The consumption of energy from renewable sources in Europe from 2004 to 2019: a study based on the Cluster Analysis

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Abstract

This article aims to apply the statistical technique of hierarchical cluster analysis on a dataset in historical time series on the gross final consumption of energy from renewable sources in Europe from 2004 to 2019. The application of this method was very important for the creation of homogeneous groups with internal cohesion and external validity and to identify the different speeds with which EU countries have implemented their race towards the quotas established by Directive 2009/28 / EC of consumption of energy from renewable sources to be achieved in 2020.

Keywords: *Energy transition, Cluster Analysis, Hierarchical methods, Dynamic Time Warping distance; Historical series*

JEL codes: C19, Q42, Q47, Q54

Index

INTRODUCTION

The objective of this thesis is to carry out a study based on Cluster Analysis with reference to the data in historical series, from 2004 to 2019, published by the statistical office of the European Union (Eurostat), on the percentage of gross final consumption of energy deriving from renewable sources. The data refer to the 28 member countries of the European Union (EU), including the United Kingdom. In addition, there are Montenegro, Albania, Serbia, which are in the process of transposing EU legislation into national law; Kosovo, which represents a potential candidate but still does not meet the requirements for joining the European Union and Norway and Iceland, closely linked to the European Union thanks to the agreement on the European Economic Area (EEA), which brings together all the 27 EU member states and three of the European Free Trade Association (EFTA) countries, Iceland, Norway and Liechtenstein in the Single Market. The global emergency caused by climate change is the subject of many international debates. The twenty-first century has opened the doors to great economic, social and political changes. Among these, a significant change is affecting the energy sector and goes by the name of energy transition. The purpose of this thesis was to segment the reference countries into natural groups, based on the trend of energy consumption from renewable sources, by means of an appropriate hierarchical cluster analysis technique.

The first chapter provides an overview of the world of Renewable Energy in relation to the problem of global pollution and the energy transition that is gradually developing in the European Union. The second chapter describes the methodologies and theoretical tools applied in the following Thesis. The third and final chapter contains the analysis and interpretation of the results obtained from the application of the Cluster Analysis using the R studio statistical software.

CHAPTER 1: THE IMPORTANCE OF RENEWABLE ENERGIES

1.1 The problem of global pollution

For decades, the global emergency linked to climate change has been present in all major economic and social debates. The twenty-first century has opened the doors to great economic, social and political changes [3]. Among these, a significant change is the one that is affecting the energy sector and that refers, in particular, to the so-called energy transition. The phenomenon can be described as the shift towards a mix of primary sources of energy that is markedly different from the one that has dominated the world economy to date. A transition that has new renewable resources as its protagonists and is destined to have significant repercussions also in sectors other than energy. To benefit, first and foremost, is the environment.

The energy transition could represent an important step to reduce carbon dioxide emissions into the atmosphere and to promote the advancement of developing countries, as it would be an opportunity for many of them to gain access to electricity; moreover, it could have an evident economic implication because it would offer the possibility of expansion to a new green industry. Finally, from a geopolitical point of view, the energy transition would reduce the power of those few countries that hold most of the hydrocarbon resources. Scientists say that human-induced climate change with the use of fossil fuels has put the planet at risk of mass extinction. The intergovernmental Panel on Climate Change (IPCC) said that greenhouse gas emissions are accelerating, and we are on the verge of a series of increasingly intense climatic events that will endanger life on the planet [6].

The coal was the most used resource for the completion of the industrial revolution, which consequently accompanied the technological revolution in the world of industry. Oil made it possible to implement industrial innovations in the twentieth century, providing the fuel for the internal combustion engine, starting mass electrification and producing energy. The refining of oil and the petrochemical industry of the twentieth century meant that in most of the objects, important percentages of petroleum derivatives were found in their composition: from plastics to medicines, from the steel industry to the paper industry, from books to household appliances, tools for packing goods, tools, steel, building construction, even for food use. Oil has thus joined coal and has, in turn, given way to gas, the use of which has been significantly increasing in the heating, refrigeration and electricity generation sectors and in the various industrial production sectors, from thermoelectricity. to the motorization [3]. The demand for energy has increased with the growth of Gross Domestic Product (GDP) in advanced and industrialized countries, thus becoming an indicator of social and economic well-being.

Towards the end of the last century, the first problems began to appear. At the beginning there was the concern, in a static and erroneous view, that primary sources, oil in particular, would run out, limiting economic development. There was a real defensive and then offensive reaction of the oil-producing countries gathered in the OPEC cartel (organization of oil exporting countries), which contributed to making oil the object of financial speculation and military horrors by the most industrialists who felt hit at the heart of their economic development. Awareness began to grow that development based on hydrocarbons was not sustainable not only from an economic point of view, but above all from an environmental point of view. Air pollution has grown exponentially after the stability found until the industrial revolution, with a significant increase that puts life on earth today at risk. The IPCC, the global network on environmental issues coordinated by the United Nations, warns against the risk of disastrous events for the planet, irreversible changes due to climate change.

The IPCC has estimated that due to human activity, the temperature has increased, compared to pre-industrial levels, by one degree centigrade, and has predicted that this increase will lead to a cascade of climate change that will decimate the earth's ecosystems. To avoid environmental catastrophe, it will be necessary to reduce greenhouse gas emissions by 45% by 2030. This will require an unprecedented transformation in the history of our global economy, our society and our very lifestyle. Rulers, scientists, civil society, environmental movements are involved in a heated debate on the anthropological causes of change, on the responsibility of fossil fuels and their emissions on global warming.

At this moment, humanity is faced with a radical reorientation of its civilization, to be achieved in a very short time. The problem of environmental pollution is a global problem. Being global in nature, it is not possible to refrain from analyzing its aspects linked to the international market or linked to open economies. Considering an open economy means considering a potentially much more complex economy than a closed economy, as there is the interaction of various heterogeneous communities with each other, with different levels of income, different cultures, traditions and preferences. The policy coordination plans need to involve not only businesses but also citizens, and this heterogeneity will not facilitate the work of institutions. A very important aspect is to understand how, in a globalized world, this heterogeneity impacts on the choices of consumers and on the production choices of companies. For economic and environmental reasons, governments have started to implement energy saving and efficiency policies. In the new millennium, for the first time, we are witnessing a decoupling between growth in energy demand and economic growth and policies are taking hold to change the composition of raw materials.

The idea of sustainability and energy saving began to enter all the main international debates, which resulted in December 2019 with the presentation of the European Green New Deal, presented by the President of the European Commission Ursula Van Der Layen following the plenary session [16]. The European Green Deal is the new European strategy for sustainable growth. This € 750 billion Recovery Plan, approved by European leaders and backed by the European Parliament, will help strengthen sustainability and create jobs. The goal is to make Europe the first climate-neutral continent by 2050, at the same time stimulating the economy, protecting health, people's quality of life and nature. The change we are witnessing in the world of energy finds its main driving force behind technological progress.

1.2 Definition and classification of renewable energies

To understand the reasons for these latest changes, it is first of all necessary to distinguish between the different renewable sources. In general, the following definition of renewable energy is provided by the International Energy Agency (IEA):

"It is an energy that derives from natural processes, such as sunlight and wind, which are recreated at a faster speed than they are consumed" [3].

These are forms of energy derived from sources that regenerate or are not "exhausted" in a short time [3]. Their use therefore does not jeopardize the availability of natural resources for future generations. The term "renewable", therefore, captures the essence of this type of energy: the ability to be available in nature and continuously regenerate, without human intervention, spontaneously and in basically inexhaustible quantities. They are alternative energies to those traditionally used over the past centuries, and are for the most part clean, since they do not release harmful or climate-altering substances into the atmosphere, such as carbon dioxide. Renewable energies come from natural elements that are fueled by the environment over relatively short periods of time.

There is no single renewable energy but different sources of energy that make us understand the complexity of the technological resources necessary to complete the energy transition, without which the planet's disaster appears inevitable. This is a progress that is making important steps forward not only in the field of production, but also in that of conservation and storage, very important for the affirmation of a production sector that is by its nature dependent on one extremity of factors. , such as the intensity of wind, insolation and tides. The substantial optimism regarding the energy transition is based precisely on the fact that the various studies on renewable energy sources are heading towards a plurality of directions so vast and profound as to guarantee continuous progress in production techniques and cost reduction.

The world consumption of coal, which dramatically increased in 2015, has finally begun to decrease, even if, in many cases, this decrease is in favor of natural gas, a much less polluting source but still a producing source. in fact, there is an intention to definitively abandon this polluting resource like coal by some important European countries, such as Italy and Germany, which have always had coal as the basis of their industrial development. The complexity of this transition can be deduced from the fact that, in clear contradiction with these declarations and with the actual steps forward in the fight against pollution, Germany itself is building a new power plant fueled by lignite, an even more polluting fuel than same coal. This observation leads us to highlight another difficulty of the transition, that constituted by the economic and social costs of this process. Costs that give rise to a non-negligible series of contradictions. Many governments, in fact, if on the one hand they tend to introduce or maintain aid and incentives aimed at safeguarding the levels of employment and the economy of the coal areas, on the other hand, pressed by the new needs and the new awareness of their citizens, they promote a similar incentive policy for the development of new energy sources. A policy of incentives for clean energy which has often resulted in an excessive and distorted use of resources. A highly controversial topic is certainly that dedicated to public incentives. Basically, such aids are placed in the traditional line of subsidies that, throughout economic history, governments have lent to nascent industries; but the same history has always highlighted the significant gaps in terms of efficiency and health of the nascent companies, especially in a long-term perspective. Today we are exactly in this passage which is strongly conditioned by the competitive changes of traditional energy sources. For this reason, the speed of the change process will also depend on government policies towards coal, while being certain that the current revolution cannot be stopped.

The fact that the revolution is proceeding can also be deduced from the behavior of the great protagonists of the world economy and finance who, albeit slowly and in many cases only because driven by public opinion and profit expectations, direct increasing resources towards new energy production subtracting them from traditional uses.

Technological progress and changes in society will bring the transition in the right direction but it is a long and complex path. Its dynamics encounter economic, social, political and industrial obstacles and barriers to be thoroughly understood and overcome. The forces that ignore and resist change are powerful and widespread. It is a battle for democracy and survival, which has matured in this century, and which creates the basis for the autonomous development of developing countries and to bequeath a livable planet to future generations.

In a world where energy is increasingly at the center of the organization of daily life, social well-being, economic power and growth, new sources introduce the possibility of producing energy in small local plants. This involves the reorganization of the industrial chain and, therefore, the behavior of citizens also plays a crucial role. In the future, the possibility of privately generating electricity for consumption from one's own site will be more widespread in order to fall into the so-called category of "presumer", that is the person who has the right to produce and sell energy privately, with the support of the tools made available to disposition from the digital revolution.

Among the main renewable energy sources are:

- solar.

- wind.

- geothermal.

- hydroelectricity.

- marine.

- bioenergetics.

Not only solar and wind are considered renewable energies, but also geothermal, hydroelectric, wave and tidal energy and some types of biomass and biofuels. At the moment there are two technologies that are protagonists of the energy transition: solar and wind. The others have landscape or environmental constraints that reduce the possibility of development, or are not uniformly distributed (such as, for example, hydroelectric and geothermal). Others are still at an embryonic technological stage (wave motion and tides), or are controversial due to their dubious ability to renew themselves and the impact produced by emissions (biofuels and biomass). We are faced with a very complex but, at the same time, crucial picture for understanding the future of the energy transition. The possibility of combining intermittent renewable sources with others of constant generation (for example wind with hydroelectricity), could guarantee a continuous supply of electricity. Furthermore, the technological maturation of other sources, such as those linked to wave motion, could increase the possibilities of diversification in the generation of energy, causing a further reduction of fossil fuel plants.

The thermal or electrical energy generated by the sun's irradiation on the Earth is called "solar energy". Solar is the energy that, together with wind energy, represents the heart of the energy transition. According to the International Renewables Agency (IRENA), in the last five years it is the renewable resource that has grown the most compared to the others on the market. There are different types of solar renewable energy:

1- photovoltaic solar energy. This is the most widespread technology and represents the majority of installed solar generation technology. It consists of a series of solar panels, which directly produce energy from sunlight.
2- concentrated solar energy. This type of energy is reflected by a series of mirrors towards a small area where the stored energy powers a heat engine, such as a steam turbine, thus generating electricity.

The cost differences between the two types are still important according to the levelized cost of energy (LCOE). Solar energy is an important renewable source but, for its exploitation, major investments are required compared to other energy generation systems. For this reason, technological research is very active in the study of apparatuses that propose increasingly cheaper alternatives.

Figure 1.1: Solar Energy - Source- quifinanza.it

As regards wind energy (Figure 1.2), together with solar energy, it is the engine of the energy transition. The production of wind energy takes place through the rotation of a blade by the wind, connected to a turbine which thus produces electricity. As for solar, there are different wind technologies divided mainly into vertical axis turbines, in which the blades rotate along a vertical axis with respect to the ground, and horizontal axis turbines, the most common and whose blades are perpendicular to the ground. The technological evolution and innovation have contributed significantly to the development of this energy source, up to modern wind turbines. According to the data of the 2019 report of the International Renewable Energy Agency [7], wind energy is currently the second type of renewable energy for production in the world (564 GW of total installed capacity) and is constantly growing: the wind power supplies about

5% of the world's electricity production. In the last 10 years the cost of wind technology has dropped sharply, making it competitive with respect to conventional sources and favoring its exponential growth. For this reason, it has been stated that, in general, wind energy, compared to solar energy, has slightly lower costs, but greater difficulties in installing the blades (for which cranes and specialized equipment are also needed for the transport itself) and maintenance (for which technicians with dedicated training are needed to be able to operate, for example, suspended along the blades).

Figure 1.2: wind energy - Source- Energit.it

Geothermal energy (Figure 1.3) is produced by exploiting the energy of heat coming from the deeper layers of the earth's crust. It is obtained by conveying the vapors coming from the subsoil in turbines used for the production of electricity as well as by recycling the water vapor produced for home heating, for greenhouse crops and for various uses in spas. The geothermal plays an important role both for its historical use and for future prospects. The first geothermal power plants were installed in 1913 using the heat of the earth. The diffusion of geothermal energy is less widespread than other renewables: not in all territories it is possible to find a large amount of heat conveyed in the same area in the subsoil. However, this does not preclude its potential.

It is a renewable resource severely limited by its geographical position. Low levels of warming can be obtained anywhere in the world, while the average high temperatures necessary to operate current geothermal technology are found only in specific areas, such as those close to places of strong volcanic activity or along faults. An expansion of technology, however, would require an evolution on several fronts such as, for example, the construction of power plants capable of using lower temperatures. The Global Geothermal Alliance has launched an initiative to incentivize countries of the world with geothermal territory to give priority to this renewable resource to accelerate the energy transition process.

Figure 1.3: geothermal energy - Source- fontidienergiarinnovabile.it

One of the most widespread renewable energy sources in the world is hydroelectric energy, an example of which is shown in Figure 1.4. Water is one of the oldest sources of energy used by man: it is essential for living, for producing food, for hygiene. According to data from the 2019 report of the International Renewable Energy Agency [7], the total power of hydroelectric plants in the world is approximately 50% of the total renewable sources. Even though it is the oldest among renewables, over the years continuous innovation has made hydroelectric plants more and more efficient. Thanks to current technologies, it is possible to transform approximately 90% of the energy from water resources into electricity, a percentage almost three times higher than the level of efficiency of conventional sources. Low environmental impact and high efficiency are two of the factors that contribute to an excellent final yield: among the largest renewable plants in the world, the top five for energy produced are powered by the power of water. Most of the hydroelectric power is produced in a conventional way, through the creation of a dam and the consequent reservoir. The water usually flows through a channel in the dam, through turbines or, in some cases, through an underground tunnel, near which the power plant is inserted. The spread of hydroelectricity is also due to its maturity: this technology has been in use since the second half of the nineteenth century. Furthermore, its success is due to a number of factors: hydroelectric plants have large capacity, have a very long life and great flexibility due to the low start-up; moreover, planned dams can be inserted for other purposes such as water management. All with markedly low production costs. Hydroelectricity is thus found to be one of the most cost-efficient sources for generating energy, with considerable potential worldwide. However, there are also several limits to the expansion of this type of energy. Compared to ease of management, the construction of a dam is a long and expensive process, and the impact of turbines, transformers and other components on the final cost can be very onerous. This is rather influenced by the cost of materials and means and their availability, as well as by the costs for environmental and hydrogeological assessments and monitoring. Times and cost variability that have often paralyzed some large projects.

Despite these limitations, at the energy level, hydroelectricity remains the most widespread and cheapest renewable source at the moment:

Figure 1.4: hydroelectric energy- Source- Artingegneria.com

As regards marine energy (Figure 1.5), it currently represents a huge energy reserve, almost unused, with inexhaustible potential. If we were able to fully exploit the strength of the seas and oceans, we would cover all the energy consumption envisaged by the IEA (International Energy Agency) already by 2035. A potential which, however, clashes with the current limits in terms of costs and replicability of necessary technologies. Marine power generation systems are closely linked to technological development. Both wave motion and tidal energy are at an almost embryonic stage. The plants in the world bear extremely high costs. The absence of a dominant technology for the methods of generation leads to the absence of an industry for the production of components, which are expensive and difficult to find. These are systems that are still in an embryonic state of development and are likely to join the transition boom in the coming years. When innovation reaches the right level of technical and commercial maturity, the production of energy from the sea will become much more advantageous and widespread. Tidal energies could be very useful not only for their potential but also for a combined use of renewable resources. For example, the wind energy sector could install underwater turbines to exploit the tides, thus having an intermittent energy source available.

Figure 1.5: Marine energy - Source - www.studiosalvatore.com

Last but not least in the context of renewable energy sources, are those deriving from bioenergy. Bioenergy is divided into biofuels and biomasses. They represent a very controversial chapter in the world of renewables. They consist of energy produced from a multitude of potentially renewable fuels, from waste to agricultural production waste. Unlike solar and wind energy, unfortunately they produce CO2 emissions, using materials that, in some cases, can create distortions in the food market such as, for example, olive pomace. In fact, in 2015, the Antitrust Authority considered the incentives for the production of energy and biofuels from olive pomace to be distorting competition. The most widespread biomasses are represented by hearths and stoves that burn wood or coal, with enormous damage to health and deforestation. Despite these problems, bioenergy still represents three quarters of renewable generation as a whole, mainly for the consumption of fossil fuels (wood and charcoal). The importance of bioenergy is present in sectors where, unfortunately, it is still very expensive or impossible to replace fossil fuels. Among these sectors we find heating for industrial purposes (such as ovens or blast furnaces); the transport sector, in particular for aviation and maritime where the electric or gas alternatives are still limited. According to numerous analyzes and studies, the impact of traditional biomasses should be eliminated or at least reduced. The main problem is the fuel used for cooking. The promotion of new bioenergy, especially biofuels, should be closely linked to the principles of sustainability. The materials from which they are produced should not compete with food production or pose a risk to ecosystems. Palm oil and timber do not qualify in this sense.

1.2 The energy transition in the European Union

Among the places of transition, Europe was the only continent that most of all has shown its commitment in the fight against climate change and in building global agreements on the decarbonization of the planet [3]. It is the only continent that has taken unilateral and binding commitments from the outset to design a path of sustainable growth and reduction of carbon dioxide emissions into the atmosphere. Overall, however, the objectives of the European Union (EU) in the energy sector have overlapped over time. Taking a quick historical excursus, in the post-war years, with the signing of the Treaty of the Coal and Steel Community (ECSC-1951) and the Atomic Energy Community (Euratom-1957), energy was at the center of the project of construction of the European Economic Communication, which contributed to the realization of the integration of rules and markets, with a more radical orientation of sharing and solidarity and in a time that was four times shorter than what was necessary in the last century for the United States to connect the energy markets of individual states. The ratified treaties proposed the goal of pooling resources between member countries. Unfortunately, there was no concrete implementation of the long-term vision of the initial political project. At the end of the nineties, the transition was grafted onto the path already begun of the liberalization of national markets, which led to the definition of a common energy policy among the member countries. It was the EU that led the international process of the Kyoto Protocol [17] to protect the environment from carbon dioxide emissions into the atmosphere (1997), in a path of solidarity towards future generations built on rooted social values in the pro-European culture. In terms of rules, the conditions for addressing the difficulties of a common and harmonized approach between the EU member states were thus defined, even if, unfortunately, this process was slowed down and partly stopped by the social and economic differences present between the member states, characterized by conditions of institutions and the energy industry that are very different from each other: this has weakened the political will of national governments to find elements of convergence in common and effective European energy policies, objectives and consequently. In terms of implementation, the environmental dimension only burst onto the scene among the EU's priority objectives at the beginning of the new millennium, when it was clear that specific interventions were needed to promote the transition to a world powered by renewable sources instead of fossil fuels. The institutional turning point came with the 2007 Lisbon Treaty and the "Third Energy Package" [3] which profoundly innovated the Union's competences in the sector. In addition, a new title of the Treaty on the Functioning of the European Union (TFEU) was introduced which was dedicated to energy and established the objectives to be pursued. As regards the contents, objectives and instruments relating to energy and environmental protection were integrated and the general principles of solidarity between the member countries were established. Finally, the future of a European energy policy was restarted and rewritten in the Energy Union construction project initiated in 2015 by the President of the European Commission Jean-Claude Junker and approved by the European Parliament, which potentially represents an important step forward to bridge the political vacuum of planning and induce national governments to overcome the competitive divergences of the sector within the Union. The Project is based on four fundamental pillars: the integration of markets; decarbonization; the security of supply of sources and energy efficiency. For the first time, the European Commission is also equipped with tools to insert itself into the decisions of national governments regarding European energy policy. Governments are responsible for preparing national energy plans, but the Commission is assigned specific tasks, such as ex ante verification of National Energy Plans to assess their consistency with European objectives and ex post monitoring activity, to verify the compatibility of instruments and methods implemented by member states and compliance with binding commitments undertaken by the Union. This whole series of complex dynamics of energy transformation positions the European Union in the face of substantial choices that affect governments, industry, citizens and those who offer the new services. In this context, considerable conflicting forces emerge. There are those in favor of change coming from the innovative part of the industrial world, which grasps future profit opportunities, and from civil society where the new course is grafted on sensitivity towards sustainable development. Others, on the other hand, represent obstacles: these are the more conservative forces, activated by industrial subjects who find it difficult to radically reconvert the business organization, and by political subjects who have drawn financial and economic advantages from the old world of fossil fuels. political support. Furthermore, the concern of the world of work is grafted onto them, made more fragile by the new organizational models, where the fragmentation of the energy production chain is added to the unemployment risks implicit in the digitization of the sector and the possibility of a relocation that could affect employment at a time of great economic uncertainty and weak growth. All these dynamics outline a very clear path for the EU, but not linear. The differences between the member countries and a short-term political vision create barriers of a nationalistic nature to the sharing of policies to give strength to the transformation that has begun. Following the enlargement that took place in the period 2004-2006 and the dramatic financial crisis of 2008-2009, the economic gap between the countries of the European Union has widened, highlighting the political limits of the EU and the difficulty of governments in overcoming the economic and institutional differences that divide them. It was evident that the EU has its main weakness in the difficulty due to the fact that governments have allowed regulation to advance, by itself, with wide margins of centralized intervention, without accompanying it with common policies, which are the real engine of planning shared. In the chessboard of the energy transition, the European Union has at stake a set of strategic factors such as the ability to cohesion with member countries in a difficult path of institutional governance reform that is still under construction and that requires defining the perimeter of a long-term strategy for the development of a crucial sector such as energy. On the economic level, which will be explored in the next paragraph, the energy transformation affects the extraordinary interests that affect the industry, imposing a transformation of the industrial model built in the past decades. In particular, in electricity production, the market opens up to competition from subjects offering new services connected to digitized electricity platforms. Finally, the change is politically projected on the social sensitivity of citizens who see sustainable development as one of the ways out of the identity crisis that politics is going through and face the daily social unease. The energy transformation initiated in the EU unfolds between contrasting forces, which respectively activate or slow down the process of change in a complex dynamic, involving the EU institutions and member countries from time to time. Despite these obvious obstacles, the infrastructural investments already made to connect the European energy circuit and the great opportunity opened by the cooperation of energy regulators with the southern shore of the Mediterranean strengthen the opportunities for the EU to obtain important results from the transition in the coming decades.

The growth of the renewable energy sector is mainly due to the recent collapse of their costs, which potentially provides any country with non-polluting sources, apparently inexhaustible, available locally, even with a marginal cost equal to zero. It could be argued that the greatest novelty of the energy transition is that which allows society to reach a mix of sources that is not only sustainable from an environmental point of view but also from an economic point of view. Change affects both industrialized and developing countries because it allows the former to more easily manage the trade-off between competitiveness and environmental sustainability and, to the latter, not to have to give up green development, which they could not afford without the fall in the costs of renewable energies. To fully understand the characteristics of these changes, however, it is necessary to provide some further historical details. A crucial historical stage is represented by the oil crises of the seventies: they brought attention back to the need for energy security and the danger of dependence on fossil fuels, due to their concentration and the power of OPEC in the management of supplies and oil prices, but also in the fear that these resources will sooner or later run out.

However, the distrust of fossil fuels and the growing attention of environmentalists towards alternative energies were not enough to solve the cost problem, which for both wind and solar power was markedly higher than the generation costs of other technologies. It was climate change and the attention paid by the media and governments, starting from the Rio Conference in 1992 and the Kyoto Protocol of 1997, that once again brought attention to renewables as a means of reducing emissions of greenhouse gases. At the turn of the century, the existence of global warming and its human origin were for the first time recognized globally. Although, however, the will to invest in renewables had been strengthened by the Kyoto Protocol, technological advancement was still limited, and consequently the propensity towards mass development for renewables was also limited. However, a gradual decrease in generation costs began, also stimulated by widespread incentive policies which led to an increase in investments. Since 2014, technological maturation and the rapid growth of installed capacity have finally elevated renewables from a minor and complementary role in the global energy mix to a potentially central one for the years to come.

However, there are still doubts that make their future role in the energy transition uncertain, as demonstrated by the long, yet unfinished debate involving the main European institutions. The economic, social and geopolitical implications of all this are immense and make the definition of the energy transition difficult to establish and very broad. The complexity is in fact represented by the change in the global energy mix towards renewables, but there are numerous additional elements that influence the process and make the final result uncertain. Indeed, if coal and oil are reduced resources in the transition, gas will still maintain a significant role, thanks to its lower emissions than other hydrocarbons and complementarity with intermittent renewables. The heterogeneity is very wide between production costs, different technologies and future prospects. Surely compared to the complex picture of renewables, solar and wind generation appear to be the only sources to drive the transition. In fact, they have zero emissions, increasingly widespread and standardized technologies, the possibility of being installed practically anywhere in the world and a limited environmental impact. With the passing of the years and the consequent technological progress, the installation and production prices of some of the main renewable energy sources are falling dramatically. The causes of the reduction in prices can be identified through a combination of technological factors, such as the spread of new turbines, longer blades, new materials for the creation of new increasingly efficient photovoltaic cells. A real *learning by doing* mechanism is being developed due to the increasing use of technology. For example, with each doubling of the cumulative installed capacity, the price of solar falls by 20% and that of wind by 12%. This is due to a number of factors such as research and development and economies of scale. Another element of great importance for the reduction of the price of renewables is the reduction of barriers. The maturation of renewable technologies and their increasing diffusion increase investor confidence, thus reducing financial barriers. The collapse of financial and international barriers thus began a virtuous circle fueled by confidence in renewables, by the expansion of production capacity and the consequent *learning by doing*. The major transformations underway are already having a significant impact on the world energy scenario, and the influence will be ever greater as the energy transition progresses. Renewables are bringing significant job opportunities. The need to develop a new energy system, to attract investments and therefore to provide greater guarantees as a union of countries rather than as a single entity, as well as the possibility of sharing know-how and technologies, could be the key to success. cooperation initiatives, also promoting cooperation in a broader sense. From this point of view, energy could become a very important means of peaceful resolution of disputes between states. According to IRENA [7], the solar energy sector has employed 3 million people since 2015. With the progressive expansion of renewables, these numbers are destined to increase, also thanks to the greater work intensity of these sources compared to fossil fuels. However, the greatest benefit brought by renewables is the environmental one. Together with energy efficiency and the reduction of deforestation, renewables are the best tool to reduce greenhouse gas emissions and, consequently, mitigate the effects of climate change. However, there are many open questions about whether and when a 100% renewable mix will be possible and whether the timing of the change will avoid disastrous global warming of more than two degrees. What the future impact will be on the global economy and whether it will ultimately occur to an extent both in the North and in the South of the world will depend on how the transition takes place in the different European regions and in the world.

CHAPTER 2: METHODOLOGY AND TOOLS

The Cluster Analysis technique is one of the most widely used statistical methods for classifying units into homogeneous groups. It is a typically exploratory method that searches for groups of similar units, without knowing a priori whether such homogeneous groups actually exist. Therefore, classifications of this type take on a clear interpretative value only in cases in which natural structures of groups are really present in the data. One of the most important aspects of Cluster Analysis concerns the choice of variables and it is the researcher's specific knowledge, based on the topic to be analyzed, which can guide the variable selection process. Given n units and p variables, many Cluster Analysis methods require the calculation of the distance matrix, which contains the measures of "proximity" between all pairs of units. The choice of the type of distance may affect the results of the classification, since by varying the type of distance the ordering of the pairs of units does not remain unchanged, from those most similar to each other to the most diverse. The choice of the most appropriate distance must be based on the characteristics of the individual metrics.

Before deepening the technical aspects related to the different methods of Cluster Analysis, a brief description of the characteristics of the data subject to classification in this thesis work is appropriate. In this regard, the next paragraph contains a brief description of the data in historical series.

2.2 Data structure: historical series

Thanks to the ability to collect information over long periods of time and the growth in computing power, data is often represented in time series. This data structure is very popular; most socio-economic (GDP, employment, birth rate, education), financial (share prices, exchange rates) and environmental (pollution, gross final energy consumption) indicators are collected over time. Time series are also widely used in medicine and meteorology (meteorological analysis, earthquakes). In general, the analysis of this type of data is essential in the context of Data Science.

The historical series have been studied from the second half of the seventeenth century. The goal is to dominate uncertainty. Faced with economic phenomena, there is a need to understand why a phenomenon has a certain trend. It is important to apply certain methods to identify regularities, that is to see if the phenomena present themselves in a similar way when the circumstances are similar, or to see which are the anomalous cases, that is when a phenomenon completely changes intensity and direction and if there are any. of the triggering events behind these exceptional values. When there are measures of a phenomenon expressed in terms of time series, and therefore at different time intervals, we try to understand what is the process that generated this series and possibly if the generating process is linked to other economic variables.

The classic analysis of the historical series starts from the principle that the achievements of an economic system that have occurred over time are the result of the combined effect of different components, each of which has a very specific social and economic meaning that allows us to understand its progress.

2.2.1 Main components of a time series

Whenever we observe a phenomenon over time, the observations that are actually observed are composed of a systematic component and an accidental component. *Trend*, *cycle* and *seasonality* (the latter present for infra-annual data) are the 3 components that explain the structure of a historical series. They are the systematic part and therefore the one we are able to interpret and use to make predictions. In particular:

- the *trend* is that part of the systematic component that represents the long-term trend of the series, increasing or decreasing, which can depend on numerous factors such as, for example, technological progress.

- the *cycle* represents non-regular oscillations around the value of the trend that do not have a fixed component and have the characteristic of presenting an oscillation between increasing and decreasing phases with a long period of time. If we consider an annual series, then the structural component, that is the generating process of the series that can be estimated, consists of the interaction between the *trend* component and the *cycle* component. If we consider series measured at a higher frequency (monthly data), an additional component affects the assumed value, described below, known as the seasonal component.

- the *seasonal* component represents oscillations around the representative value of the *trend-cycle*, which unlike the cycle, have a predictable frequency and are repeated regularly.

However, each observation is characterized by the effect of an additional component, called *residual* or accidental component.

In classical analysis it is assumed that the structural part has been estimated well, in the sense that the variables that act on the trend have been identified and that the form of the function that explains how these variables interact has been correctly identified; therefore, that there is neither an omitted variable problem, nor an interpretation problem of how explanatory variables affect the actually observed value. Under these hypotheses of classical analysis, it is assumed that the residual component is comparable to a *white noise*, that is a succession of independent random variables, whose distribution is identical and with zero mean and constant variance (homoskedasticity). If these assumptions actually hold true, classical analysis tries to identify, with respect to the series of values actually observed, what is the specific effect of each component.

2.3 Data matrices

In general, the starting data consist of a table which, for the n statistical units taken into consideration, presents the modalities of p quantitative and / or qualitative variables. In the case of quantitative variables, the modalities are numerical values, while in the case of qualitative variables the modalities are categories that express characteristics or qualities. The information can be represented with a matrix of dimensions $n\ x\ p$:

$\mathbf{X} = [\mathrm{x_{is}}],\ \ i = 1 \dots 2 \dots, n; s = 1, 2, \dots, p.$

x_{is} corresponds to the modality of the s-th variable assumed by the i-th unit.

In the context of the data used in this thesis, referring to spatial units in time series, the space-time data matrix can be formalized algebraically as follows (D'Urso, 2000, 2004, 2005):

$$\boldsymbol{X} \equiv \{x_i(t): i = 1, \dots, N; t = 1, \dots, T\}.$$

Within the formula, i indicates the generic spatial unit and t the generic time; $x_i(t)$ is the value of the variable observed for the i -th unit at time t. The temporal data matrix **X** can be conveniently represented as the set of vectors:

$$\boldsymbol{x_i} \equiv \{x_i(t): t = 1, \dots, T\}\ i = 1, \dots, N.$$

The generic term << proximity >> refers both to the concept of <<resemblance>> between the units, and to that of << diversity >>. A proximity index between two statistical units is defined as a function of the respective row vectors in the data matrix [1]:

$IP_{ij} = f(\boldsymbol{x'_i}, \boldsymbol{x'_j}) \qquad i, j = 1,2 \dots, n.$

The knowledge and information provided by the proximity indices, for each of the possible pairs of units, make it possible to identify those most similar to each other.

2.4 The definition of distance and its properties

Distance between two points corresponding to vectors is defined $\boldsymbol{x}, \boldsymbol{y} \in R^p$ a function $d(\boldsymbol{x}, \boldsymbol{y})$ which has the following properties [1]:

1- **NON NEGATIVITY**: $d(\boldsymbol{x}, \boldsymbol{y}) \geq 0 \quad \forall \ \boldsymbol{x}, \boldsymbol{y} \in R^p$

2- **IDENTITY**: $d(\boldsymbol{x}, \boldsymbol{y}) = 0 \quad \leftrightarrow \boldsymbol{x} = \boldsymbol{y}$

3- **SYMMETRY**: $d(\boldsymbol{x}, \boldsymbol{y}) = d(\boldsymbol{y}, \boldsymbol{x}) \ \ \forall \ \boldsymbol{x}, \boldsymbol{y} \in R^p$

4-**TRIANGULAR INEQUALITY**: $d(\boldsymbol{x}, \boldsymbol{y}) \leq d(\boldsymbol{x}, \boldsymbol{z}) + d(\boldsymbol{y}, \boldsymbol{z}) \ \ \forall \ \boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z} \in R^p$

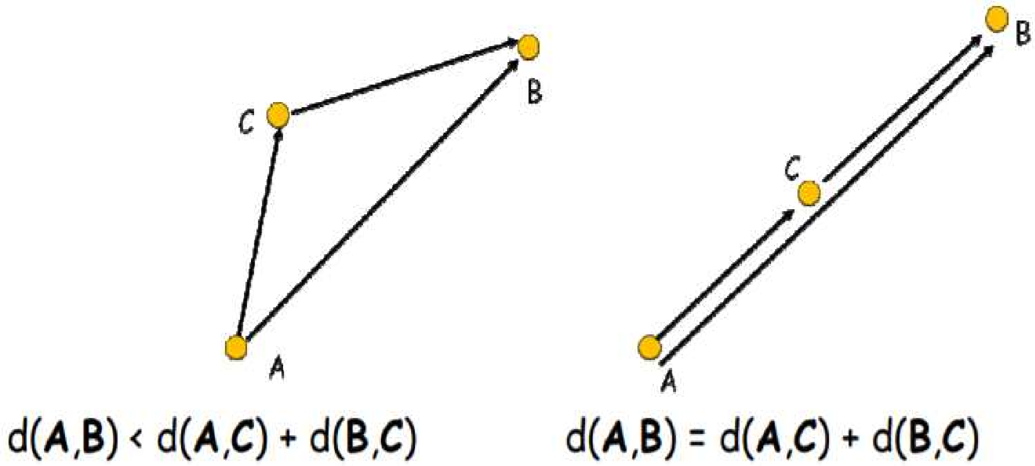

Figure 2.1: Triangular inequality - Multivariate Statistics teaching material - Professor Pierpaolo D'Urso-Sapienza University of Rome

Figure 2.1 provides an illustration of the triangular inequality. A space with reference to which a distance has been defined is called a metric space.

In order for a function to be qualified as a distance it must satisfy the four properties described above. The four properties are not independent of each other. If the properties of identity and triangular inequality hold then the properties of non-negativity and symmetry also hold [1].

2.4.1 Types of distances

There are various types of distances applicable on a matrix of quantitative data. The best-known distance between two points is the Euclidean distance. With reference to a data matrix, with n statistical units and p variables, the Euclidean distance between two statistical units i and j is defined as the Euclidean norm of the difference between the respective vectors [1]:

$$d_{ij} = \|\boldsymbol{x}_i - \boldsymbol{x}_j\| = \left[\sum_{s=1}^{p} \left(x_{is} - x_{js}\right)^2\right]^{1/2}$$

In the peculiar case where there are only two variables, X_1 and X_2, , it is possible to represent in a Cartesian plane the points corresponding to the statistical units. For this reason, the Euclidean distance between two points is equal to the length of the segment joining them.

Another type of widening distance used is the Block City Distance. This type of distance between two statistical units i and j is defined as follows:

$$d_{ij} = \sum_{s=1}^{p} |x_{is} - x_{js}|$$

From the geometric point of view, this distance corresponds to the sum of the two legs and the name derives from the fact that it is the length that must be traveled to move from x_i to x_j if it is allowed to move only in the directions parallel to the axes, as is the case in a city with a regular grid of streets intersecting at right angles [2]. For this reason, this distance is called the Manhattan distance [1].

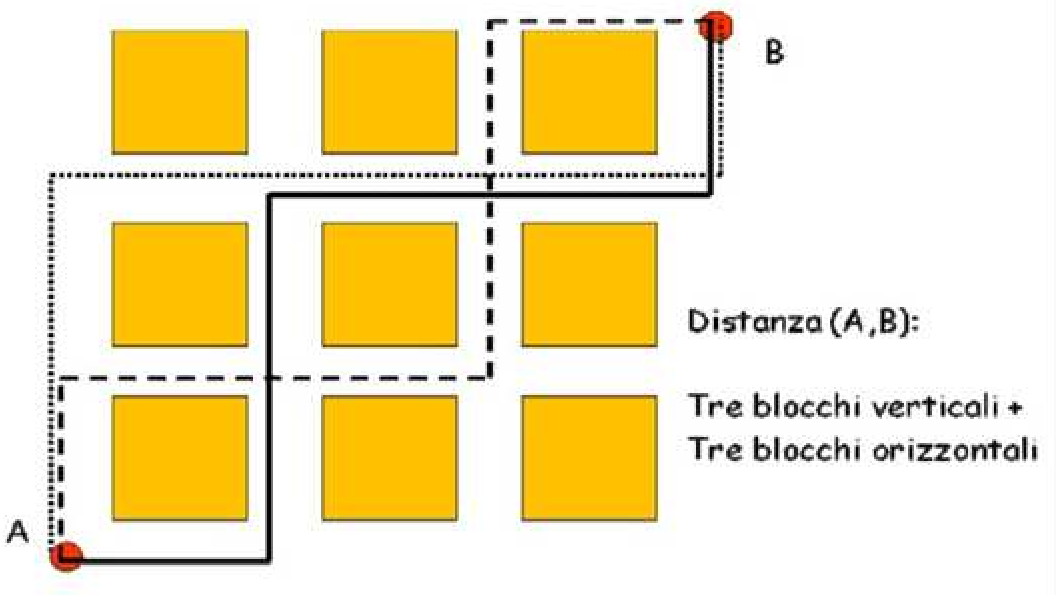

Figure 2.2: Manhattan distance - Multivariate Statistics teaching material - Professor Pierpaolo D'Urso-Sapienza University of Rome

As shown in Figure 2.2, the distance between A and B is given by the sum of three vertical blocks and three horizontal blocks.

The two types of distance, introduced previously, can be obtained through a more general distance formula, also called Minkowski distance of order k between the units i and j:

$$d_{ij} = \left[\sum_{s=1}^{p} \left|x_{is} - x_{js}\right|^{k}\right]^{1/k} \qquad k \geq 1.$$

From this formula it is easy to understand that the Euclidean distance can be interpreted as Minkowski's metric for $k = 2$, while the block distance can be interpreted as Minkowski's metric for $k = 1$.

2.4.2 Dynamic Time Warping Distance

One of the distances applied in this thesis is the Dynamic Time Warping (DTW) distance. It is an algorithm that allows to measure the similarity between two different sequences [18]. The basic idea is to calculate the distance between two vectors / time series regardless of their length, and to do this, the vectors must comply with the following rules:

- - all the indices of the first sequence must be able to be compared with all the indices of the others and vice versa.
- - the first index of the first sequence must be associated with the first index of the other sequence (but it must not be its only match);
- - the last index of the first sequence must match the last index of the other sequence (but it must not be its only match);
- - the mapping of the indices from the first sequence to the indices of the other sequence must be monotone increasing; regardless of the length of the series, the initial and final index must coincide.

The DTW algorithm is therefore an excellent method for solving the problem of time misalignment of time series. This algorithm is particularly useful for dealing with sequences in which individual components have characteristics that change over time, and for which the simple linear expansion or compression of the two sequences does not bring satisfactory results. Thanks to this distance it is possible to identify an optimal non-linear alignment of time sequences, calculating the distance through an application-specific d function. The DTW distance allows for temporal sequences that can vary in speed and was initially conceived to be used in speech recognition.

2.5 The choice of the method of formation of the groups

As regards the method of forming groups, the fundamental objective is to classify the units into groups with the characteristics of:

1) INTERNAL COHESION (the units assigned to the same group must be similar to each other);
2) 2) EXTERNAL SEPARATION (the groups must be as distinct as possible from each other).

Group classification algorithms are divided into hierarchical and non-hierarchical:

- the hierarchical methods allow to obtain a family of partitions, with a number of groups from n to 1, starting from the trivial one, in which all the units are distinct to arrive at that, also trivial, in which all the elements are gathered in a single group (aggregative hierarchical methods). It should be noted that there are also splitting methods, not covered here.
- non-hierarchical methods provide a single partition of the n units into g groups, with g set a priori.

An aggregative hierarchical classification method has the following characteristics [1]:

1- consider all levels of distance.
2- the groups obtained at each at each distance level include the groups obtained at the lower levels. When two units join together, they cannot be separated in the next steps of the procedure.

From a matrix of distances D calculated for the n statistical units, the procedure followed to obtain the subsequent partitions is divided into the following phases:

1- the two units with the shortest distance (ie those most similar to each other) are identified in matrix D and come together to form the first group. In this way, there is a partition with (n-1) groups of which (n-2) consisting of single units and the other consisting of two units.
2- proceed by recalculating, on the basis of a specific criterion, the distance of the new group from the other remaining units, obtaining a new matrix of the distances, with dimensions decreased by one.
3- the pair of units (or groups) with the shortest distance is identified in the new distance matrix, bringing them together in a single group.
4- the second and third phases are repeated until all the units are united in a single group.

The differences between the various hierarchical methods consist in the criterion used to calculate the distance between the two groups of units.

2.6 Classification of the hierarchical methods applied

In this work, hierarchical methods that require both knowledge of the distance matrix and hierarchical methods that use the data matrix have been considered and applied. Among the hierarchical methods that require only the knowledge of the distance matrix are:

1- SINGLE-LINKAGE CLUSTERING METHOD. Let n_1 and n_2 be the numerosity of two generic groups, C_1 and C_2 , respectively. The distance between two groups is defined as the minimum of $n_1\, n_2$ distances between each of the units of one group and each of the units of the other group:

$$d(C_1,C_2)= \min\,(d_{rs}),\ \text{per}\ r\epsilon C_1,\ s\epsilon C_2.$$

The single link method has the so-called << chain effect >>, that is, it can bring together even very distant elements in a single group when there is a succession of intermediate points between them.

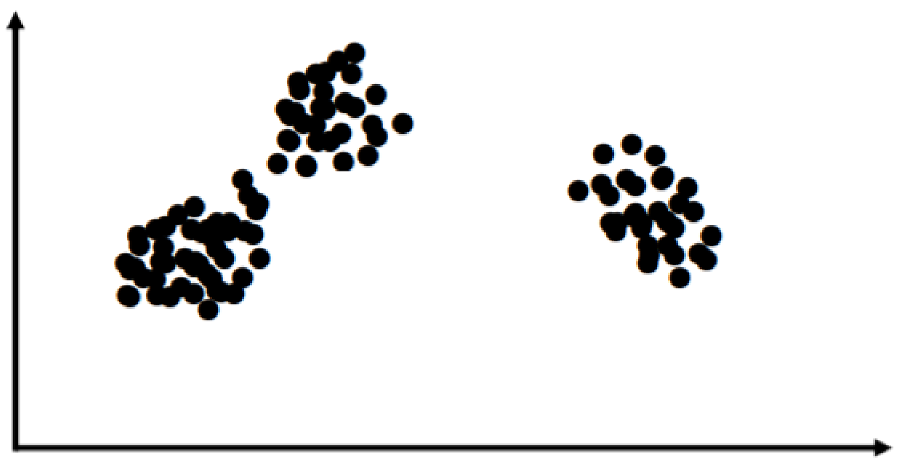

Figure 2.3: chain effect - Multivariate Statistics teaching material - Professor Pierpaolo D'Urso - University of Rome La Sapienza

Figure 2.3 shows an example of the ripple effect. The existence of three clusters in the plane is clearly noted, but the presence of some units representing the links in the chain leads, with the single bond method, to the union in a single group of the two clusters placed on the left of the plane. It is important to note, however, that this group does not exhibit internal cohesion. The chain effect of the single bond, while on the one hand has a disadvantage linked, precisely, to the lack of internal cohesion, on the other, has the advantage of identifying clusters with elongated shapes, as in Figure 2.4.

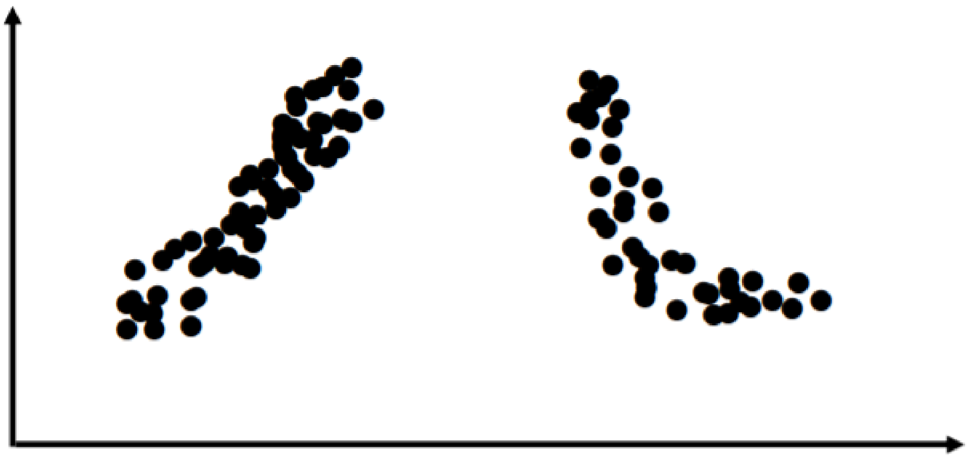

Figure 2.4: Cluster formation with elongated shapes due to the chain effect - Multivariate statistical teaching material - Professor Pierpaolo D'Urso - University of Rome La Sapienza

2- COMPLETE LINKAGE CLUSTERING METHOD. The distance between two groups is defined as the maximum of $n_1\,n_2$ distances between each of the units of one group and each of the units of the other group:

$$d(C_1,C_2)= \max\,(d_{rs}),\ \text{per}\ r\epsilon C_1,\ s\epsilon C_2.$$

The method of the complete bond instead identifies compact groups within them, but always of an approximately circular shape, without the possibility of obtaining clusters of elongated shape. In the graph previously analyzed on the chain effect, in Figure 2.3, the complete bond method, on the other hand, would be able to identify three groups

The method of the medium bond constitutes in many circumstances a reasonable compromise to obtain groups with good internal cohesion and external separation.

As specified above, there are other hierarchical methods that also use the starting data matrix [1]:

1- CENTROID-LINKAGE CLUSTERING METHOD. The distance between the two groups C_1 and C_2 of numerosity n_1 and n_2 is defined as the distance between the respective centroids $\bar{\boldsymbol{x}}_1, \bar{\boldsymbol{x}}_2$.

$$d(C_1,C_2)= d(\bar{\boldsymbol{x}}_1, \bar{\boldsymbol{x}}_2)$$

Calculating the centroid of a group of units requires knowledge of the respective values of the p variables, which can be identified from the data matrix.

2- WARD'S-LINKAGE CLUSTERING METHOD. In Ward's method, an objective function is explicitly defined. Since the purpose of the classification is to obtain groups with the greatest internal cohesion, we consider the decomposition of the Total Deviance T of the p variables into Deviance into groups (Within, W) and Deviance between groups (Between, B)

$T = W + B,$

where, considering a partition into g groups,

$$T = \sum_{s=1}^{p} \sum_{i=1}^{n} (x_{is} - \bar{x}_s)^2$$

is the total deviance of the p variables obtained as the sum of the deviances of the single variables with respect to the corresponding general mean $\overline{x_s}$. While,

$$W = \sum_{l=1}^{g} W_l$$

corresponds to the Deviance in the groups, i.e., the sum of the group deviances W_l:

$$W_l = \sum_{s=1}^{p} \sum_{i=1}^{nl} (x_{is} - \bar{x}_{s,l})^2$$

which represents the deviance of the p variables in the l-th group (of numerosity n_l and centroid $\overline{\boldsymbol{x}_l} = [\bar{x}_{1l}, \dots \bar{x}_{p,l}]'$

The deviance between groups is equal to:

$$B = \sum_{s=1}^{p} \sum_{l=1}^{g} n_l (\bar{x}_{s,l} - \bar{x}_s)^2$$

and corresponds to the sum, calculated on all the variables, of the (weighted) deviations of the group averages with respect to the corresponding general average. At each step of the hierarchical procedure the groups that involve the least increase in

Deviance in the groups are aggregated, that is, which ensure the greatest possible internal cohesion.

2.6.1 The properties of hierarchical methods

Starting from the distance matrices, different hierarchical classifications can be obtained. We can therefore ask ourselves if there is a better classification than the others. The answer is not unique. The problem can be solved in terms of <<desirable>> properties, which should have a method of forming groups and verifying these properties for the various classification algorithms. Logically, there are two very important properties to take into consideration:

1- 1- THE MINIMAL WELL-STRUCTURED PARTITION. A minimal well-structured partition is defined as a well-structured partition with the least number of clusters. Starting from the initial data matrix, suppose we have obtained a matrix of the distances between the various statistical units. The calculation of the matrix implies various preliminary choices such as the evaluation of the type of metric, the standardization or not of the variables and the possible weighting of the variables. It is important to ask ourselves the question of what is the maximum degree of objectivity that can be achieved in the formation of groups of units starting from this matrix of distances. A very important criterion for determining the groups is to require that the maximum distance within the groups considered is less than the minimum distance between the groups. All the distances between the elements of a generic group are smaller than the distances between the elements of a particular group and the remaining elements of another group. In this case, the groups correspond to internally homogeneous subsets. Graphically, an illustration of the Minimal Well Structured Partition criterion is provided (Figure 2.5). As you can see, the maximum distance within the two groups is less than the minimum distance between the two [1].

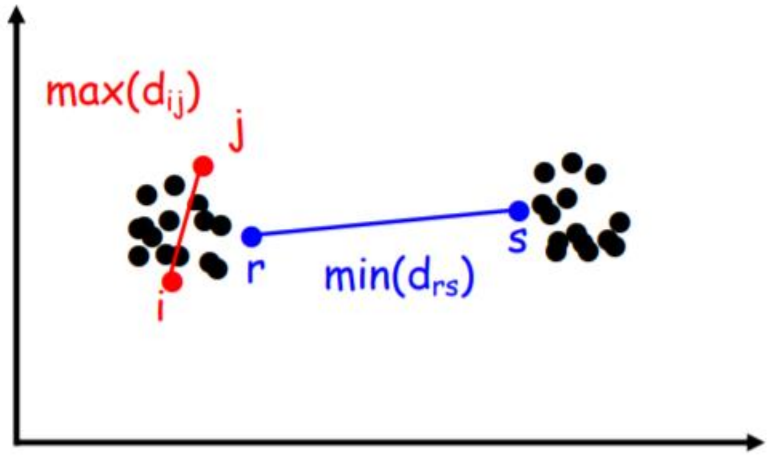

Figure 2.5: well-structured minimal partition - Multivariate Statistics teaching material - Professor Pierpaolo D'Urso - University of Rome La Sapienza

The methods of the single, medium and complete link considered are able to identify the well-structured minimal partition, which represents the most synthetic classification obtainable in an objective way. Consequently, these methods are all logically acceptable and differ from each other with regard to the aggregations of the elements and groups for which it is not possible to define an objective criterion a priori. On a practical level, however, the well-structured minimal partition is almost always made up of an excessive number of groups, that is, with too high a dispersion. One solution is to proceed with the subsequent steps of a hierarchical method, which never splits the groups obtained in the previous steps but allows to further aggregate the groupings that make up the identified objective partition.

2- INVARIANCE DUE TO MONOTONE TRANSFORMATION OF DISTANCES. A hierarchical method of group formation is said to be invariant under increasing monotone transformation of distances when it provides the same succession of partitions for each increasing monotone transformation of distances appearing in matrix D.

The single bond method and the complete bond method both satisfy both the minimal well-structured partition property and the invariance property for monotonous distance transformations.

2.7 Graphic representation: the dendrogram

The family of partitions obtained through the application of a hierarchical method can be represented graphically by means of an n-Dimensional Tree (n-Tree). Specifically, a system of Cartesian axes is considered in which the statistical units are identified on the abscissas while, in the ordinate, the levels of distance that characterize the aggregations of the various divisions are set. This type of graph is called a dendrogram.

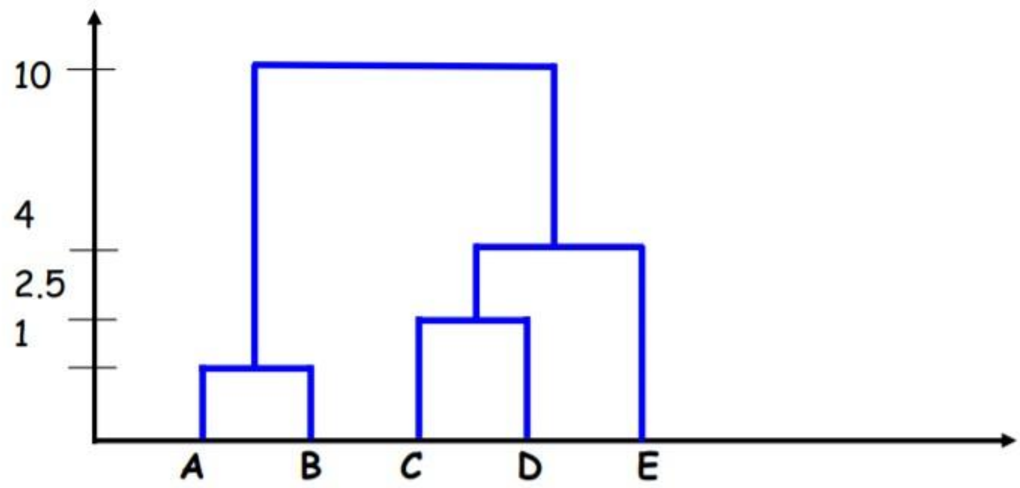

Figure 2.6: dendrogram - Multivariate Statistics teaching material - Professor Pierpaolo D'Urso - University of Rome La Sapienza

This type of graph (Figure 2.6) provides important information regarding the choice of the most appropriate partition in the context of the succession of partitions provided by a given hierarchical method. For example, when the distance between one step and the next is very large, it means that the groups that should meet are very far from each other. In this case it might be convenient to stop the classification before this jump, choosing the partition that is still characterized by strong internal cohesion.

2.8 Internal validation index

For the choice of the number of groups and, in the case of hierarchical methods, to decide the point in which to "cut" the dendrogram, it is possible to resort to the use of indices that provide important information regarding the number and the optimal structure of clusters. Once the division into clusters has been obtained, it is essential to understand how many clusters to take into account. The Silhouette Index was applied in this paper.

It checks for consistency within data clusters. The silhouette value is a measure of how similar an object is to other objects in its cluster. A high value indicates that a unit that is part of the dataset is well matched to its cluster and very different from neighboring clusters. If most of the objects have a large value, very close to the value of 1, then the cluster configuration is appropriate. If the values of the index are too low or negative, the configuration of the groups may have too many or too few clusters. This internal validation index can be calculated with any distance metric.

CHAPTER 3: ANALYSIS AND INTERPRETATION OF RESULTS

Introduction

The exploratory technique of Cluster Analysis was applied to a dataset of time series from 2004 to 2019, published by the statistical office of the European Union, Eurostat, relating to the percentages of gross final consumption of energy from renewable sources. The data refer to the 28 EU member states (including the United Kingdom). In addition, there are Montenegro, Albania, Serbia, which are in the process of transposing EU legislation into national law, Kosovo, which represents a potential candidate, but which still does not meet the requirements for joining the Union. European Union, and Norway and Iceland, closely linked to the European Union thanks to the agreement on the European Economic Area (EEA).

The data pre-treatment phase involved a normalization procedure of the single historical series, characterized by very different orders of magnitude. The annual data were normalized with respect to the average value of each individual country, for the time period from 2004 to 2019. In this way, it was possible to identify the different speeds with which the countries have implemented their race towards the objectives of the 2020 established by Directive 2008/28 / EC. With reference to the data described above, it was decided to apply a hierarchical clustering method based on the distance of Dynamic Time Warping; the best results in terms of goodness of the partition were obtained with reference to the agglomerative methods of the complete bond and of Ward, respectively. It should be noted that the results, commented on in this chapter, refer to the partition based on the Ward method.

For the choice of the number of groups, the Silhouette index was calculated for a number of groups from 2 to 10. Although the highest value of the index corresponds to 2 groups, in this particular case, the presence of the outlier unit (Malta) causes a masking effect of natural groups; in fact, as can be seen in Table 3.1, excluding this unit, the highest value is obtained in correspondence of 3 groups. For this reason, it was decided to proceed with the analysis of the results, including Malta, and considering 4 clusters. The corresponding dendogram is shown in Figure 3.1.

Table 3.1: Silhouette Index results for a number of groups from 2 to 10 with the exclusion of Malta

	N. Groups								
Silhouette index	**2 groups**	**3 groups**	**4 groups**	**5 groups**	**6 groups**	**7 groups**	**8 groups**	**9 groups**	**10 groups**
	0.4816	**0.5191**	**0.4133**	**0.3273**	**0.3273**	**0.3328**	**0.3423**	**0.3448**	**0.3440**

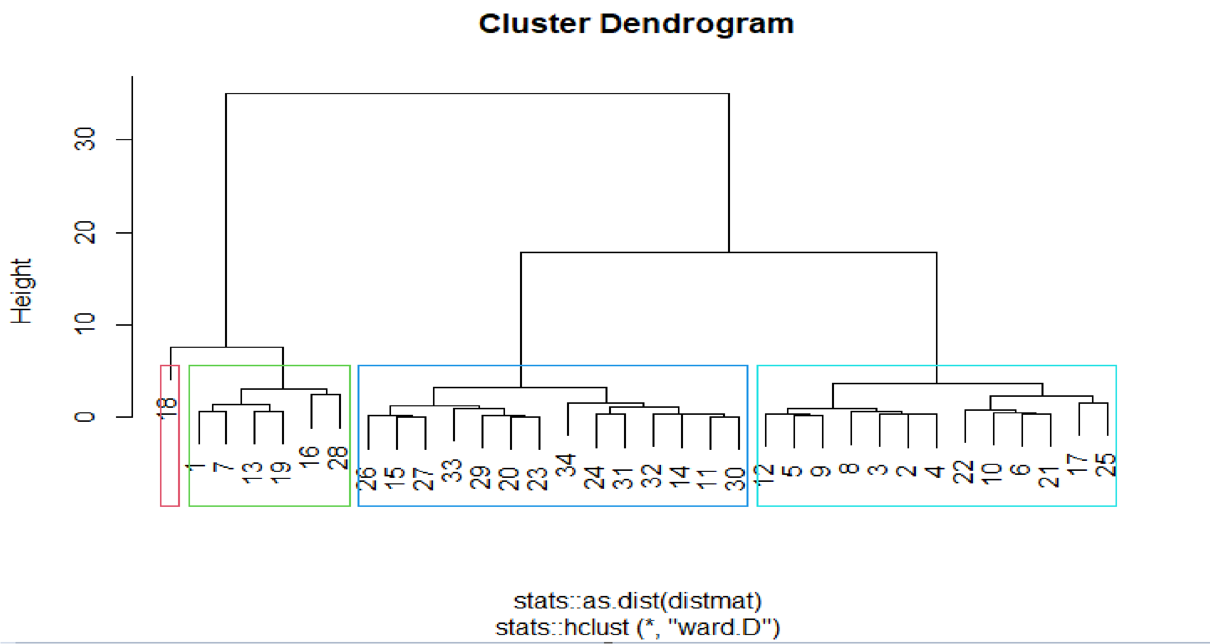

Figure 3.1: dendrogram generated with R studio software containing the groups of countries

Table 3.2 provides the association between the numerical labels present in the dendrogram and the countries of the European Union analyzed.

Table 3.2: association between the countries and the numerical labels present in the dendrogram

Cluster Labels	Countries	Cluster Labels	Countries	Cluster Labels	Countries	Cluster Labels	Countries
1	**Belgium**	11	**Croazia**	21	**Poland**	31	**Montenegro**
2	**Bulgaria**	12	**Italy**	22	**Portugal**	32	**Albania**
3	**Rep. Cieca**	13	**Cyprus**	23	**Romania**	33	**Serbia**
4	**Denmark**	14	**Latvia**	24	**Slovenia**	34	**Kosovo**
5	**Germany**	15	**Lithuania**	25	**Slovakia**		
6	**Estonia**	16	**Luxembourg**	26	**Finland**		
7	**Irland**	17	**Hungary**	27	**Sweden**		
8	**Greece**	18	**Malta**	28	**England**		
9	**Spain**	19	**Netherland**	29	**Island**		
10	**France**	20	**Austria**	30	**Norway**		

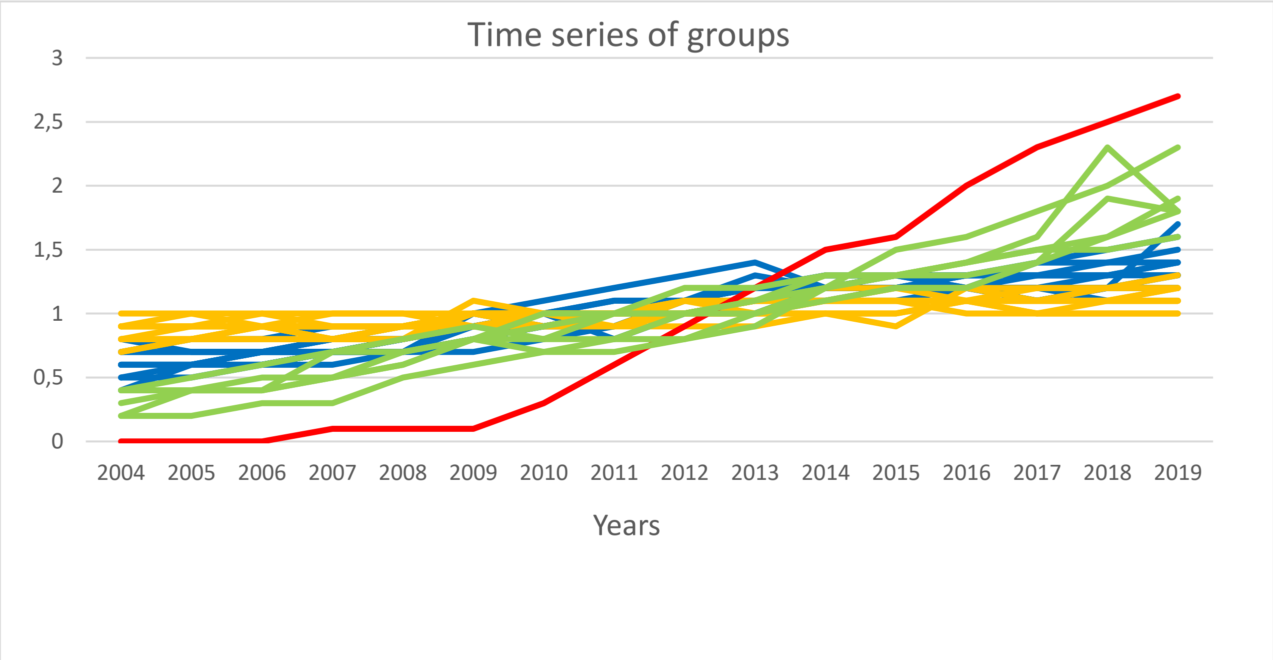

Figure 3.2: graph of the partition into four clusters obtained with the Ward-Linkage method and the distance of Dynamic Time Warping

In Figure 3.2, the graph containing the partition into four clusters obtained with the Ward method and the Dynamic Time Warping distance is shown. Analyzing the graph, each single cluster presents a growth rate of the percentage of gross final consumption of energy from different renewable sources. The time series in red, represented by Malta, is the one with the fastest and most sudden growth rate. It represents an outlier, as it presents values and a historical trend that differ significantly from that of the other countries analyzed. The high rate of growth is mainly due to the entry into force of the original Renewable Energy Directive 2009/28 / EC.

The second historical series in, composed of the countries belonging to the Benelux Union and the two countries belonging to Ireland, Ireland and the growing one, shows a marked trend compared to the other groups, but with a less rapid and sudden growth rate. to that of Malta respect.

The Third Cluster in yellow, represented by the Scandinavian countries and Eastern European countries, has the lowest rate in terms of percentage growth in the consumption of energy from renewable sources. In fact, graphically there is no particularly growing trend. This is due to the fact that within this cluster there are the countries that, since 2004, had the highest percentages of energy consumption from renewable sources among the member states of the European Union, including Norway and Iceland.

The fourth and last cluster in blue, containing the countries of Southern Europe and Central Europe, has a slightly higher percentage growth rate than the third group. Graphically, a gradually increasing historical trend is highlighted, without the presence of particular fluctuations. In paragraph 3.3 an interpretation and a detailed comment on the individual clusters analyzed will be provided.

In table 3.3, the composition of the groups is given in detail.

Table 3.3: composition of the four Clusters obtained with the Ward method and the distance of the Dynamic Time Warping

Groups	**Countries**
1° Group	**Malta**
2° Group	**Belgium; Netherland; Luxembourg; England; Irland; Cyprus**
3° Group	**Serbia; Montenegro; Albania; Kosovo; Romania; Finland; Lithuania; Sweden; Island; Austria; Norway; Latvia; Slovenia; Croatia**
4° Group	**Hungary; Slovakia; Greece; Germany; Spain; Bulgaria; Denmark; Czech republic; Italy; Portugal; France; Estonia; Poland**

Each group analyzed has a Medoid unit inside. Each of them is representative of the cluster to which it belongs and is, properly speaking, that unit whose sum of dissimilarities with all the objects in the cluster is minimal. Below is shown, in Figure 3.2, the graph with the four Medoids representative of the four groups.

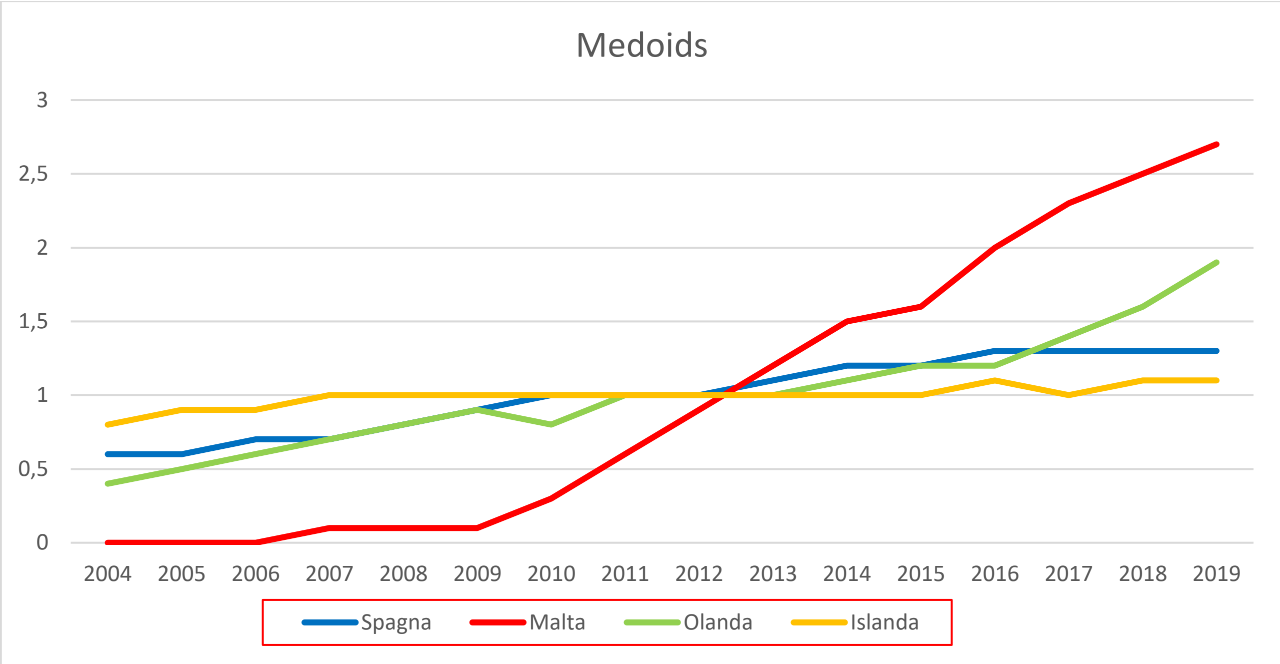

Figure 3.3: graph of the representative Medoids of the four groups of countries

3.2 The importance of Directive 2009/28 / EC

As previously described, each group presents a significantly different trend, and Directive 2009/28 / EC has played a fundamental role in stabilizing the percentage shares to be achieved in 2020 for each individual European country. Specifically, the original Renewable Energy Directive, adopted by co-decision on 23 April 2009 (Directive 2009/28 / EC) established that, by 2020, a mandatory 20% share of EU energy consumption had to come from renewable sources. Until 2020, the directive confirmed the existing national renewable energy targets for each country, taking into account the starting situation and the overall potential in terms of renewable energy (from a 10% renewable energy share for Malta to a share of 49% for Sweden). Each EU country was able to define how it planned to achieve its individual target and overall roadmap for its renewable energy policy in a national action plan. Progress towards national targets was measured every two years, together with the publication by EU Member

States of national renewable energy progress reports. Figure 3.2 is shown below, which shows the gross final consumption of energy deriving from renewable sources in 2019 of the EU countries with the respective national targets to be achieved by 2020.

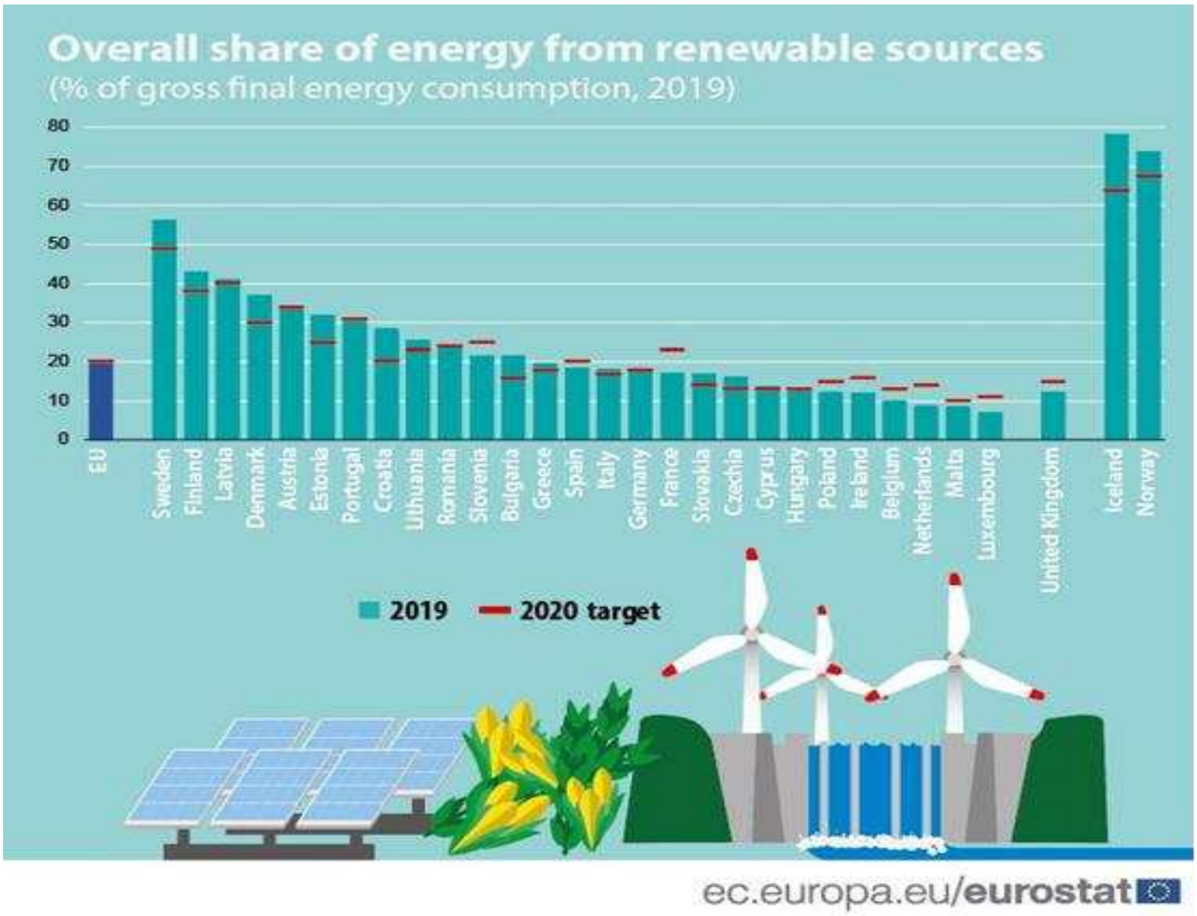

Figure 3.4: gross final consumption of energy from renewable sources in 2019 in relation to the objectives set for 2020 for the European Union - source Eurostat

3.3 Interpretation of clusters and historical trends

1st CLUSTER. The first Cluster is represented by Malta (Figure 3.5), the smallest country among the EU member states, which joined the European Union following the great enlargement of 2004. It is, properly speaking, an outlier, as it presents some values and a historical trend that differ significantly from that of the remaining 34 countries.

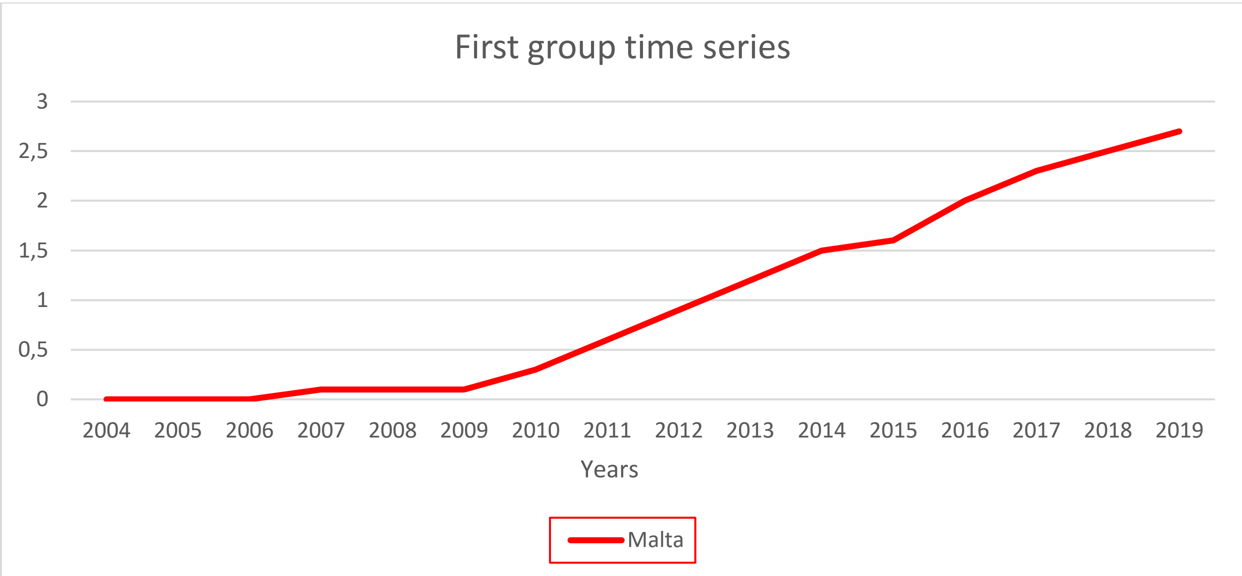

Figure 3.5: historical series belonging to the 1st Cluster

In consideration of the starting conditions and the overall potential of Malta in terms of renewable energy, the European Union has established a share of 10% of gross final consumption of energy from renewable sources to be achieved in 2020. As shown in the graph in Figure 3.5, the country, from 2004 to 2009, has values close to zero. Following the original Renewable Energy Directive which came into force in 2009, there is a sharp increase in the gross final consumption of energy from renewable sources. It is a very small country but with great potential for solar energy. Compliance with the objectives set by the European Union regarding renewable energies is just one of the reasons for the growth of photovoltaics in this island republic. The high percentage of insolation makes it a perfect place for the installation of solar panels. The country has officially become the 4th market in the European Union for the spread of photovoltaic panels per capita and has grown more than 8 times since 2012. This rapid growth is helping Malta to create a highly competitive photovoltaic market. It is a state with 300 days of sunshine per year. It should be added that its climate is characterized by a high amount of dust, salt from the surrounding sea and strong winds. For this reason, in a climate like this, the installation of photovoltaic panels of certain durability and resistance to thermal excursions is absolutely necessary to optimize production, and this may take longer. In 2019 Malta reached a percentage of gross final consumption of energy deriving from renewable sources of 8.5%, approaching the 10% quota established by the European Directive.

2nd CLUSTER. The second Cluster is made up of six countries: England, Ireland, Belgium, Luxembourg, Holland and Cyprus (Figure 3.6).

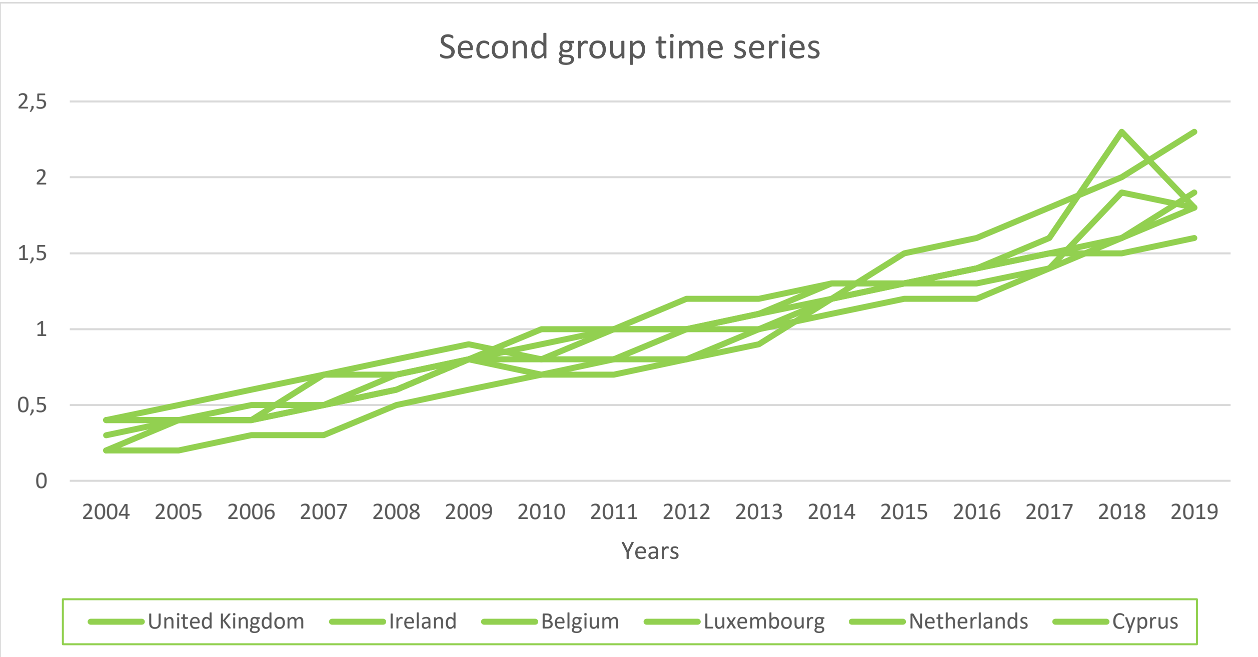

Figure 3.6: historical series belonging to the 2nd Cluster

As for England and Ireland, the two neighboring countries have established a memorandum for urban regeneration aimed at sustainable development through the construction of cycle paths, electric public transport and installation of wind turbines.

The two countries show a growing trend thanks, in particular, to the increased production of wind energy over the years, with the construction of new offshore plants and the strengthening of those already existing along the Irish and English coasts. Despite the growth in the percentages of renewable energy consumption, England and Ireland have to face various problems regarding a joint project on sustainable development which, if implemented, would have brought benefits to both parties and would have allowed the creation of the most ambitious construction of offshore wind turbines by 2020. In fact, a memorandum of understanding had been ratified which provided for the installation of 2,300 offshore wind turbines between the two countries, by 2020, to supply 5000 MW of energy to the English market. Ireland, due to the delay by England in the installation of the various plants, has threatened to take a step back and this has caused a sharp slowdown in the ambitious energy plan. As regards Belgium, Luxembourg and the Netherlands, the latter Medoid unit of the group, they represent the Benelux Union, or the intergovernmental cooperation agreement between Belgium, the Netherlands and Luxembourg, whose founding act dates to 1958 and takes the name of the Benelux Economic Union Treaty. On June 17, 2008, a new treaty was signed in which it was established that cooperation between these three countries will focus on three fundamental issues:

1- EU internal market.
2- Sustainable development.
3- justice and home affairs.

Since the signing of the new treaty, the percentages of final energy consumption deriving from renewable sources have always had an increasing trend. However, although there have been some steps forward in recent years, among the lowest percentages of renewable energy in 2019, there were precisely those belonging to Belgium, Netherlands and Luxembourg, still finding themselves far from the target set by the European directive for 2020 (Luxembourg 7.0%, Netherlands 8.8% and Belgium 9.9%). A factor that is certainly limiting progress in the adoption of renewable energy in the three countries is certainly the lack of efficient political and regulatory reforms that can increase the incentives to invest in renewable sources.

The last country belonging to the second cluster is Cyprus. Despite being among the countries with the lowest percentages of gross final consumption of energy from renewable sources, it is the only country within the group to have reached the share of renewable energy established by the directive for 2020 with a percentage of 13,5%.

3rd CLUSTER. The third cluster is the largest among those present in the dendrogram and is represented by the following countries: Sweden, Finland, Iceland, Norway, Latvia, Lithuania, Austria, Slovenia, Serbia, Montenegro, Albania, Romania, Kosovo and Croatia.

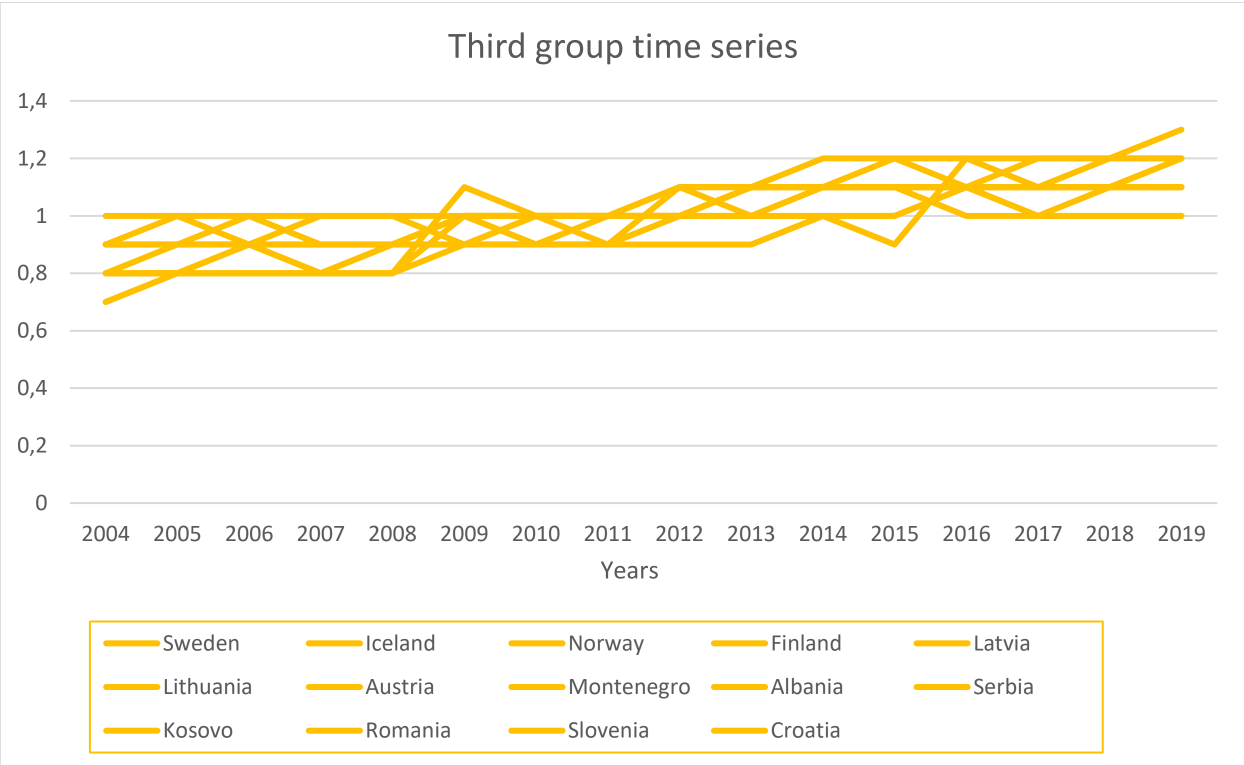

Figure 3.7: historical series belonging to the 3rd Cluster

By qualitatively analyzing the graph in Figure 3.7, the trend of the historical series of the countries does not show a particularly growing trend. This is due to the fact that within this cluster there are countries that already had by far the highest percentages of energy consumption from renewable sources among the member states of the European Union; the group also includes Norway and Iceland, closely linked to the European Union thanks to the agreement on the European Economic Area (EEA).

Since these countries, as early as the 2000s, had a very high percentage of energy consumption from renewable sources, the percentage increase over the years has been very gradual without sudden peaks. Iceland, the group's Medoid unit, and Norway, in 2019 recorded a share of their primary energy consumption from renewable sources of more than 70%. Norway has always been an oil country but capable of generating most of its energy from hydroelectricity. As government agency Orkustofnun explains, the generation of electricity with geothermal and hydroelectric energy has increased significantly in recent years. Geothermal plants currently generate 25% of the country's total electricity production.

Over the course of the twentieth century, Iceland went from being one of the poorest countries in Europe, dependent on imported coal for its energy, to a country with a high standard of living where virtually all stationary energy comes from renewable resources. Already in 2014, about 70% of primary energy consumption in Iceland came from renewable resources. Geothermal sources currently account for 66% of primary energy consumption [16].

As for the EU Member States belonging to the third cluster, Sweden (56.4%) presented the highest percentage among all EU Member States, in 2019. Sweden has taken significant actions to invest in renewable energy and use them for everyday activities. Currently, up to 56.4% of the energy used in Sweden comes from renewable energy sources and, in 2016, the world's first fully electrified road was established.

Furthermore, within the largest country in Northern Europe, sources such as waste, biomass, solar, wind and hydroelectric energy are used on a large scale to ensure sustainable and ethical development for the whole country. Sweden was the first country to reach the renewable energy targets set by the European Union (EU) for 2020.

Furthermore, this milestone was reached eight years in advance thanks to the continuous supply of renewable energy and the efficient political and financial planning to support it. In 2019, among the countries that recorded the highest shares immediately after Sweden there are Finland (43.1%), Latvia (41.0%), Denmark (37.2%) and Austria (33.6%) confirming definitively that the Scandinavian countries are becoming full protagonists of the energy transition.

The countries belonging to the Balkan area present within the Cluster, including Montenegro, Albania, Serbia, which are in the process of transposing EU legislation into national law, and Kosovo, which represents a potential candidate but which is not yet meets the requirements for joining the European Union, they too show a trend that is not particularly growing but with a percentage of gross final consumption deriving from renewable sources already high since the beginning of the 2000s. It is important to note that these countries closed 2019 with a share of energy consumption from renewable energy well above 20% thanks to the widespread use of wind energy [25]. This is a truly important result for the entire Balkan region in terms of sustainable development and environmental protection. However, the three countries next to become member states and Kosovo were not taken into consideration by the European Directive for the definition of the objectives to be achieved in 2020.

4th CLUSTER. The fourth and final cluster contains the following countries: Italy, Portugal, Spain, Greece, Hungary, Slovakia, Germany, France, Bulgaria, the Czech Republic, Estonia, Poland and Denmark (Figure 3.8).

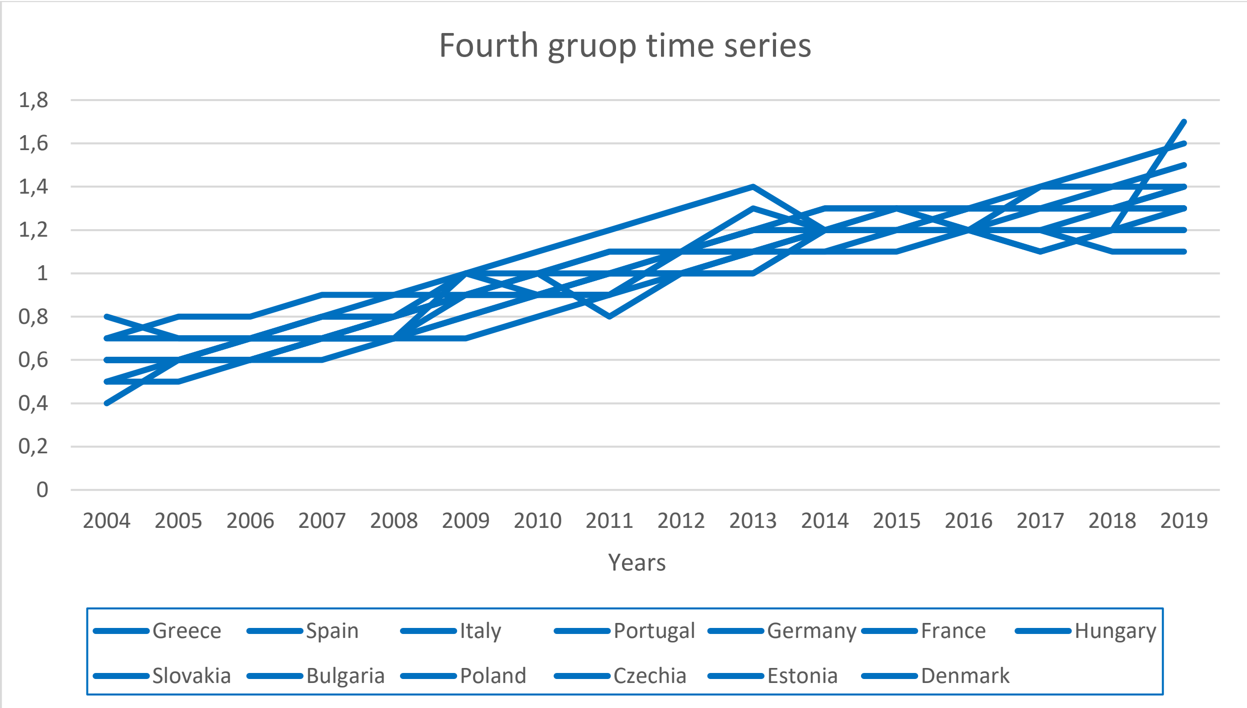

Figure 3.8: historical series belonging to the 4th Cluster

Italy, Portugal and Greece, together with Spain, which represents the Medoid unit of the group, are part of the countries belonging to the Euro-Mediterranean area and are united by a multiplicity of characteristics, especially as regards the models of the states, their situation socio-economic and cultural proximity of its members. New research conducted on Italy, Greece and Spain has shown that renewable energies have enormous potential in Mediterranean countries and could also act as a stimulus to the economy with the creation of thousands of jobs. The studies have considered a number of possibilities to decarbonize the economy by saving on carbon credits or on fuel imports. Even the most economically disadvantaged country in Europe, Greece, could find significant benefits by moving towards green energy. In Italy and Spain, island areas are able to provide good examples of the use of renewable sources such as wind, wave, solar and geothermal, without compromising energy production for tourism or desalination [20].

In relation to the 2020 objectives established by the European directive, the four countries in 2019 managed to reach the foreseen renewable energy quotas. As for France, one of the largest economies in the European Union together with Germany, it was the country that, on the other hand, is still considerably far from the national objectives established by the European Directive.

The directive established for France a percentage share of energy consumption from renewable sources of 23% for 2020. In 2019, unfortunately, the country recorded a percentage share of 18.2%, with a distance of 5.8 points percentages. Although there is a sizeable percentage of its electricity coming from hydroelectric sources, the French electricity system is dominated by still stable nuclear power generation today. In the 1970s and 1980s, the French government decided to build thirty-four nuclear reactors and very few of these were dismantled. 2016 data [21] reported that, in France, 72.4% of the country's electricity was generated by nuclear energy. France is now considered the only country in Europe to have such a high percentage of nuclear production. According to the newspaper "il Post", French President Emmanuel Macron has proposed an important investment project to encourage the revival of the country's economy. The plan is called "France 2030" and the priority objective is to "reinvent nuclear power" by building new high-efficiency nuclear power plants for the production of electricity. This result, together with a low cost of electricity, allow France to be the first net exporter of electricity in the world. A figure that can certainly be positive, but which is leading the country to slow down if not take steps backwards in its energy transition towards renewable energy.

Within the fourth cluster there are also Bulgaria, the Czech Republic, Hungary, Poland and Slovakia. These countries represent an important block of Central Europe, and they all share an interesting aspect. In the European race for climate neutrality, these countries have always struggled to find workable plans to reduce polluting sources. And more than one of the following governments, led by France, has pushed for a return, albeit partial to nuclear energy and among these we find Poland, the Czech Republic, Slovakia, Hungary, Bulgaria [23]. In relation to the objectives for 2020, in 2019, with the exception of Poland, the only EU country that has not yet adhered to the EU goal of climate neutrality by 2050, the countries of Central Europe have largely reached the quotas established by the Directive. Graphically, the five countries show an overall growing trend with an average value of final energy consumption deriving from renewable sources of around 15%.

The last country belonging to the fourth cluster is Denmark. Denmark, world leader in wind technology, together with the other Northern European countries previously presented in the third Custer, recorded one of the highest percentages of energy consumption from renewable sources in all of Europe in 2019, with 37.2 %, far exceeding the target set by the European Directive of 30% for 2020. The smallest and southernmost state from Scandinavia has not been combined with the other neighboring countries as it presents a significantly different historical trend. Denmark is present within the fourth cluster because, unlike the other Scandinavian countries, it started from lower gross final consumption levels of energy from renewable sources. Its growth trend was faster. The use of energy from renewable sources has grown by 60%. This is a very high percentage, which led the Danish Parliament to launch a plan to bring Denmark to produce 100% renewable electricity by 2030 and achieve energy independence by 2050.

3.4 An in-depth analysis of Italy

Historically Italy has always been at the forefront, in Europe and in the world, on the renewable energy front. The various types of alternative energies to those of fossil fuels represent an important share of the country's energy production. The percentages are constantly growing, year after year. Below, in Figure 3.7, the historical series of its gross final energy consumption deriving from Renewable Sources from 2004 to 2019 is shown.

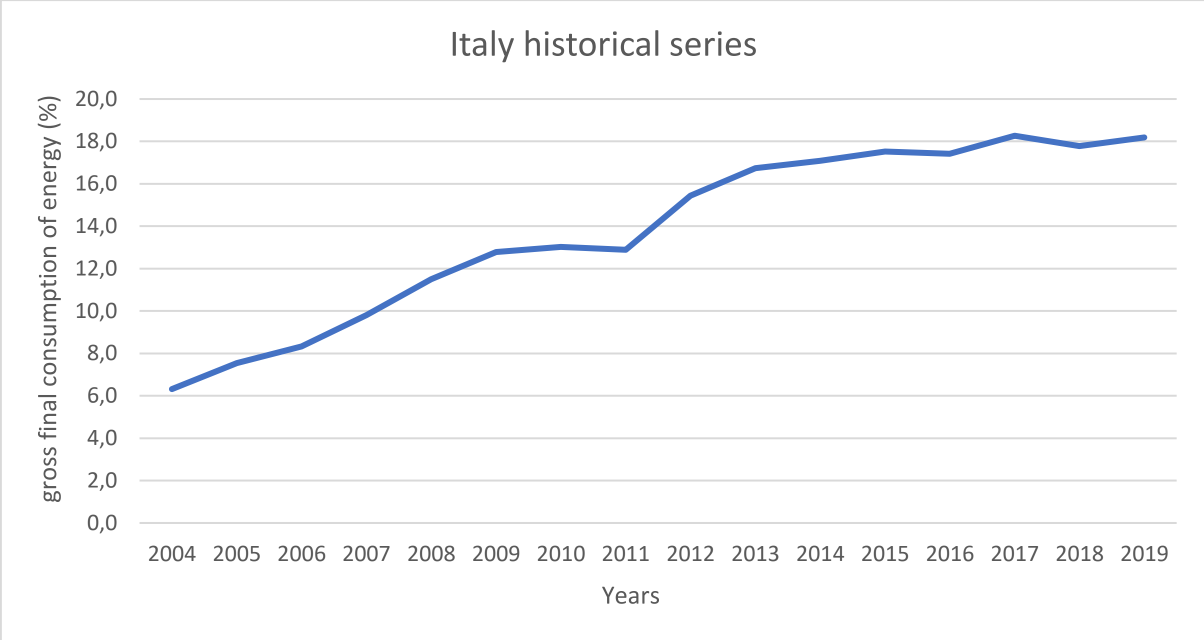

Figure 3.9: time series on the percentages of gross final consumption of energy deriving from renewable sources in Italy from 2004 to 2019

Directive 2009/28 / EC, implemented in 2011, assigns Italy the binding national target in terms of the share of gross final consumption of energy covered by renewable sources (RES) in 2020:

"Achieve by 2020, a share of total gross final consumption of energy from renewable sources equal to at least 17%" [22].

As it can be noted graphically, the share of renewable energy exploited for the gross final consumption of energy presents, starting from 2004, a gradually increasing trend until 2011. Starting from the year of implementation of the European Direct, there has been a substantial increase in the share of renewable energy collected, bringing Italy, one year ahead of the target set for 2020 of 17%, to have an 18.2% share of gross final consumption of energy from renewable sources.

The distribution of the various categories of renewable energy used throughout the territory presents important differences especially in consideration of the geographical characteristics. For example, one of the most important sources of renewable energy exploited by Italy, hydroelectric energy, is prevalent where the land has steep slopes, such as in the Alps and along the Apennine ridge [8]. Photovoltaics are more exploited in the south, thanks to the lower latitude and higher insolation. Wind energy is collected mainly in the islands, such as Sicily and Sardinia, to which the southern part of the Apennine ridge is generally added, starting with Puglia, Campania and Basilicata. In conclusion, geothermal energy has Tuscany as a pole of excellence, for historical reasons and geological characteristics. The growth that has occurred in the renewable energy sector in recent years in terms of distribution and on the territory has been considerable.

The official website of Enel Green Power reports that, in 2010, only 356 Italian municipalities had internal electrical or thermal systems based on renewables, while in 2020, Italy managed to reach a total of municipalities that exceeded 7,900. That of renewables is a more open and difficult challenge than ever, for which we are working simultaneously on many fronts, and it is possible to say that Italy is on track to become one of the most avant-garde countries in the whole context. European not only for the present, but also for the future.

Conclusions: A look to the future with the European Green New Deal

In conclusion, the application of the statistical method of cluster analysis on a historical series dataset has provided a strong contribution, creating groups of units with strong internal cohesion (represented by the economic and social characteristics in common between the countries belonging to a specific group) and external separation. Furthermore, it was possible to identify the speed with which the countries of the European Union have progressed in the sector of renewable energies.

As reported by the official website of the European Commission, becoming the first climate-neutral continent by 2050 is the goal of the European Green Deal [6].

This is a very ambitious plan of measures which should enable European citizens and businesses to benefit from a sustainable green transition. The use of renewable energies has many potential benefits, such as reducing greenhouse gas emissions, diversifying energy supplies and less reliance on fossil fuel markets.

The growth of renewable energy sources can also stimulate employment in the EU by creating jobs in new "green" technologies. The European Green Deal set the blueprint for this change. To achieve the transformation of the European Union into the first climate-neutral continent by 2050, the 27 EU member states have committed to reducing the percentage share of emissions by at least 55% by 2030. The implementation of these measures could give a very important contribution to creating new opportunities for innovation, investment and employment.

The benefit provided by these energy sources, as anticipated in the first chapter, however, is the environmental one. Renewable energies represent the best way to reduce greenhouse gas emissions and, consequently, contain and reduce the effects of climate change. However, there are many open questions about whether and when a 100% renewable energy mix will be possible, if all the efforts being made at European and world level will be sufficient to avoid a disastrous global warming of more than two degrees. It will be crucial to verify that the impact on the world economy is equally distributed between the North and the South of the world.

It is currently difficult to predict the future development of the energy transition. As has been highlighted, some countries have achieved the established objectives; others find themselves in a situation of delay which, in the next few years, could have numerous negative consequences. The fate of the green transition in Europe and in the world will certainly largely depend on the way in which the energy transition will be proposed and applied in the different regions, where the consumption of fossil fuels still represents 85% of the total global energy consumption.

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Index of Figures