, Al-Mulali, & Ozturk, 2017).

CONCLUSION

The goal of this work was to analyze a possible correlation between renewable energy investments, economic growth and carbon dioxide emission. It succeeded in giving an answer to the main question of whether these resources are worth investing in and it showed that the relationship is positive meaning that the more we invest in renewable energy the lower the level of polluting emissions will be released, without repercussions on economic growth. As I worked on this study my interests towards the subject have grown considerably, starting from a simple question I succeeded in understanding the solutions to a global problem which can be defined as climate change, world pollution or energetic and economic transition. I am even more proud of this work because not only the analytical model has demonstrated that there is a brighter future ahead of us, but it also showed that our decisions can affect the lives of many, especially in those countries that struggle in reaching a mediocre level of development. This study included only 26 countries of the European Union, but it could be extended to include more nations, even though it is a heterogenous sample since it includes many developed and developing countries. This could be a limitation to it, and it would be interesting to analyze the impact of renewable energies on growth including more variables or studying the relationship from the 2020 onward, nevertheless, the research ended up giving us astonishing results even for a period where these modern technologies were just beginning to be developed and spread all over the globe. For what concerns the development of this paper I found helpful the existing literature, in particular I considered the work of Ferroukhi et al. "Renewable energy benefits: Measuring the Economics (IRENA)" very important, but also the precious work of Vallanti has been a source of inspiration. Carrying out this paper was not an easy task, but its weight has been lightened by the interest and curiosity I feel towards the subject, and I can finally admit that the main goal of showing how a different idea can change the world we live in has been achieved.

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