UNIVERSITA' DEGLI STUDI DI PADOVA

DIPARTIMENTO DI SCIENZE ECONOMICHE ED AZIENDALI "M. FANNO"

CORSO DI LAUREA MAGISTRALE / SPECIALISTICA IN

BUSINESS ADMINISTRATION

TESI DI LAUREA

"Decomposition of Italy's carbon emissions from 1971 to 2013: an extended Kaya Identity applied"

RELATORE: CH.MO PROF. Fontini Fulvio

LAUREANDO/A: Gallinaro Martina

MATRICOLA N. 1105988

ANNO ACCADEMICO 2015 – 2016

Il candidato dichiara che il presente lavoro è originale e non è già stato sottoposto, in tutto o in parte, per il conseguimento di un titolo accademico in altre Università italiane o straniere.

Il candidato dichiara altresì che tutti i materiali utilizzati durante la preparazione dell'elaborato sono stati indicati nel testo e nella sezione "Riferimenti bibliografici" e che le eventuali citazioni testuali sono individuabili attraverso l'esplicito richiamo alla pubblicazione originale.

Firma dello studente

____

ABSTRACT

Negli ultimi decenni c'è stata una crescente attenzione, a livello internazionale, al problema del riscaldamento globale. Di conseguenza, notevoli sforzi sono stati spesi per l'attuazione delle più corrette politiche e misure, al fine di ridurre l'inquinamento ambientale. Comprendere quali sono le forze che determinano l'anidride carbonica, ossia la principale componente dei gas serra, è risultato essere fondamentale al fine di definire politiche sia efficaci, che efficienti. In questo studio è stata utilizzata un'identità di Kaya estesa, che include anche la penetrazione delle risorse rinnovabili, come schema di decomposizione, e il log mean Divisia index (LMDI I) è stata la tecnica di decomposizione scelta. L'analisi è stata effettuata a livello nazionale, per un periodo compreso tra il 1971 ed il 2013 ed ha permesso di disaggregare le emissioni di CO2 nei relativi fattori determinanti. I risultati dimostrano che l'effetto collegato al PIL pro capite è il principale responsabile delle emissioni e, curiosamente, è un determinante che non può essere direttamente influenzato dalle politiche ambientali. D'altra parte, l'intensità energetica ha un effetto opposto e controbilancia l'influenza della ricchezza sulle emissioni. Al contrario, il contributo date dalla penetrazione dell'energia rinnovabile non è rilevante, anche se, negli ultimi anni, ha seguito un trend crescente. Di conseguenza, le future politiche ambientali dovrebbero essere rivolte a diminuire ulteriormente l'intensità energetica e, al contempo, ad aumentare la penetrazione delle energie rinnovabili nel paese, anche con l'aiuto di un adeguato sviluppo tecnologico.

SUMMARY

INTRODUCTION

During last decades, there has been an increasing attention from National States to the problem of global warming, caused by the increased in pollution that has characterized the last century. The consequences are not only environmental, but also social and economic.

Most important, global warming is, as words suggest, a global problem that needs global solution and attention. All the agreements[1] set up so far, were aimed at making sure that National States implemented the most efficient policies and actions in order to reduce pollution and global warming.

This work starts with a description of Italy as country case. Italy has been chosen considering some of its peculiar characteristics. These are the increasing energy efficiency experienced over the last years[2], the great potential represented by renewable energy resources like wind and solar[3], the commitment to reduce carbon dioxide emissions while emerging from the economic recession and the strong dependence from other countries for the supply of oil and natural gas[4].

A useful tool that can be used in order to understand which are the main determinants of carbon dioxide emissions and, thus, to help designing the most proper policies and actions to reduce them, is the decomposition analysis

The second chapter is dedicated to detailed description of the method used to carry out a decomposition analysis for Italy's CO_2 emissions. Starting from the general technique most used to perform this kind of studies, that is the Index Decomposition Analysis (Granel, 2003). It is a method that helps disentangling the different causes of carbon emission and defining the proper policies to reduce them.

---

[1] Examples of agreements and plans, can be found at global and regional level. Those are: Kyoto Protocol, 2020 and 2030 packages adopted by the European Union. 2020 package established three main targets: 20% cut in greenhouse gas emissions (from 1990 levels), 20% of EU energy from renewables, 20% improvement in energy efficiency.
2030 package sets the following targets: a 40% cut in greenhouse gas emissions compared to 1990 levels, at least a 27% share of renewable energy consumption, at least 27% energy savings compared with the business-as-usual scenario

[2] *Efficienza Energetica: primo combustibile del mondo*. Avvenia, 2016

[3] According to the *Studio sulla sicurezza energetica in Italia e in Europa*, hydroelectric, solar, wind and geothermal energies could cover the energy need of the entire country

[4] Energy import dependency of 83.8% in 2010 (Annicchiarico B. et al., 201)

Then, the second section will continue by describing the decomposition method, within the IDA methodology, that has been applied: Log Mean Divisia Index I (LMDI I), which should be the preferred method, thanks to its desirable properties, i.e. perfect in decomposition and consistent in aggregation (Ang and Liu, 2001). The aggregate to be decomposed are, of course, CO_2 emissions and the method designed to separate the effect of different factors on emissions is the Kaya Identity. It was proposed by Kaya in 1990 (Wei Li and Qing-Xiang Ou, 2013), but, since then, it has been revised up to obtaining an extended Kaya identity. The one applied in this study that considers also the consumption of renewable energy, which best suit for the Italian case, since the relevant role played by renewable resources. The aim is to understand what is the reduction of emissions produced by the renewable energy penetration within a State. The non – extended version of this identity, only considers the contribution of CO_2 emissions from fossil fuels, making the model useless in order to define the contribution of renewables. In fact, their CO_2 emissions are theoretically zero. An extended version of the Kaya identity was proposed by Ma and Stern (2008) and by Wang et al (2005), who applied it to China carbon emission and was also applied by O' Mahony (2013) to study the Ireland case.

Last chapter will be dedicated to the application of the extended Kaya Identity to Italy, covering a period of 42 years (1971 - 2013), according to the method specified in the second chapter. On one hand, the analysis shows that the main positive determinant of emissions is GDP per capita, on which is not possible to directly act, since it is not possible or socially accepted to stop or limit a country economic growth. It would be, however, possible to break the link between GDP and emissions, i.e. decoupling the two elements, by means of, among all, technological development and energy efficiency. On the negative effects are driven by energy intensity, although special attention will be given also to renewable energy penetration, in view of the interesting results[5] obtained and of their future role. Unlike economic growth, for the governments is possible to act on these two determinants, by introducing the proper policies and measure and the analysis enables to understand on which leverages the country should focus in order to obtain noteworthy results as for the reduction of emissions and the improvement of sustainable development.

---

[5] Renewable resources penetration demonstrates to have an increasing, negative effect on emissions, after the introduction of the relative incentives

CHAPTER 1

COUNTRY PROFILE: ITALY

In recent years there has been an increasing attention by National States to the topic of the climate change. In light of this, there has been several initiatives, especially at international level, aimed at reducing Carbon Dioxide Emissions and Greenhous Gas emissions. Efforts in this sense encompassed agreements such as the Convention of Climate Change and Kyoto Protocol, at global level, and the 2020 and 2030 packages adopted by the European Union. Italy has always participated to this efforts: is an Annex I nation under the Kyoto protocol and is subject to the constraints given by the 2020 and 2030 packages. This is only one of the reasons why Italy is a good case study; attention should be paid also to the increase in energy efficiency faced recently, the not fully exploit potential represented by renewable energy resources and the import dependence from other countries for the supply of, above all, oil and natural gas. In addition, it should be considered also that the country is in a phase of recovery from the Great Recession and that a fundamental role can be played by the development of the national energy market. The consequence would be an improvement of Italian competitiveness and the creation of a roadmap to sustainable growth[6]. Besides, Italy is one of the biggest economies in the world[7], therefore, a study focused on this country and on its role as global emitter of pollutions should be extremely interesting.

1.1 General country profile: attention to CO2 emissions, energy consumption and role of economic growth

First of all, it is important to make it clearer the Italian position and characteristics about carbon dioxide emissions and its relationship with energy consumption and economic growth (recession).

Although Italy is a small country, it's role in the production of pollution is quite relevant. In fact, is the fourth country in Europe as regard for the emissions of CO_2[8] and is ranked twentieth at global level[9]. This, together with some peculiar characteristics of this country, make it

[6] National Energy Strategy
[7] It's eighth richest country in the world, according to 2015 data of the World Bank on GDP
[8] The main contributor to GHG emissions
[9] Author's own elaboration. Data source: IEA

important to focus the attention by policy makers on the problem of emission reduction. Some of this characteristics are that it has limited domestic energy resources, highly dependence on external energy supply and, since 1990 final energy consumption has been increasing steadily (Annicchiarico et al., 2014). Moreover, it has a strong industrial basis. Consequently, the reduction of carbon dioxide emissions represents a serious task for this economy (Cerdeira Bento J. P., 2014). Therefore, it will follow a preliminary overview of the aforementioned relations, that will be further investigated in the third.

1.1.1 Italian Carbon Dioxide Emissions and its relation with economic growth

Considering what is has been specified above and that Italy is emerging from a deep economic crisis, we can state that one of the main challenge of the country consists in reducing pollution, also in compliance with the requirements set at European Union level, without compromising economic growth. In fact, as indicated by Annicchiarico et al., Italy has been able, by means of reforms, to managed the recent economic recession, but, in light of this context, the debate on the environmental policy has been put aside. Nevertheless, the crisis could represent an opportunity for Italy to revise its economy, searching for alternative sources to satisfy its energy needs.

As a starting point for this preliminary analysis of Italian carbon dioxide emissions, it is necessary to look at the trend followed CO_2 emissions and Figure 1.1 shows their path over the last forty years. As we can see, starting from 1971, emission followed an overall positive trend, but some slightly declines can be observed in correspondence of the years of the first (1973) and second (1979) oil shocks. After 1979 the growth of CO_2 emissions levels out; this could be the consequence of the adjustment of the Italian economy to the oil price shocks (Annicchiarico B. et al.). Then, the crisis faced in the early 90s reduced emissions to some extent, but, after that, it began a period of constant growth of carbon dioxide emissions. This trends stopped starting from 2007 – 2008 which continued till 2013. Of course, this movement can be due to the last economic crisis (Annicchiarico B. et al.).

As already anticipated in the analysis of CO_2 emissions trends, by making a preliminary inquiry on the determinants of carbon dioxide emissions, it is possible to ascribe their movements to the economic situation of the country. Several papers, in fact, (Cerdeira Bento J. P., 2015; Mercan M. and Karakaya E., 2015; Acaravci A. and Ozturk I., 2010; Annicchiarico B. et al., 2014) investigate the role played by economic growth as a determinants of CO_2 emissions.

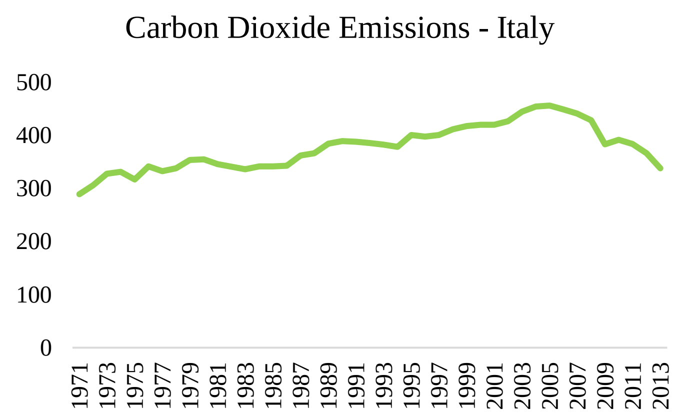

Figure 1.1 Author's own elaboration. Carbon Dioxide Emission from fossil fuels in million tonnes. Data source: IEA

These works contribute to the stream of literature which wants to understand the relationship between economic growth, pollution and energy consumption. As explained by Acaravci and Ozturk in 2010, there are three main strands in literature about this topic:

1. The first strand focus on the link between economic growth and pollution using, as instrument, the so called environmental Kuznets curve hypothesis.
2. The second strand analyse the relation between energy consumption and economic growth.
3. The last strand combined the previous two approaches, by investigating the dynamic relationship between the three elements altogether.

For the moment, the focus will be on the link between economic growth and CO_2 emissions, expressed by the environmental Kuznets curve. This curve hypothesizes an inverted - U relation between the two variables. In other terms, when an economy is in its early stage of development, environmental degradation will increase. Then, when per capita income gets higher, environmental degradation decreases (Cerdeira Bento J. P., 2014).

Results of this analysis with respect to Italy carried out by Annicchiarico, Bennato and Zanetti underlie a strong relation between real GDP and carbon dioxide emissions, even if the predicted change in the path of environmental degradation is expected at relatively high level of GDP. Also Acaravci and Ozturk (2010) and Cerdeira Bento (2014) found evidence of a short – run causal effect of economic growth on CO_2 emissions, while, in the long run, the effect becomes smaller or even negative (Acaravci and Ozturk, 2010; Mercan and Karakaya, 2015). These results give support to the environmental Kuznets curve hypothesis when applied to Italy.

1.1.2 Italian Carbon Dioxide Emissions and primary energy consumption

It will now follow a description of the relation that exist among carbon emission and primary energy consumption, which can be defined as the total energy demand of a country. It includes consumption of the energy sector, losses during transformation and distribution of energy, and the final consumption by end users[10].

First of all, I will provide an overview of the trends followed by primary energy consumption in Italy, that, despite being a small country, have faced a recent increase in the service based sectors. As a consequence, also energy consumption increased in last years (Cerdeira Bento J. P, 2014).

Indeed, this can be seen in Figure 1.2, which represents Italian primary energy consumption, expressed in million tonnes of oil equivalent (Mtoe hereinafter). Starting from the late ’80, energy consumption experienced a quite constant growing trend, with the most consuming sectors being industry, transports and households[11]. It is important to notice that, since 2000, all sectors have experienced a downward trend, with only one exception: the service sector, which showed an increase of 37%[12] and, as anticipated above, drove energy use trend.

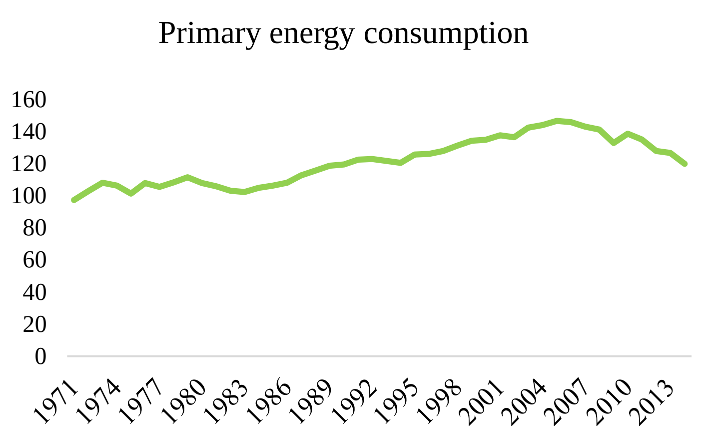

Figure 1.2 Author's own elaboration. Primary energy consumption in Italy in millions tonnes of oil equivalent. Data source: Istat

Figure 1.3 clearly shows how Italy consumes, among all, oil and natural gas, while only a small share is represented by renewable resources. Fossil fuels represent 81% of the total Italian energy consumption[13].

Furthermore, it is possible to assert that Italy consumes less than average Europeans. This is due to several factors, such as the relative high power prices and the impact of the economic

[10] Source: Eurostat
[11] Data source: Istat
[12] European energy market reform – country profile: Italy. *Deloitte, 2015*
[13] Data source: BP

crisis, which causes a decrease on electricity demand by the industrial sector. The lowest pick of electricity demand ever registered, since the liberalization of the market, was experienced in 2012 – 2013[14].

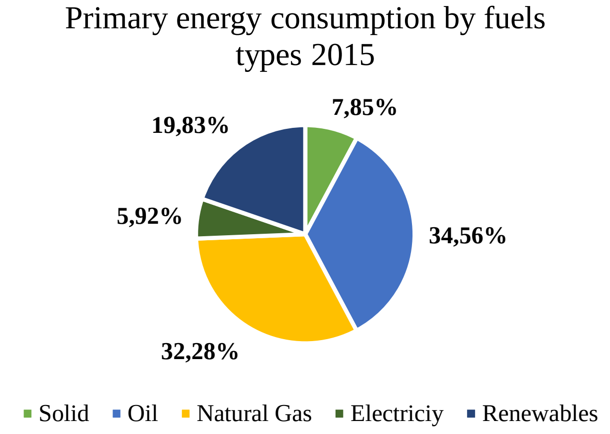

Figure 1.3 Author's own elaboration. Primary energy consumption by energy source in Mtoe. Data source: Ministry of economic development – national energy balance 2015

Now, will follow a continuation of the analysis about the relationship among economic growth, pollution and energy consumption, by taking into consideration the other two strands of literature about this topic: the one focused on the relation between energy consumption and economic growth and the one that investigates the dynamic relationship between the three elements altogether.

Results from the analyses conducted in several works are in line with theoretical expectations: energy consumption has a positive effect on CO_2 emissions. Indeed, higher economic growth should generate an increase in energy consumption, which, in turn, will lead in carbon dioxide emissions to growth (Cerdeira Bento J. P., 2014).

According to the estimation made by Cerdeira Bento in 2014, when energy consumption increase by 1%, CO_2 emissions increase by 0.776% in the long run. Even if this relation resulted to be statistically significant both in the long and in the short run, the effect on emissions in the short run is smaller and has a lower magnitude. This work also explains the positive link among economic growth and energy consumption, founding that a 1% increase in economic growth will cause an increase in 1.123% in energy consumption. In other words, since it has been already verified a relation between economic growth and CO_2 emissions, it is possible to assert that growing energy consumption in Italy, will lead, over time, to higher emissions, causing the environment to be more polluted.

[14] European energy market reform – country profile: Italy. *Deloitte, 2015*

This positive effect of energy consumption on carbon dioxide emission was underlined also by other researches. Mercan and Karakaya (2015) found that a 1% of increase in energy consumption will increase the CO_2 emissions by 0.94%, while Acaravci and Ozturk (2010) obtained evidence of a long-run unidirectional causal relationship from energy consumption per capita to carbon emissions per capita.

1.2 Main policies adopted to reduce CO_2 emissions: Italian commitments and results

Despite the decreasing trend in carbon dioxide emission shown above, in Italy is more and more difficult to ignore the effects of the climate change that the country may experience over the next decades. According to the national communication released by Ministry for the Environment, Land and Sea of Italy to the United Nations (2013), several expected negative impacts of climate change made the Mediterranean area one of the most vulnerable in Europe. This effects are mainly related to possible extraordinary heat spells, increased frequency of extreme weather events (heat waves, droughts and severe rainfalls) and reduced annual precipitation and river flow. As a consequence, Italian natural environment will face some critical dangers. Just to make few examples, water resources and areas could face risk of desertification and Alpine regions and mountain ecosystems could deal with glacial loss and snow cover loss.

Considering also that observed annual temperatures in Italy and in the Mediterranean Sea have increased more than world average[15], that from 1850 Alpine glaciers have already diminished by 50%[16] and that several extreme weather events have already been experienced, it is not surprising that big concerns aroused about the preservation of the environment though appropriate policies and measures. At this regard, Italy has proved, since the Kyoto Protocol ratification, its deep commitment and effort with respect to the solution of the climate change problem.

Even if actions to contrast climate change were put in place since 1994, when CIPE[17] approved the National Programme for the Containment of Carbon Dioxide Emissions, which aim was to stabilize emissions by 2000 at 1990 levels[18], it was after the ratification of the Kyoto Protocol that Italy found itself internationally committed to reduce emissions. Since then, it started monitoring and regularly update policies in order to meet its targets.

[15] *Sixth National Communication under the UN Framework Convention on Climate Change Italy.* Ministry for the Environment, Land and Sea of Italy, 2013
[16] *Sixth National Communication under the UN Framework Convention on Climate Change Italy.* Ministry for the Environment, Land and Sea of Italy, 2013
[17] Inter-Ministerial Committee on Economic Planning
[18] IEA, 2014

1.2.1 Main European and International level commitment to reduce GHG emissions

- 1998 - The Kyoto Protocol

The Kyoto Protocol was adopted during the third Conference of the Parties to the UN-FCCC in 1997 and it was aimed at committing industrialized countries to stabilize greenhouse gas emissions[19]. Italy ratified the Protocol in 1998 and, since then, the Inter-Ministerial Committee on Economic Planning (CIPE) has started issuing policies and measures to reduce GHG emissions. Moreover, it is committed to developing, publishing and annually updating national emission inventories of greenhouse gases. The guidelines established to comply with this obligation were issued the first time in 1998 and then were revised in 2002, setting the new targets: reducing greenhouse gas emissions by 6.5% below base-year levels, with respect to 1990 levels. In other words, Italy aimed at maintaining emissions within an average of 485.7 $MtCO_2e$ a year within the period 2008-2012, which is a real challenge for the country, considering that is has one of the lowest energy intensities among OECD countries[20]. The strategies the Environment Ministry intended to use identifies procedures mainly aimed at:

a) increasing energy efficiency and promoting the use of renewable energy sources;
b) increasing carbon dioxide removals deriving from land use, land use changes and forestry;
c) implementing the Clean Development and Joint Implementation mechanisms[21];
d) fostering R&D work aimed at incentivise hydrogen as a main fuel in energy systems and in the transport sector;
e) promoting the construction of biomass plants, solar thermal, wind and photovoltaic, waste and biogas fuelled power plants (Marinella D. et al., 2010).

As for the results actually achieved, according to ISPRA[22], it is possible to affirm that total GHG emissions, in CO_2 equivalent, excluding emissions and removals from land use, land use change and forestry, decreased by 11.4% (from 519 to 460 $MtCO_2e$). However, considering the variation between the average of emissions in the 2008-2012 period and the emissions in the base year, the level of emissions decreased by 4.6%, meaning that Italy failed to reach its targets[23]. The body also highlighted that the reduction accomplished was mainly due to the decrease of CO_2 emissions (the main contributor of GHG emissions) related to the crisis. In

[19] UNFCCC, 2014
[20] UNFCC, Italian Report On Demonstrable Progress Under Article 3.2 of The Kyoto Protocol, 1997
[21] Two of the three flexible mechanisms suggested by the Kyoto Protocol as measures to reduce GHG emissions
[22] Italian National Institute for Environmental Protection and Research
[23] Kyoto Protocol objectives have to be calculated on the average of emissions during the period 2008-2012

fact, the main reduction was observed in 2008, suggesting that the decrease in emissions was largely caused by the financial crisis and by the delocalization of certain productive sectors. Nevertheless, ISPRA underlie that a role was played also by the intensification in use of renewable energies and by the increase in energy efficiency.

To conclude, despite Italy failed its target under the first commitment period of the Kyoto Protocol, it can be said that it has anyway started a policy path aimed at the improvement of the climate change problem. By means of the flexibility mechanisms established under the Kyoto Protocol, the achievement of the 6.5% target would require little effort by the country[24].

- 2003 - EU ETS

The European Emissions Trading System (EU ETS hereinafter) was implemented with the Directive 2003/87/CE by the European Union and represents one of the major policy implemented in order to deal with climate change. Moreover, it's the first international, multisector cap and trade system ever implemented[25]. A cap and trade system, consists in establishing a predetermined level of allowed emissions with respect to some greenhouse gases and in reducing this cap over time, so that also pollution will decrease. It is developed in four trading phases, covering a period that goes from 2005 to 2028. Over these years the cap will be gradually reduced.

In order to receipt the EU directive, Italy adopted a decree that defined emission reduction target for the 1100 Italian industrial installation involved. The National Allocations Plans adopted by the country entailed the allocation of emissions allowances. With the first Plan, Italian government decided to allocate an annual average of 223.2 Million tCO2 between within the period 2005 - 2007, then, with the second Plan Italy planned to allocate an annual average of 201.6 MtCO_2 emissions for the period 2008 - 2012. This plan will allow reduction of 13.65 MtCO_2 emissions. Over that period, the contribution to GHG emissions by EU ETS sectors was equal to 201.6 MtCO_2 per year (Minister of Economy and Finance), which is clearly equal to the allocated allowances, signaling that companies involved did not issue more emissions than allowed, since, in that case, they would have to buy more allowances from the market.

- 2009 - 2020 climate and energy package

European Directive 2009/29/CE set up a strategy that aimed at promoting overall growth, creating the basis for a more competitive economy. Its target encompasses five goals in the areas of employment, innovation, education, poverty reduction and climate/energy. This work will focus on the latter goal, which, in few words, requires the achievement of three targets at European level within 2020:

[24] Politiche sul clima e scenari emissivi, ISPRA
[25] European Commission *The EU Emissions Trading System (EU ETS), 2013*

1. Lower greenhouse gas emissions by 20% (or even 30%, if the conditions are right) with respect to 1990 levels
2. 20% of energy produced by renewables sources
3. 20% increase in energy efficiency

This package implies for Italy an even stronger commitment toward the reduction of GHG emissions and represent an increased challenge. The country, to comply with the new requirements, will have to reduce emissions from non – ETS sectors by 13% below 2005 levels, 17% of its energy consumption will have to come from renewable sources and has a 10% target for renewable energy in transport (Marinella D. et al., 2010).

Moreover, European Union member States agreed to further extend their efforts, adding commitments to be achieved within 2030. The so called 2030 climate & energy framework was adopted in 2014 and set three main targets:

1. At least 40% cuts in greenhouse gas emissions (from 1990 levels)
2. At least 27% share for renewable energy
3. At least 27% improvement in energy efficiency.

Italy, in order to comply with the 2020 climate and energy package, issued in March 2013 the National Energy Strategy (NES hereinafter). NES established seven main goals: energy efficiency, competitive gas market and Southern European hub, sustainable development of renewable energy, development of the electricity infrastructure and market. restructuring the refining sector and the fuel distribution network, sustainable development of domestic hydrocarbons production, the modernisation of the governance system. For the moment, this work will focus on energy efficiency and renewable energy, in relation to the target set by the 2020 regulation.

On one hand, with respect to energy efficiency, Italy has, as priority, the of eliminating barriers to the adoption of energy efficiency technologies in sectors such as civil sectors and government and civil service. The main initiatives will be:

1. Stronger minimum and legal standards and the relative actions of compliance control and sanction
2. An extension of the timescale for tax deductions[26], mainly for the civil construction sector (refurbishment and renovations).
3. The introduction of direct incentives for Government and Public Administration initiatives
4. More rigorous targets and strengthening of the White Certificates mechanism.

[26] 55% tax deduction to support energy savings in existing buildings (2013 Italy Climate Policy Progress Report)

On the other hand, Italy will achieve its objective in terms of development of renewable energy by means of:

1. Reduction of the per-unit incentives, in order to make them more close to European levels.
2. The electrical mix will be shifted towards more innovative technologies
3. Will be adopted Actions to stimulate a greater integration of different renewable electricity technologies with the market and with the grid

1.2.2 Policies aimed at enhancing energy efficiency

This work will now make an overview of the main instruments introduced by Italy to improve energy efficiency, a concept that will be discussed in detailed later.

- White certificates

  Introduced with a Ministerial Decrees of 2000, that was subsequently amended in 2007 (Nachmany M. et al., 2015), the White Certificates or Title of Energy Efficiency (TEE) system, represent the main energy efficiency program in Italy. It covers industrial, service and residential sectors (Hogan P. et al, 2012).

  This mechanism establishes that Italian Distribution System Operators of gas and electricity with more than 50,000 customers have to achieve primary - energy savings of not less than the targets set by the system, within 2012 (Nachmany M. et al., 2015). The decree was then implemented and extended till covering the period 2013-2016.

  Companies, to comply with this scheme, can implement a variety of projects for energy savings, also by means of intermediary companies. Once they obtain a reduction of one tonne of oil equivalent (toe) they are given a white certificate[27], which can be traded in the Energy Efficiency Certificates Market

- 55% tax deduction

  This measure was introduced with a 2007 law and entails a 55% tax deduction for the energy upgrading of buildings. It has then been revised in 2012 and again in 2013 in occasion of issuance of the NES, with the aim of providing extensions of the action. Deductions can be claimed by all taxpayers, such as natural persons, professionals, companies and undertakings that faced costs relative to the implementation of energy efficiency actions on existing buildings. Moreover, it is granted both for residential and commercial

[27] A white certificate is a tradable instrument that give proof of the achievement of end-use energy savings through energy efficiency improvement initiatives and projects (GSE, *White Certificates*)

buildings, consisting of reduction of IRPEF[28] and IRES[29] (ENEA). Tax deduction has been one of the most significant driver of energy efficiency improvement.

Table 1.1 depict a clear picture of the energy savings achieved by several measures, including white certificates and tax deductions in the period 2011 - 2013. It appears clear how a major role was played by improvement in the residential sectors thanks to tax deductions and in the industry sector because of the white certificates scheme. Thus, this two measures are giving an important contribution within the achievement of 2020 sectors, even if much work has to be already done in order to get positive results in all sectors involved.

Annual achieved energy savings (Mtoe/year) by sector: period 2011 - 2013								
	Regulatory standards	White Certificates	Tax deductions	Measures and investments for mobility	Other measures	Energy Savings		Achieved target
						At 2013	Expected at 2020	
Residential	0.75	0.29	0.33	-	0.01	1.31	3.67	35.7%
Services	0.02	0.04	0.01	-	-	0.07	1.23	6.6%
Industy	0.06	1.28	0.02	-	-	1.36	5.10	26.6%
Transport				0.45	0.02	0.47	5.5	8.6%
Total	0.83	1.61	0.35	0.45	0.03	3.21	15.50	

Table 1.1 Annual achieved energy savings (Mtoe/year). Source ENEA

- *Conto Termico*

  It is the one of the most recent measure introduced, by means of a Ministerial decree in 2012. It is the first nationwide direct incentive scheme for the generation of renewable thermal energy and it is aimed also at stimulate public authorities to implement energy efficiency actions in buildings and technical installations[30].

- Buildings Regulation

Regulation that requires minimum mandatory standards on new and existing buildings to incentivize energy efficiency.

1.2.3 Policies aimed at boosting renewable sources use.

- 2002 - Green Certificates System

  Introduced by a Legislative Decree, the Green Certificates System wants to promote the development of new renewable capacity (Marinella D. et al, 2010). It’s a scheme that

[28] Personal income tax
[29] Corporate income tax
[30] *Italian Energy Efficiency Action Plan, 2014*

completes the introduction of a cap-and-trade mechanism to promote renewable energy sources, implemented in 1999.

It obliges producers and importers of electricity generated from non – renewable sources to introduce in the national electricity system a minimum share of electricity produced by plants that use renewable resources. The green certificate, attests the production of 1 MWh of renewable energy.

- 2005 - "Conto Energia"

Established in 2005, "Conto Energia" is a scheme that aim at promoting renewable energy use for energy generation. It simply consists in giving incentives for the construction of photovoltaic systems. These incentives will be obtained by selling all energy produced to GSE[31]. "Conto energia" was extended also to comply with Directive 2009/28/CE32.

- Biofuels target

Mandatory use of biofuels in the transport sector. The target set in compliance with the Directive 2009/28/CE is of 10% to 2020.

1.3 Italy energy efficiency

Energy efficiency entails providing the same service or output, using less energy, i.e. introducing energy savings techniques[33].

During last years, there has been an increasing attention by policy makers, both at European and National levels, to the improvement of energy efficiency through the introduction of appropriate technologies, that can allow to decrease energy consumption, waste, emissions and imported energy supply (Castro Camioto F. et al., 2014) and, at the same time, to increase energy savings.

As mentioned above, Italy's main instruments to promote energy efficiency are the white certificates, the 55% tax deduction and the thermal account. These mechanisms essentially influence three main sectors: buildings[34], industrial and transport. Furthermore, they allow Italy to prove its technological leadership both at European and International level: it is one of the best country in the world as for improvement of energy efficiency[35].

---

[31] *Conto Energia*, GSE
[32] Directive to promote the use of energy from renewable sources (European Commission)
[33] *Efficienza Energetica*, Legambiente
[34] Private and public
[35] *Efficienza Energetica: primo combustibile del mondo*. Avvenia, 2016

1.3.1 Italy: a world leader in energy efficiency.

Recent studies and researches emphasize how Italy, thanks to the measures adopted, was able to become one of the worldwide front-runner in terms of energy efficiency.

According to a work conducted by Castro Camioto et al. (2014) on G7 countries and BRICS, Italy, together with France, obtained the best scores and it also shows that the country's energy efficiency followed a positive trend, demonstrating that it was able to increase economic growth, using fewer resources and without increasing emissions[36].

Moreover, a research led by Avvenia, an Italian energy service company, provide further evidence on the role played by Italy. They suggest that energy efficiency could be considered as an "hidden fuel", since it can deliver not only reduction in CO_2 emissions, but also it can enhance energy security and support a sustainable economic development. Therefore, Italy should exploit further this "fuel", going beyond the results achieved during last year. Even if fossil fuel dependence is still strong, projects aimed at enhancing energy efficiency that were implemented during 2015, enable to gain an estimated savings equal to 9 Mtoe. In other words, Italy avoid to import 2.4 billion euro of natural gas and oil, thus preventing the production of about 21.6 million tonnes of CO_2.

Another report issued by ENEA[37] considers the ODYSEE database to study energy efficiency in Italy. The measure considered for energy efficiency is the ODEX index, which is used by the ODYSSEE-MURE project[38] and is calculated as the weighted average of sub-sectoral indices of energy efficiency progress; sub-sectors being industrial or service sector branches or end-uses for households or transport modes. Specifically, the sub-sectoral indices are calculated from variations of unit energy consumption indicators and the weight used is the share of each sub - sector in the total energy consumption of the sub –sectors considered in the calculation[39]. According to this work, Italian energy efficiency improved by 11% in the period 2000 – 2013, thanks to the contribution of all sectors considered (buildings, transport and industrial). More in details, transport sector improved by 12.8%, with a major support given by transport roads, followed by industry with 12.2%. Within the industrial sector, the most efficient industrial branch resulted to be the chemical one.

[36] The paper uses as input inputs gross fixed capital formation and workforce and energy consumption and it considered tow outputs: carbon dioxide emissions (undesirable output) and GDP (desired output)
[37] Italian National Agency for New Technologies, Energy and Sustainable Economic Development
[38] The general objective of the project is to provide a comprehensive monitoring of energy consumption and efficiency trends as well as an evaluation of energy efficiency policy measures by sector for EU countries and Norway
[39] ODYSSEE-MURE

1.3.2 Energy Efficiency by sector

As anticipated above, each sector mainly touched by the regulation about improvement in energy efficiency contributes differently to the national result and the report delivered by ENEA depict a clear picture of the current situation of buildings[40], transport and industry and of the trend they followed during recent years. This work will now analyse each sector separately.

1. Buildings – Household

   Within the sectors considered, it is the one that contributes the less to the total national's energy efficiency development. Throughout the period 2000 – 2013, the improvement in energy efficiency were not enough to cover the increase in energy consumption. This rise, can be ascribed to a demographic effect (more dwellings) and to changes in the lifestyle: Italians installed more appliances, aiming at have a better comfort. Therefore, the low improvement in energy efficiency of 7.5%, depend on the increase in energy consumption, not on a slowdown in energy efficiency.

2. Transport

   As shown by data contained in the report, the main transport in Italy as for energy consumption is the road one, which, in 2013, accounted for 86.6% of the overall energy use. It is followed by air transport, with a percentage of 9.7%, and by water transport, 2.6%. For that reason, the analysis is concentrated on the road transport, since energy efficiency for the entire sector largely depend on those means. Indeed, on one hand, over the years 2000 – 2013 energy efficiency of cars improved by 15.8% thanks to production of more efficient cars and the shift from gasoline cars to other types. On the other hand, energy efficiency of trucks worsened by 59.0%. Besides, also the other transport modes experienced an improvement in energy efficiency, but their impact is limited.

3. Industry

   Within the industrial sector, it can be noted that over the period 2000 – 2013, production, and consequently consumption, decreases. This was not only due to the crisis, but, above all, by the improvement in energy efficiency, which has been constant over the period considered (1.1%/year). However, in the last years the progress is slowing

[40] Household

down. Furthermore, different industrial branches showed improvements, but with different trends: in the years 2000 – 2003 for all industrial branches a loss of efficiency were observed, with the exception of chemical and cement; in the period 2003 – 2008, a larger improvement were experienced, except for cement and paper.

1.4 Dependence on other countries for the supply of energy

It is well known that Italy is one of the most energy dependent country in Europe, since net imports in 2015 covered 75.35%[41] of national energy requirements and that only other five countries which performed worst and two of them are islands[42]. With respect to 2014, net imports increased by 6.4%, with an amount of 129,069 Mtoe instead of the 121,281 Mtoe recorded the previous years[43].

As described by Figure 1.4, which shows a trend followed by the energy dependence rate of the country[44], since 2010 Italy experienced a decreasing trend, which can be attributed both to an effort to reduce net imports, but also to the decrease in energy consumption faced after the crisis.

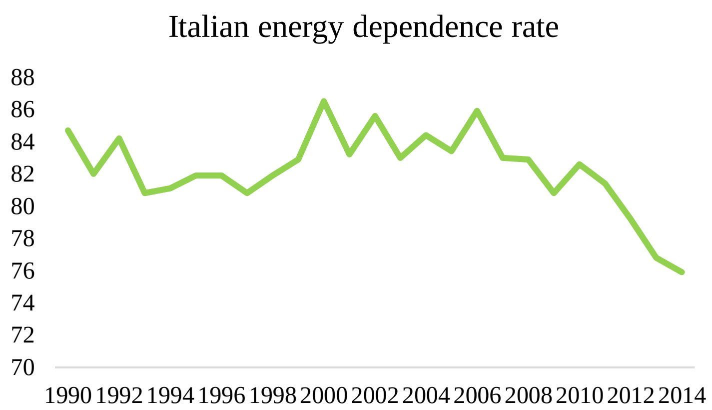

Figure 1.4 Author's own elaboration. Italian energy dependence rate. Data source: Eurostat

Despite this results, Italian energy dependence is still too high, causing households and industries to be exposed to international price volatility and geopolitical crisis (Bardazzi R. et al. 2016). Moreover, to reduce energy dependence it is essential for a sustainable economic growth. For these reasons, Italy committed to reduce its reliance from abroad for the supply of energy. As specified in the NES, the country aims to decrease to 67% the net imports needed to cover national energy consumption. This will be achieved thanks to increased renewable

[41] *La situazione energetica nazionale,* Ministry of economic development, 2015
[42] Elaboration made on data by Eurostat
[43] *La situazione energetica nazionale,* Ministry of economic development, 2015
[44] Calculated as net imports divided by the sum of gross inland energy consumption plus bunkers

production, lower electricity imports, increased production of national resources and energy efficiency. The positive results expected on net imports will have benefits also on energy security, a concept that it will be discussed later, and that is one of the main Italy's challenge described in the NES.

All the things considered, the country enjoys also a number of mitigation factors, such as a composite energy mix and a well-diversified range of trading partners. Actually, the Herfindahl – Hirschamann Index[45], shows that input sources are varied, especially for gas (Bardazzi R. et al., 2016). In the following sections, this work will give a deeper insight to the key aspects concerning energy dependence.

1.4.1 Energy imports by energy source

A first look at Table 1.2, give us an idea about the ratio between energy produced and imported by Italy. As it has already seen, it results soon clear that, for all sources considered except renewables, the majority of the energy is imported, rather than produced internally. To better understand the Italian situation, it will be now provided an analysis of all the fossil fuels taken separately, thanks to information obtained by the National Energy Situation.

Italian Energy Balance 2015						
	Solid	Natural Gas	Oil	Renewables	Electricity	Total
Production	0.299	5.545	5.47	31.407	24.076	42.722
Import	13.193	50.124	81.281	1.86	11.18	157.638
Export	0.257	0.181	27.041	0.108	0.982	28.569
Gross Domestic Consumption	13.456	55.301	59.206	33.127	34.274	195.364

Table 1.2. Author's own elaboration. Italian Energy Balance 2015. Unit measure Mtoe. Data source: Ministry of Economic Development – provisional data.

1. Oil

   As we can see from Table 1.2, in 2015 total consumption of oil, which is the most consumed fuel in Italy, accounted for 59.2 Mtoe; 9% was covered by national production, while 90% (net of accumulated stock), was provided by imports. Oil use augmented from 2014, mostly because of the better economic situation and price decline. Moreover, with respect to 2014, imports have increased by 16% and involved areas

[45] Index used to measure diversification. It is usually applied in industrial organization literature to study market concentration and it is calculated as the sum of the squares of the market shares of each participant. It is also use to measure the energy supplies diversity, by summing the shares each foreign suppliers have in the total net imports of the country (Le Coq C. and Paltseva E., 2009)

such as Middle East (+ 42.6%), Africa (+29.1%) and Europe (+ 6.6%). On the contrary, negative variation have been observed toward imports from America (-60.5%) and Asia (-29.1%).

2. Natural Gas

   In 2015, total demand of natural gas has been covered for 10% by national production, while for 90% by imports, above all through pipeline. In details, supplies from Algeria (+7.2%), Russia (+14.4%) and Libya (+9.1%) increased. On the opposite side, it has been registered a decrease in imports from North Europe (- 7%).

   Consumption raised from 2014 by 9% and special attention should be given to the automotive sector: the increment is justified by incentive policies for natural gas cars, benefits such as exception to traffic ban and more availability of new car models.

3. Solid

   In 2015 total imports of solid fuels diminished by 2%. In particular, imports of coking coal contracted by 5%, while the one of steam coal reduced by 1.3%. As for the areas of origin, main supplies came from USA, Russia, Indonesia, Colombia, South Africa.

1.4.2 Main issues concerning Italian energy dependence

At this point, some facts should be clear. Above all the reliance of Italy on gas and oil that are both widely used in the power generation sector and in the civil and industrial sectors (Qualiano A., 2007) and that heavy imports of these resources imply risks and vulnerability to crisis and price trends.

Italy's reserves of gas and oil are relatively scarce compared to other countries such as Saudi Arabia, but it is still the third country in Europe, soon after North European countries, as for oil reserves[46]. The problem is that production has a limited capacity and is not able to fill the National demand for oil and gas. Therefore, Italy is forced to resort to imports to supply its demand.

One of the main challenge clarified by the Italian Government in the NES is the sustainable development of domestic hydrocarbons production, so that it will be possible to exploit substantial national resources, rather than rely that much on imports. To reach this objective it is necessary to increase oil searches, which, in the last five years, have been almost absent[47]. The strategy specified in the NES will bring benefits also in terms of economic growth and

[46] *La situazione energetica nazionale,* Ministry of economic development, 2015
[47] *La situazione energetica nazionale,* Ministry of economic development, 2015

employment, but a special consideration should also be given to the environmental impact of this choice.

Another aspect that is peculiar of Italy's energy situation is that, while oil comes from a well-diversified mix of countries, 61% of gas imports depend on mainly two nations: Russia and Algeria[48]. What's more the transport infrastructures are quite rigid, considering that the major part of gas supply relies on cross – border pipeline systems. Vulnerability is thus increased, especially to geopolitical setbacks, as the international crisis between Russia and Ukraine of 2006 already proved (Qualiano A., 2007). Even in 2012 Italy suffer a gas shortage from Russia, consequently to extremely cold weather conditions that increased Russian demand. In light of this, it should be one of Italy's priority to reduce this weakness, by increasing the diversification of origin countries. This is not an easy task, mostly because of the aforementioned rigidity of infrastructures, even if it would allow to rise supply and control prices (Qualiano A., 2007).

All previous consideration takes to one more generic issue connected with energy dependence: energy supplies security. Internationa Energy Agenty (IEA) defines energy supplies security as "the uninterrupted availability of energy sources at an affordable price". Yet, there is the need to clarify that, despite this general definition, supplies security is a dynamic concept which takes different meanings depending on the circumstances (Ang and Choong, 2015.) and on the risks considered (Winzer, 2012). As for Italy, it is possible to assert that its energy supplies security is affected by energy dependence and by the few trading partners as regards for gas imports (Qualiano A., 2007). The country is therefore exposed to price shocks, given its high reliance on non-EEA countries, especially for oil and solid fuels[49], as it has already been described. Not surprisingly, the mitigation of this problem is a major challenge for the country, which put it at the centre of its energy strategy, hoping it will help to improve Italian competitiveness through a path aimed at sustainable growth. Italy is expecting to achieve this goal by means of reduction of imports, increasing renewables production, improving infrastructures and diversifying imports partners[50].

[48] *La situazione energetica nazionale,* Ministry of economic development, 2015
[49] *Member States' Energy Dependence: An Indicator-Based Assessment,* European Commissions, 2013
[50] NES

1.5 Renewable resources

As part of Italian effort with respect to climate change, a leading role is played by renewable resources, especially wind and solar. They find widespread use not only for the production of electricity (electric field), but also for the production of heat (thermal sector) and as biofuels for transport (transport field).

To continue, in the Figure 1.5 is shown the steady increasing trend followed by use of renewables within total energy consumption: they went from 6.3% in 2004 to 17.1% in 2014. Moreover, recent provisional data from the Ministry of economic development have revealed that this percentage further rose in 2015. This makes renewables the third source of energy used in Italy. Remembering the target set by the country for 2020, which is that 17% of energy should be produced by renewables sources, it is possible to affirm that the country is perfectly in line with this target, that it has been already reached. Therefore, Italy now need to concentrate on the 27% target to be achieved in 2030.

Renewable energy development has been favour by the major measures implemented by the country during lasts years, such as "thermal account", green certificates and tax deductions. Additional attention to this topic has been given in the NES, in which Government put the sustainable development of renewable resources within the seven main goals as regard to the Italian energy strategy, toward the objective of improving Italy's competitiveness.

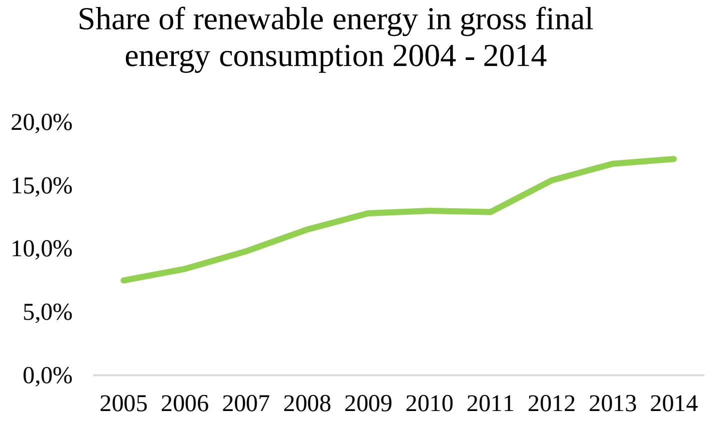

Figure 1.5 Author's own elaboration. Share of renewables on total energy consumption 2004 – 2014. Data source: Eurostat

1.5.1 Benefit deriving from renewable energy sources

Development of renewable resources is one of the most important strategy aimed at climate change mitigation. Recent data confirm that consumption of fossil fuels accounts for the majority of global anthropogenic GHG emissions[51]. It has to be mentioned that there are several

[51] *Special Report on Renewable Energy Sources and Climate Change Mitigation.* IPCC, 2012

ways to lessen this effect, still satisfying demand for energy. Some of these options are energy conservation and efficiency, fossil fuel switching and renewable resources. Indeed, several works, as the one issued by Aliprandi F. et al (2015). proved that the increasing integration of renewable energy as substitute of fossil fuel, actually can reduce CO_2 emissions. Also the European Environmental Agengy provided data showing that without the use of such resources, since 2005, in Europe there would have been GHG emissions higher by 7% than actual ones.

To move further, one other positive impact that renewable energy have is the one on energy efficiency, since it will contribute to the growth of energy savings, and on energy security. Replacing fossil fuels with renewable sources, it will allow to decrease imports from abroad, thus improving Italian energy security[52]. It is interesting to notice that, according to estimates conducted in the "Studio sulla sicurezza energetica in Italia e in Europa", hydroelectric, solar, wind and geothermal could cover the entire energy needs of Italy.

NES also underlie that the faster than expected expansion of renewable energy production also cause, together with other factors, changes to the electricity market. In this context, the main choices and decision will be focus on keep and develop a free and efficient market.

Renewable resources development will also have an impact on employment, since it creates jobs, as estimated by GSE. Impact on employment according to 2014 data can be resume in 20.400 temporarily[53] Annual Working Unit[54] (AWU) and 54.900 permanent[55] AWU, with a major contribution given by solar.

Italian Government, in the NES, specify that Italy, which historically has the highest incentives in Europe for renewable production (unit incentives for photovoltaic production were about double those of Germany), will continue throughout this path. The aimed is to exploit the aforementioned positive effects, with a special consideration to the strong impact on energy costs, since over 20% of the Italian electricity bill (taxes excluded) goes to cover incentives for production from renewables. While meeting its target, in fact, Italy has also to keep energy bills down, given the burden they place on businesses and households. Incentives should be brought in line with European levels and focus should be given to the development of renewables in heating and cooling[56]. Another need should be to concentrate spending on the worthiest technologies and sectors, i.e. those with the highest returns in terms of environmental benefits. In this respect, two examples are energy recovery from waste and re-use.

[52] NES
[53] Persons employee in the design, development, installation and construction phase
[54] Quantity of work performed by a person, employed full – time, within a year
[55] Persons employee for maintenance of plants for their whole life cycle
[56] They have good growth potential and lower specific costs than electricity

Current and future attention by Italy about renewables confirm that they are a central segment of the green economy, which is more and more considered as an opportunity for economic recovery[57].

1.5.2 Renewable energy by source and sectors

This work now, with the support of data provided by GSE, will make an overview of the situation concerning the latest development of renewable energy sources in three main sectors: electric, thermal and transports. This progresses, favoured by several aforesaid initiatives and incentives, demonstrate how this resources gained a central role in the Italian energy context, making the country a model for the entire world. Just to make an example, with respect to solar, Italy is the third country in the world as for the consumption of solar energy consumption. Data provided by BP in the Statistical review of world energy 2016 (2016), Italy ranked soon after the United States (8.8 Mtoe) and China (5.2 Mtoe), with a consumption of 5 Mtoe of solar energy.

Below it will follow a short outline of the three sectors named above with specification about the impact of different renewable sources.

1. Electric sector

   At the end of 2014 there were more than 650.000 operating plants using renewables[58] for total power of about 50.6 GW and were able to produce electric energy for an amount equal to 120,7 TWh (+7,8% with respect to 2013). Provisional data for 2015 suggest that installed power further increased between 2014 and 2015 of around 2%. This intensification was mainly due to wind and solar plants. On the contrary, production seems to have decreased: not because 2015 was a particularly negative year[59], but rather because in 2014 climate condition were extremely good: precipitations have been exceptional.

   Table 1.3 displays what have been the most used sources in 2015: water (40.4%), solar (21%) and bio energy (17.4%).

[57] NES
[58] Data are not yet available for 2015
[59] As shown by Table 6, production was in line and even above the one of years before 2014

What is even more interesting to observed, is the trend followed by some of these resources, above all solar and bioenergy. Their contribution for the production of electricity over the period considered has been more than impressive: bio energy registered a + 100% between 2010 and 2015, while solar faced a growth equal to + 1.098%.

Electricity Production from Renewables Resources in GWh							
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**% on 2015 total**
Water	51.117	45.823	41.875	52.773	58.545	43.902	40.4%
Wind	9.126	9.856	13.407	14.897	15.178	14.883	13.7%
Solar	1.906	10.796	18.862	21.589	22.306	22.847	21.0%
Geothermal	5.376	5.654	5.592	5.659	5.916	6.160	5.7%
Bio energy	9.440	10.832	12.487	17.090	18.732	18.894	17.4%
Total	78.975	84.972	94.235	114.021	122.691	108.701	100%

Table 1.3 Author's own elaboration. Electric production from renewable resources in GWh. Data source: GSE

2. Thermal sector

   As for consumption in the thermal sector, in 2014 were used about 9.9 Mtoe of renewables sources generated energy for heating, which represented 49% of total energy consumption in this sector. Of these 90% was consumed directly by companies and households (stove, boiler, thermal solar panel, etc.), whereas 10% represent derived heat, that is the thermal energy produced by the energy conversion plants fuelled by renewable sources and intended for consumption by third. Regarding production, provisional data of 2015 show that during last year it has increased with respect to 2014 (6.6%), due to more rigid temperatures and the consequent rise in the use of firewood and pellets. The most widely used sources is solid biomass[60] (more than 6.7 Mtoe in 2014 and about 7.7 in 2015). It appears also relevant the contribution given by heat pump equipment (2.6 Mtoe of renewable energy in 2014 and in 2015), while energy produced by geo thermal and solar sources is still limited.

3. Transport sector

   GSE data demonstrate that in 2014 there has been a consumption of about 1.2 million of biofuels, for an energy content of about 1.07 Mtoe. While with respect to 2013 this consumption has decreased, provisional data for 2015 shows a decisive increment: +

[60] Firewood and pellets consumed for residential heating

10.5% with an energy content of near 1.2 Mtoe. As for 2014. The 99% of total consumption were caused by biodiesel, whereas a very little impact was given by ETBE[61] and bioethanol. It is important to notice that the differences between sustainable biofuels and total biofuels are very narrow: almost the entire quantity of biodiesel and bioethanol consumed is sustainable and also more than 82% of ETBE is.

This first chapter give a clear idea of the reasons why Italy not only is the perfect case study for the following analysis, but also that it is a quite advanced country in terms of measures to reduce CO_2 emissions. Therefore, the following analysis will help to understand how this actions actually contributes to the reduction of emissions in the country.

[61] Ethyl tert-butyl ether (IEA)

CHAPTER 2

INDEX DECOMPOSITION ANALYSIS: AN EXTEND KAYA IDENTITY

In the previous chapter there was a presentation of Italy's energy market situation, with a special focus on the areas where the country has been able to better perform, by implementing policies and measures in order to try to decrease carbon emissions.

The following chapter will go further into the analysis, which entail an assessment of the main determinants of Italian carbon dioxide emissions, with the help of the index decomposition analysis method.

This section of the work aims at providing details about the methodology used, which is inspired by a work conducted by O'Mahony on Ireland CO_2 emissions (2013).

First of all, a special focus will be given to a description of the Index Decomposition Analysis, a method which allow policy makers to formulate actions and measures relatively to the specific aggregate indicator studied. As for this work, the aggregate considered are carbon dioxide emissions, that will be decomposed accordingly to the extended Kaya Identity, which differs from the non – extend version because it includes also renewable resources.

Then, will follow an overview of the several methods available within the framework of the decomposition analysis, which will be helpful in explaining why the Log Mean Divisa Index I (LMDI I), first introduced by Ang and Liu in 2001, has been chosen for the purpose of this work.

After having clarified the reasons behind the selection of the model proposed by O'Mahony (2013), as it was considered suitable for this case study, there will be a last part dedicated to a detailed explanation of this model, that will be apply to Italy in the subsequent chapter.

2.1 Index Decomposition Analysis

The first step in conducting an analysis on the determinants of carbon dioxide emissions at country level, is to define the most appropriate instrument designed for the intended purpose. As stated by Granel (2003), the method that has been broadly apply in last decades in order to disentangle and separate changes in aggregate indicators is the Index Decomposition Analysis (IDA hereinafter).

Within the various method that have been developed within the IDA framework, it has been chosen to use the Kaya Identity as decomposition scheme. This technique disaggregate was proposed by Kaya Yoichi in 1990 and that will be adopted in one of its extended version, which help to evaluate also the effect on carbon dioxide emissions of the penetration of renewable resources.

It will now follow a detailed explanation of the aforementioned aspects.

2.1.1 Index Decomposition Analysis: an introduction

IDA has proven to be an effective tool to be applied in energy and environmental fields, with the aim to study measures such as energy consumption, energy intensity or GHG emissions. However, as it will be described later in this chapter, aggregate indicators studied can take various forms and there has been a development, since the introduction of this method, as for the measures studied.

Before explaining why this method began to be used by researchers and institutions, it is worth explaining what an aggregate indicator is. As explained by Granel (2003), they can be defined as indicators at aggregate level and are commonly used in a wide range of fields for better understanding, because of their desirable properties, such as simplicity and their ability to explain changes in the amount studied. Even if indicators at lowest level should be preferred, as they are more detailed, their analysis requires many data that can be difficult to find and to manage. Moreover, they can be hard to interpret. Speaking about the energy area, usually aggregate indicators try to find a link between energy use and human activity and enable to understand important trend from a large amount of disaggregate data.

From a mathematical point of view, an aggregate indicator can be described as follows:

$$V = \sum_i V_i = \sum_i x_{1i}\, x_{2i \ldots .} x_{ni} \tag{1}$$

where V is the aggregate indicators and $x_{1i} x_{2i \ldots .} x_{ni}$ are the causal factors on which the aggregate depends.

Speaking, now, about the reasons behind the introduction of the IDA, it can be said that there are mainly two. First of all, it found large application from the oil crisis of the 1970s, when it began clear that there was the need to change energy consumption habits (Granel, 2003). The method was initially introduced to study the impact of structural changes[62] and sectoral energy intensity change[63] on trends in the energy use in industry (Ang, 2004), since the solution found to the 1973 crisis was to decrease consumption through conservation (Granel, 2003). Starting from this assumption, it became clear the need to study energy consumption patterns, understanding the driving forces behind changes in energy consumption itself. Indeed, it was fundamental to investigate historical and future trends in energy demand.

The second reason is related to a major awareness of problems related to the environment, such as the need to decrease carbon dioxide emissions and other GHG. Since the main contributor to GHG emissions is energy consumption, it is important to understand the path followed by energy use and its main determining factors. The need of effective tools to decompose aggregate indicators appeared to be even more significant (Granel, 2003).

Considering the wide number of studies and researches that applied IDA, it is clear that it is a major tool used by policymakers in order to define national measures and actions in the environmental and energy areas, thanks also to its simplicity and flexibility (Ang, 2004).

2.1.2 Areas of application

Based on around 200 different studies regarding the topic, Ang (2004) has found five main IDA application areas: energy demand and supply, energy-related gas emissions, material flows and dematerialization, national energy efficiency trend monitoring, and cross-country comparisons. Below follows a detailed description of these different fields, with the purpose of understanding the usefulness and benefits of this method.

The major part of works and researches in 1980’ have been made in the energy demand and supply area, especially regarding industrial energy demand analysis. Then, starting from the 1990’, there has been an expansion in the scope of application, including sectors as transports and residential and also issues related to the energy supply area. Generally, works on this field aim at measuring the impacts of structural change and energy intensity change.

To continue, starting from 1990, as a response to the worries about environmental issues, energy-related gas emissions field has been explored by an increasing number of studies, above all about energy related carbon dioxide emissions. The governing function changes when conducting this kind of work, since it includes more than two factors. When analyses are conducted at industry sector level, are included also sectoral fuel share change and fuel gas emissions coefficient. Moreover, energy consumption can take zero values, since it is considered at fuel

[62] Changes in industry product mix
[63] Changes in the energy intensities of industrial sectors

level. Therefore, some decomposition methods can't be used because they cannot handle zero values.

In addition to the two areas mentioned above, also material flows[64] and dematerialization[65] in a national economy have been analysed by means of the IDA. Recently used to study the development of material use in an economy, its application in this areas requires the substitution of energy intensity with resource use intensity[66].

Index decomposition analysis has also been applied to study the trend of energy efficiency and the progresses achieved in order to meet national energy efficiency targets. For this purpose, it was required the creation of adequate efficiency indicators or indices. At the beginning, energy efficiency was calculated as inversely proportional to energy intensity, while, in recent times, more reliable indicators have been developed, helping national states to understand the main determinants of energy efficiency changes (Granel, 2003; Ang, 2004).

The last use of IDA described is cross – country comparisons, which requires a calculation and then the comparison, among at least two countries or regions, of factors that determine differences in energy consumption, carbon dioxide emissions or some other aggregate. Within this field, it must be paid attention when choosing a decomposition method, since some of them can lead to poor performance. In fact, it must be beard in mind the large amount of data considered and that is expected a bigger variation in the data across country than over time for a single country.

As Ang (2004) further suggested that, for each application areas, it is required an appropriate method, since the choice affects the numerical results. Nonetheless, from qualitative point of view, the environmental or economic meaning of factors that affect the aggregate indicators, is the same for each decomposition method.

It appears clear that this work will contribute to the studies in the second application areas described, since it entails the disaggregation of CO_2 emissions. It is fundamental to underline that, while most of the studies are made at sectoral level, this it is performed at national level. Now that these aspects have been specified, it is worth – describing other features and choices that should be made while carrying out a similar work.

[64] Material metals and non – metallic minerals. Some examples are oil, coal and natural gas
[65] It indicates the reduction of materials use in production due to technological changes or changes in production Systems (Hoffrén et al.)
[66] It is calculated as resources used per unit of economic output or value-added

2.1.3 Choice to be taken before performing and IDA: multiplicative or additive approach?

One of the most important decision to be taken when adopting the IDA methodology is whether to use the multiplicative or additive approach. Both have positive and negative sides and there are cases in which the use of one of them is preferred with respect to the other and vice versa.

Computationally, if we observe a change in the aggregate indicator from year 0 to year T, the multiplicative form requires to measure this variation as a ratio, which is then spread among the factors considered. The ratio and the estimated effects are given in indices. On the contrary, the additive form allows to decompose an absolute change of an aggregate, i.e. the change between year 0 and year T is calculated by taking the difference between the two amount. Also in this case, the result is then distributed among all factors included in the governing function (Ang et al., 2003).

After this considerations, it is possible to show the general form taken by results when adopting the two forms.

In case of the multiplicative approach:

$$D_{tot} = \frac{V^T}{V^0} = D_{x1} * D_{x2} \dots .* D_{xn} \quad (2)$$

When using the additive decomposition:

$$\Delta V_{tot} = V^T - V^0 = \Delta V_{x1} + \Delta V_{x2} + \dots + \Delta V_{xn} \quad (3)$$

where D_{tot} and ΔV_{tot} represent the aggregate calculate from time 0 to time T, and D_{xi} and ΔV_{xi} represent the effects associated to the *xi* factor.

As highlighted by Ang and Zhang (2000), the choice that researches can made between the two does not depend on the method they apply. Indeed, they explain that the main difference between the approaches can be found in how easily results are presented and interpreted. Actually, results given in form of relative change are more concise and difficult to understand, while they can be easier to comprehend if shown in absolute terms (Granel, 2003).

Therefore, since both approaches are mathematically efficient, the choice may depend on the aggregate studied, i.e. whether it is given as a ratio or in absolute terms (Granel, 2003) or on the scope of the analysis, the presence of negative changes and the ease of application. Moreover, it can be stated that, when for purpose of decomposition, data on a yearly basis over a period are considered, it is better to use the multiplicative approach. In fact, results are often presented in indices and can be appropriately plotted over time. On the contrary, in case only two benchmark years are considered, additive decomposition should be preferred (Ang and Zhang, 2000).

In light of this considerations about additive and multiplicative approach, the choice made is straightforward: given that the analysis is performed over 42 years, the more suitable choice was to use the multiplicative approach.

2.2 Decomposition method

One of the last choice an analyst has to make when executing an index decomposition analysis, is what decomposition method to use, since, once the governing function has been defined, there are many decomposition methods one can select.

Until mid-1980s, decomposition was performed with quite straightforward and intuitive methods. To make an example, Ang and Zhang (2000) described how, based on energy intensity, the impact of structural changes was calculated. In few words, hypothetical energy intensities for all the industrial sectors was calculated for a target year and then they were compared to the actual energy intensities observed. The difference between the two would represent the impact associated with sectoral energy intensity.

After that period, several authors started to developed more sophisticated, alternative ways to measure the impacts that changes of the determinants can have on an aggregate indicator. In particular, Boyd at al. recommended a method aimed at highlighting the analogy between industrial energy decomposition problem and the index number problem in economics, i.e. the Divisia index approach. Afterwards, an approach based on the Laspeyres index was formalized (Ang and Zhang, 2000).

Even if there is still no consensus about what decomposition method is the best one, debates concentrated on the ones abovementioned: Divisia index and Laspeyres index, which are the two methods mostly used in last decades. In both cases, there have been developments aimed at enhancing and refining. Furthermore, over the years, several authors introduced additional and different ways in which the they can be performed (Ang 2004; Granel 2003; Ang and Zhang 2000).

In the next section, there will be an overview of the several decomposition techniques that lie within the Divisia index and Laspeyres index method, with the purpose to try to understand why the LMDI I has been selected for the analysis contained in this study.

2.2.1 Decomposition methods: overview and desirable properties

As it has been already stated, the major part of recent studies uses two groups of decomposition method, i.e. Divisia index and Laspeyres index method. Both have strong and weak aspects, therefore the debate about which should be the preferred one is still open. Despite that, several authors recommended the use of the Log Mean Divisia Index I, which is part of the techniques related to the Divisia index method.

In view of the fact that this work apply a method linked to the Divisia index, there will be only a quick description of the Laspeyres index and the relative techniques, while the analysis will be concentrated on the first method.

First of all, is presented the Laspeyres index, which was originally formalized by Howard et al. and Park and that has been the main instrument used in the 1980s and on which methods used in previous years were based (Ang, 2004). It comprised methods such as the Laspeyres and Paasche indexes, which can be defined as follows:

$$I_P = \frac{\sum_i x_{1i}^T \cdot x_{2i}^0 \dots x_{ni}^0}{\sum_i x_{1i}^T \cdot x_{2i}^0 \dots x_{ni}^0} \tag{4}$$

$$I_L = \frac{\sum_i x_{1i}^T \cdot x_{2i}^0 \dots x_{ni}^0}{\sum_i x_{1i}^T \cdot x_{2i}^0 \dots x_{ni}^0} \tag{5}$$

and the Shapley/Sun[67] method, which can be performed only additively and can be described by the formula (6)[68]

$$\Delta V_k = \begin{Bmatrix} \left[\sum_i X_{i1,0} \dots \left(X_{ik,T} - X_{ik,0}\right) \dots . X_{in,0}\right] \\ + (equally\ distributed\ high\ order\ interaction\ terms) \end{Bmatrix} \tag{6}$$

It follows the Laspeyres price and quantity indices in economics and it requires to isolate the impact of a variable, by letting that variable change, while all the other are kept at their respective base year values. Based on these values, the formula provides for the application of weights (Ang, 2004).

One of the main advantage that made the methods linked to the Laspeyres index so common is their simplicity, since it is based on the familiar notion of percentage change, which makes them easy to understand. That's why it has been the most widely apply method since

[67] Ang referred to the techniques proposed by Sun as the refined Laspeyres index method. Since the two method are very similar, Granel aggregated them in order to conduct its analysis

[68] The formula related to the refined Laspeyres index is quite complicated. For more details, see Sun, J.W., 1998. *Changes in energy consumption andenergy intensity: a complete decomposition model*

1985. Conversely, even if it can be performed both additively and multiplicatively, the relation between the two approaches is not so obvious as for the Divisia index method (Granel, 2003).

A different technique, is the Divisia index, which use in the energy field was first suggested by Boyd et al. in 1987 and include, for example, the Arithmetic Mean Divisia index (AMDI), the LMDI I and LMDI II methods. During 1990, the desirable quality related to this instruments, made it one of the most used, together with the Laspeyres index method. In fact, according to a research conducted by Ang and Zhang in 2000 over more than 100 studies published during the previous 25 years, there is equality between the number of works that used the Laspeyres index approach and the one the applied the Divisia index method.

Besides, it is calculated as a weighted average of relative logarithmic growth rates (Ang and Zhang) and the weights used are expressed in the form of a line integral. An interesting consideration that can be made is that, since Divisia index is defined for continuous time interval, but data in empirical studies are typically available in discrete time interval, integral have to be accurately approximated (Jorgenson and Griliches).

Another worth – analysing characteristic of this method, is that it uses log growth rates and, as emphasised by Tornqvist et al. it has some desirable properties and its use is recommended. In fact, by using log changes, the Divisia index method has two main desirable properties: relative changes are additive, i.e. $\ln(D_{tot}) = \ln(D_{str}) + \ln(D_{int})$ and symmetric, while ordinary percentages are asymmetric and non – additive. An example will be useful in order to clarify the symmetry concept. If we suppose that energy intensity increased from 15 in year 0 to 30 in year T, applying the ordinary percentage the results will depend on which of the two year is used as point of comparison, i.e. intensity in year T increased by 100% with respect to year 0, or it was 50% lower in year 0 than in year T. On the contrary, by applying the natural logarithm, the relative change will not be reference year - dependent; in other words, the changes are symmetric and results will be: $\ln(20/10) = 0.693$ or $\ln(10/20) = -0.693$.

When deciding the method to use in conducting an analysis, there are many factor to considered and several instruments to use in order to scream between the available choices. As underlined by Granel, there are numerous mathematical tests that can be performed, however also other contextual factors should be considered, such as the characteristics of the situation to which the analysis applied.

Ang, in his study aimed at determining which should be the preferred decomposition method, suggested four desirable properties that a method should have: (a) theoretical foundation, (b) adaptability, (c) ease of use and (d) ease of result interpretation. The work conducted by Granel, considering several researches that compare decomposition methods, gather ease of result interpretation, ease of understanding and how clearly results are presented, suggesting another property: (c) transparency. This concept, introduced by Nanduri in 1996, refers to how simple a method is. Then, he also adds (d) applicability, (e) ease of formulation and (f) computational ease. Moreover, in the study performed by Granel, the six factors are divided into two groups, that is a useful framework in order to better understand the above mentioned properties: the first group gather all tests related to the theoretical foundation, while the second one include all other factors[69].

When considering the theoretical foundation property, it can be said that it refers to some tests[70] which are used to understand whether the method considered has some specific properties. On one hand Ang (2004) took into consideration the factor-reversal, time-reversal, proportionality and aggregation tests. On the other hand, Ang and Zhang (2000) only considered time-reversal, circular, and factor reversal tests. Nonetheless, there are several others that can be performed, as Granel (2003) clearly demonstrated, by providing a list of more than twenty tests.

Researches often considered the factor reversal test as the most important (Granel, 2003; Ang, 2004), since it deals with the residual terms. When a decomposition method does not pass this test, it means it leaves an unexplained residual terms that have to be investigated (Granel, 2003). Methods that pass this test, on the other hand, have been considered as highly desirable (Ang, 2004).

Reference index	Methods	Properties			
		Factor reversal	Time reversal	Proportionality	Relation between add. & mult. appr.
Laspeyres index	Lapeyres	N	N	Y	N
	Paasche	N	N	Y	N
	Modified Fisher	Y	Y	Y	N
	Shapley/Sun	Y	Y	Y	N
Divisa index	AMDI	N	Y	Y	N
	LMDI I	Y	Y	N	Y
	LMDI II	Y	Y	Y	Y

Table 2.1 Summary of properties. Source: Granel F., A Comparative Analysis of Index Decomposition Methods, 2003

Time reversal test requires that an index for the period T based on period 0, should be the reciprocal of that for the period 0 based on period T. In decomposition analysis, it means that results should be consistent no matter if the analysis is performed prospectively or retrospectively (Ang and Zhang, 2000).

[69] The idea behind this classification, is that the theoretical foundation regards a series of test used also in the index number theory, since index decomposition is closely links to the index number theory (Ang). On the other hand, the remaining four aspects are all related to the application view point (Granel)
[70] Some of this tests have been proposed by Fisher in relation to the index numbers

The circular test can be described by the following equation: $D_{0T} = D_{0S}D_{ST}$, which means that the index calculated between a base year and the observed year should be equal to the product between the index for the base year and any intermediate situation and of the one between the same intermediate year and the observed one (Granel, 2003). In other words, if a method passes this test, it means that the index D_{0T} does not depend on how the indicator evolves over time (Ang and Zhang, 2000).

Table 2.1 shows the results presented by Granel (2003) as for the theoretical approach for some decomposition methods[71]. For every method is specified whether it pass (Y) the relative tests or not (N). It is quite clear that the most sophisticated approaches possessed more properties. Nonetheless, this is not enough to determine what should be the preferred method. In fact, there should be also an analysis of more contextual factors, that are the one relative to the application view point.

In light of this consideration, it will be now examined the second group, that, as mentioned above, take into consideration adaptability, ease of use, transparency, applicability, ease of formulation and computational ease.

When a method is highly adaptable, it means it can be applied to a wide range of decomposition problems. Analysts look in particular at how a method is able to handle dataset with zero or negative values, i.e. a method should give consistent results also in those cases (Granel, 2003; Ang, 2004).

Speaking about transparency, it will be fist describe the ease of use concept, which refers to how easily practitioners can apply the decomposition approach to different problems, while ease of result interpretation can be linked to the factor reversal test. Indeed, when a method fails this test and leave a residual term, results are more difficult to interpret (Ang, 2004). Transparency is also linked to the needs of policy makers to show their results and decisions to the public: they prefer to use instrument that are conceptually not difficult to understand and, moreover, results should be easy to interpret (Granel, 2003).

To move further, it can be stated that computational ease appears to be something subjective and, if an analyst considers it as an important issue, he should select a computationally simple method. Instead, ease of formulation is a different concept, since it refers to how complex are the formulae that define the index number decomposition. As specified by Granel, if the formulae are too complex, the method can result to be useless. An example is the refined

[71] The selected methods are the one more commonly used by researches, since they are linked to the Laspeyres or Divisa index. Furthermore, they allow an interesting comparison useful at explaining the advantages given by LMDI I methods, together with an explanation of the evolution of this kind of methods

Laspeyres index method: it has many suitable properties, but it turns out to be too complex as the number of factors considered increased.

The last concept described is applicability, which is something related to the updated data availability. It has to be underlined that, over last decades, in the most industrialized countries there has been a remarkable commitment to update energy related data (Granel, 2003).

To conclude, in this section there has been an initial analysis to understand why the LMDI I seems to be a good method to use: it has most of the desirable properties related to theoretical foundation and it is sophisticated but not too complex to apply and understand, as for example, the refined Laspeyres index or the LMDI II index. On the contrary, it cannot handle zero or negative values, but, as next section will describe, it is something that can be overcame.

2.2.2 LMDI I: perfect in decomposition and consistent in aggregation

LMDI I method is found within the Divisia index approach and is recommended for general use, given its desirable properties that have been already analysed, but also thanks to the ones that will be further described. Actually, this section aims at providing a deeper insight of the peculiar characteristics of this method, which has been one of the most used since its introduction in 2001 by Ang and Liu.

LMDI I has been developed in order to solve the most important shortcomings of other methods used in the decomposition analysis, i.e. non - perfect decomposition and inconsistency in aggregation (Ang and Liu, 2001). As explained by Ang (2004), within the methods linked to the Divisia index, the AMDI has the advantage to be simpler, since it used an arithmetic mean weight function[72], and can be use instead of the LMDI in many situations. On the other hand, it has two main limitations: it does not pass the factor reversal test, in fact there are cases in which it leaves a high residual term, and it cannot handle zero values, a problem that cannot be solved as for the LMDI I. A first attempt to overcome these shortcomings was proposed by Ang and Choi in 1997, that is the LMDI II: the first perfect decomposition techniques used in energy decomposition analysis (Ang et al., 2003). However, it is still not consistent in aggregation.

Within the techniques relative to the Laspeyres index, as shown in Table 7, the basic Laspeyres and Paasche method fail the factor reversal test, leaving some residuals. In contrast, the refined Laspeyres index, the Modified Fisher and the Shapley methods, do not. Nonetheless, as already mentioned, these techniques become inextricable and inoperative if three or more factors are used, making them useless, except if only up to two factors are considered (Granel,

[72] On the contrary, LMDI I uses a log mean weigh function

2003). Indeed, as remembered by Ang (2004), decomposition analysis is now often used to study problems that are more than three factors.

All the considerations above gave a preliminary idea of why the use of LMDI I is recommended. This analysis continues below, by explaining all the advantages and limitation of the investigated techniques, providing further proofs of its usefulness.

To begin with, a clear positive aspect of the LMDI I method is that it gives perfect decomposition, both when performed additively or multiplicatively. Though, as already said, it is not the only techniques that offer this advantage. The feature of perfect decomposition is very useful, since the aim of decomposition analysis is to spread a change of an energy or environmental indicator among the factors considered in the governing function. Without perfect decomposition, this purpose will be defeated (Ang and Zhang, 2000). Despite that, it has to be said that decomposition method which allow perfect decomposition are usually more complex to apply with respect to conventional techniques. Since ease of application is an important feature take into consideration by many practitioners, they would found an easier to apply method in the LMDI I, also when confronted with the LMDI II (Ang et al., 2003).

Furthermore, it is consistent in aggregation, a fundamental characteristic in energy decomposition studies. In fact, it happens frequently that decomposition is performed at sub – group level, with sub – grouping based on industrial or economic sector, country/region, fuel type, etc. In all these situations, consistency in aggregation has the fundamental role to allow the aggregation of sub – groups to a higher aggregation level in a consistent manner. In other words, if an index is calculated one step at a time has the same value of the index calculate in a single step, it can be stated the formula is consistent in aggregation. This mechanism enable a better understanding of the trend follow by each sub – groups and allows comparisons to be made between sub groups. Additionally, the result at aggregate level do not depend on how sub – grouping is defined (Ang and Liu, 2001). For the purpose of the analysis presented in the next chapter, in which the sub – groups are represented by the different fossil fuels considered, this is an essential feature.

As underlined in a guide provided by Ang in 2005, meant at helping manage the application of the LMDI I, it has a third advantage: the results obtained using the additive form and the one calculated with the multiplicative approach are linked by a very simple and useful relationship. This, can be described as follows: $\Delta V_{tot} / ln\ D_{tot} = \Delta V_{xi} / ln\ D_{xi}$ for all i. It simply means that, once you have calculated the results using the multiplicative approach, using the equation above it is possible to derive the results in the additive form, and vice versa. Separate decomposition using the two approaches separately is, therefore, unnecessary.

On the other hand, the LMDI I technique present also some shortcomings, first of all, it cannot handle zero values, which is a likely situation when dealing with decomposition analysis. The guide provided by Ang (2005) do not forget to provide a solution, simply suggesting to substitute zero values in the data set by a small positive constant[73]. Results, as the small positive constant approaches zero, converge. This property is only related to the LMDI method, not to the AMDI (Ang, 2005).

Secondly, since the formula contain logarithmic terms, negative values cannot be present in the dataset. Despite negative values in energy decomposition analysis are rare, it is a circumstance that has to be taken into consideration. The alternatives are to change the decomposition method or to apply the solutions described by Ang and Liu (2007) in a work designed for this purpose.

Despite the two negative sides stated above, it is clear why the LMDI I is the appropriate method for the analysis performed in this work. It is simpler than other techniques with the same characteristics[74], it is perfect in decomposition and consistent in aggregation, it has many desirable properties, even from the theoretical foundation perspective. In addition, solutions found allow to use it even when zero or negative values are present, it is easy to formulate and results are easy interpret, given that it doesn't leave any residual. Moreover, computation can be performed also with commercially available software.

All things considered, it is a method that put together a certain degree of technical sophistication, with relative ease of use and understanding.

2.3 Model: an extend Kaya Identity

The previous parts of this chapter dealt with the general methodology applied: from an explanation of the index decomposition analysis, to the analysis of the reasons behind the selection of the LMDI I as a more specific method within the IDA, together with the choice between multiplicative and additive approach. This last section will go further into this study, examining the last choice an analysist has to deal with: the selection of the aggregate to use. There will be also a deeper explanation of the applied model. This structure enables to have a clearer understanding of the analysis presented in chapter 3, since all decisions and more technical issues will have already been described. In particular, focus will be given to the description of the extended Kaya Identity used to carry out the analysis, which is inspired by O'Mahony case study on Irish carbon emissions (2013).

[73] e.g. between 10^{10} and 10^{20}

[74] Anyway, it is of course not the simplest method as for the application point of view. The analysis performed has already highlighted that, within the more sophisticated techniques, it is relatively simple to apply.

2.3.1 Disentangling CO_2 emissions: a revised Kaya Identity

The Kaya Identity is an aggregate introduced for the first time by Yoichi Kaya in 1990 and it can be used in order to decompose carbon dioxide emissions. It is an effective tool in order to understand the main determinants of CO_2 emissions. Not only it is useful in order to have an idea of the future path climate change will follow, but it also allow policy makers to develop the most appropriate measures and actions in order to influence climate change, by means of reduction of carbon dioxide emissions (Raupach et al., 2007).

First of all, it is going to be describe the basic multiplicative Kaya Identity introduced in 1990, which is not the version used in this work. Anyway, it is an initial step in order to better describe and understand the extended form of the identity. Equation (7) is the basic Kaya I dentity:

$$C = \left(\frac{C}{E}\right) * \left(\frac{E}{Y}\right) * \left(\frac{Y}{P}\right) * P \tag{7}$$

where C is carbon emitted in a predetermined time period, E is energy consumption within the same period, Y is the economic output and P the population. The ratios, on the other hand, assumes different meanings. In fact, E/Y is energy intensity, Y/P is GDP per capita and C/E is energy efficiency (Raupach et al., 2007; Lester and Finan, 2009).

The identity can be written also in differential form, as equation (8) shows:

$$\frac{\Delta C}{C} = \frac{\Delta (C/E)}{C/E} + \frac{\Delta\,(E/Y)}{(E/Y)} + \frac{\Delta\,(Y/P)}{(Y/P)} \tag{8}$$

where the change in carbon emissions depend on each of the rate change of the factors considered. The above equation can be applied to any geographical unit, from a small region, to a country or even the whole world and can be used also to forecast future trend of carbon emissions.

Although it is a very useful tool, it presents an important limit, i.e. it assumes unit elasticity. In other words, it means that a percentage change on the factors on which CO_2 emissions depend, produce an equal change on the aggregate itself. The identity, therefore, can't be use to understand the relative contribution of driving forces. Just to make an example, several empirical studies emphasized that an increase in the population produce an effect that is more than proportional on carbon emissions. Subsequently, the Kaya Identity will underestimate this effect (Rosa and Dietz, 2012).

Despite this shortcoming, this method remains an effective tool, since it was designed to deal specifically with carbon dioxide emissions and the right hand side of the equation can be constructed in order to include other determinant factors.

Extended versions of the Kaya Identity have been proposed by several authors, some examples are Zhang and Ang in 2001, Ma and Stern in 2008 and Wang et al. in 2004. The version proposed by Zhang and Ang can be described as follows:

$$C = \sum_i C_i = \sum_i (E_i/E)(C_i/E_i)\,(E/Y)(Y/P)P \quad (9)$$

where

E = Total Primary Energy Requirement (TPER)[75] of all fuel types

Ei = TPER of fuel type i

C = Total CO2 emissions from all fuel types

Ci = CO_2 emissions from fuel type i

Y = GDP

P = Population.

Furthermore, the added variable[76] E_i/E can be described as the consumption share of fuel type *i*. They used this version to decompose energy related CO_2 emissions, within a study aimed at carrying out a cross – country comparison.

Anyway, the above equation does not include the effect produced by the increased penetration of renewable resources or carbon free energy on emissions. In fact, the theoretical contribution of renewable resources to the production of carbon dioxide emissions is zero. Therefore, they are not included in the equation proposed by Zhang and Ang. (O' Mahony, 2013).

However, as it has already been underlined in chapter 1, the emissions mitigation strategy of Italy is focused also on the development of renewable resources. They have indeed faced an enormous expansion, in particular solar and wind, and there are plans to further increased their contribution to the energy supply. This is the reason why it should be better to apply an Extend Kaya identity proposed by Ma and Stern (2008), by Wang et al. (2004) and also applied by O'Mahony for Ireland.

[75] It is defined also as Total Primary Energy Supply and it is made up of: indigenous production + imports – exports – international marine bunkers - international aviation bunkers ± stock changes (IEA)
[76] Added with respect to the basic version of the equation

Ma and Stern in their study about the decomposition of China's carbon dioxide emissions, decided to apply an extended Kaya Identity, which includes also biomass, by adding a ratio for the share of fossil fuels in total carbon – based fuel use. The aim was to demonstrate the role played by the shift from biomass to carbon based fuels in the increase of CO_2 emissions faced since 2002. Inspired by this work, O'Mahony decided to apply a similar formula to the emissions of Ireland, to validate the potential of the development of renewable resources for reducing carbon emissions. It is interesting to notice that the emissions avoided thanks to the development and introduction of renewable resources can be described by the term "nega carbon". This is a concept similar to the one under the term "nega watt", which stands for avoided energy consumption derived from energy efficiency (O'Mahony, 2013).

After studying this latter paper, it has been decided to apply the same identity also for the Italian case, since it includes all the variable of interest for this case study.

Therefore, the extend Kaya Identity considered takes the following form:

$$C = \sum_i C_i = \sum_i (C_i/FF_i)(FF_i/FF)\,(FF/E)\,(E/Y)(Y/P)P = \sum_i F_1 S_1 S_2 IGP \qquad (10)$$

The variables considered take the same nomenclature as above, with the exception of FF, that is TPER for all fossil fuels and FF_i, that stands for TPER of fossil fuels *i*. In this equation, E includes also renewable resources. What is more interesting to investigate is the meaning of the ratios. F_1 is the CO_2 emission coefficient for fossil fuel type *i*, S_1 represents the share of fossil fuel type *i*, in total fossil fuels, while S_2 is the share of fossil fuels, in total fuels, *I* stands for aggregate energy intensity, *G* for GDP per capita or affluence and, lastly, *P* represents the population.

A change in the aggregate *C*, which can be described as the index of annual change in total carbon dioxide emissions (C_{tot}), will then depend on the emission coefficient effect (ΔC_{emc}), the fossil fuel substitution effect (ΔC_{ffse}), the renewable energy penetration effect (ΔC_{repe}), the intensity effect (ΔC_{int}), the affluence effect (ΔC_{ypc}) and the population effect (ΔC_{pop}). The equation, consequently, takes the form below:

$$C_{tot} = C_t/C_0 = C_{emc} C_{ffse} C_{repe} C_{int} C_{ypc} C_{pop} \qquad (11)$$

Then, the LMDI I is applied though the use of the following formula, suggested by Ang and Liu in 2001:

$$C_{emc}: \exp\left(\sum_i \frac{(C_i^T - C_i^0)/(\ln C_i^T - \ln C_i^0)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln\left(\frac{F^T}{F^0}\right)\right)$$

$$C_{ffse}: \exp\left(\sum_i \frac{(C_i^T - C_i^0)/(\ln C_i^T - \ln C_i^0)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln\left(\frac{S^T}{S^0}\right)\right)$$

$$C_{repe}: \exp\left(\sum_{i} \frac{(C_i^T - C_i^0)/\left(\ln C_i^T - \ln C_i^0\right)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln\left(\frac{S_2^T}{S_2^0}\right)\right)$$

$$C_{int}: \exp\left(\sum_{i} \frac{(C_i^T - C_i^0)/\left(\ln C_i^T - \ln C_i^0\right)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln\left(\frac{I^T}{I^0}\right)\right)$$

$$C_{ypc}: \exp\left(\sum_{i} \frac{(C_i^T - C_i^0)/\left(\ln C_i^T - \ln C_i^0\right)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln\left(\frac{G^T}{G^0}\right)\right)$$

$$C_{pop}: \exp\left(\sum_{i} \frac{(C_i^T - C_i^0)/\left(\ln C_i^T - \ln C_i^0\right)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln\left(\frac{P^T}{P^0}\right)\right) \quad (12)$$

In its work, O'Mahony, also provided a useful description of every determinant effects

- C_{tot}, as already specified, is the aggregate used. It represents the change in CO_2 emissions as for the aggregation of the factors considered.
- C_{emc} represents the change in carbon content per every fossil fuel (coal, oil and gas). This can be due to fuel quality and hypothetically also to abatement technologies.
- C_{ffse} is the fossil fuel substitution effect. In other words, it is an effect associated with the change in fossil fuel mixed structure[77] and it depends on technology (Wang et al.).
- C_{repe} represents the change in the penetration of energy from renewable resources (hydro, solar, wind, biofuels and geothermal in this case study).
- C_{int} is the change in energy intensity, which is the ratio between TPER (including renewables) and GDP per capita. It gives an idea of the energy needed per unit GDP and it depends on the structure and efficiency of the economy and the energy system, the technological progress and socio – economic behaviours.
- C_{ypc} stands for the change in GDP per capita.
- C_{pop} is change in total population.

- C_{rsd} is the residual deriving from the decomposition. Clearly, it should be zero, considering LMDI I is a perfect in decomposition method.

This chapter has provided a clearer explanation of the method that will be applied to Italy in chapter three, by presenting a step by step process from the broader methodology used to conduct decomposition analyses, to the decomposition method used and, finally, the aggregate

[77] How fossil fuels made up TPER for fossil fuels themselves.

studied. Moreover, it has been specified the reasons behind every choice related to the model applied, that has been widely described in the last section.

Next chapter will be dedicated to the application of the model, together with a better delineation of the data, application issues, results and implication.

CHAPTER 3

DISAGGREGATION OF ITALY'S CARBON DIOXIDE EMISSIONS – AN EXTEDEND KAYA IDENTITY APPLIED

In the previous chapter, there has been a detailed description of the model to apply in order to understand and analyse the main determinants of CO_2 emissions in Italy, i.e. an extended Kaya Identity. The application of this method will be deeply described in this chapter, with a particular focus on data used, results and policy implications.

As anticipated in the first chapter, Italy appears to be a good case study that, so far, has never been intensively investigate, since many works which tried to disentangle Italian carbon emissions were mainly aimed at cross – country comparisons. In fact, they were carried out at European or OECDs countries level[78].

Furthermore, many of the studies that applied the IDA, have been conducted at industrial sector level and very few of them include the renewable energy penetration effect (Ang, 2004; Granel, 2003; Ang and Zhang, 2000).

The analysis conducted will be connected with chapter one, when the main energy – related characteristics of the country has been presented. Indeed, as it will be explained also further in this chapter, energy consumption, economic growth and renewable resources penetration will be use into the model, in order to understand their relation with CO_2 emissions. Additionally, energy efficiency will be taken into account as one of the main instrument the country can exploit in order to decrease energy consumption, to decouple economic growth from emissions and to decrease energy intensity. All these aspects together bring at the same conclusion: lowering emissions. Also the dependence on other country for energy supply will be further analyse, since it can be reduced thanks to measures aimed at enhancing, for example, renewable resources use and energy efficiency, with have a direct effect also on carbon emissions.

[78] Some examples are the studies conducted by Kopidou D. et al. (2015); Andreoni V. and Galmarini S. (2016); Camarero M. et al. (2012); Karmellos M. et al. (2015)

3.1 Data

To begin with, data used in the decomposition analysis are presented. According to the equation of the Kaya Identity, data needed are the one related to *population*, *GDP per capita*, *TPES* for all fossil fuels and renewable resources and *CO_2 emissions* per fossil fuels included in the analysis presented[79].

All data needed were taken from the OECD[80] or IEA[81] database. In particular, information about TPES were obtained by the OECD sources, while all the other were made available from the IEA, in relation to a study about CO_2 emissions from fossil fuels combustion.

As for Italian population, which is expressed in millions, IEA main source has been the *OECD National Accounts Statistics* database. The same source has been use by IEA also to gather data about OECD countries' GDP, which is stated in billion 2005 US dollars. For the purpose of this analysis, it has been considered at PPP[82]. For each country, GDP at PPP was calculated at market price in local currency and annual rates. Data have been scaled to 2005 price levels and then changed into US dollars, using 2005 average purchasing power parities. Purchasing power parities can be defined as the rates of currency conversion that can be used in order to remove prices differences between countries. In other words, when the PPP is applied to an amount of money to convert it in different currencies, that converted sum can buy the same basket of food and services in all countries (IEA, 2015). With the purpose of converting national currency to US dollars, PPPs have been aggregate using the Èltetö, Köves and Szulc (EKS) Eurostat- OECD method and rebased on the United States (OECD/IEA, 2015)[83].

With reference to TPES (or TPER), data are expressed in Mtoe and they are taken from the IEA Energy Balance, which makes available information about TPES for each fuels types, both fossil ones and renewable resources. This indicator is made up by the following equation: *production + imports - exports - international marine bunkers*[84] *– international aviation bunkers*[85] *± stock changes*. Since data provided by the IEA Energy Balance were expressed in thousand tons of oil equivalent (ktoe), a conversion into Mtoe has been required, in order to obtain a more readable and clear unit of measure[86]. Bearing in mind that in this work will be

[79] As for the fossil fuels selected for the analysis, the choice was rather simple, since Italian energy consumption is made up by three fossil fuels: oil, natural gas and coal

[80] Organisation for Economic Co-operation and Development

[81] International Energy Agency

[82] Purchasing Power Parity

[83] A comprehensive explanation of the methodology used can be found on the *Eurostat-OECD Methodological Manual on Purchasing Power Parities, 2012 edition, European Union / OECD 2012 and Measuring the Real Size of the World Economy: The Framework, Methodology and Results of the International Comparison Program (ICP)*, World Bank 2013

[84] Refers to quantities delivered to ships of all flags engaged in international navigation

[85] Include those quantities sent to aircraft for international aviation

[86] Conversion has been made according to the relation 1 ktoe = 0.001 Mtoe (European Commission)

applied and extended Kaya Identity, the choice of selecting both fossil fuels and renewable resources TPESs is straightforward. It is important to notice that the two have been analysed separately, in order to disentangle the effect of renewable resources consumption from the fossil fuels one. Therefore, the first step has been to sum the TPESs of coal, oil and natural gas and to study the aggregate effect on emissions. The second step has been the one to add also the TPESs of geothermal, hydro, biofuels and solar, enabling to isolate the influence that derive from the latter resources.

To conclude, data about CO_2 emissions from fuel combustion for oil, coal and natural gas are taken from the *CO_2 emissions from fuel combustion* (OECD/IEA, 2015), calculated accordingly to the *2006 IPCC Guidelines*.

3.2 Results

In this section will be presented the results obtained applying the Kaya Identity to Italy, in relation to the data described above and to the use of the LMDI I method. It has been covered the period within 1971 and 2013, considering data availability. Results will be presented not only toward a complete time – series, but with the aggregate effect between 1971 and 2013 and for sub periods. Furthermore, in appendix A it can be found the comprehensive results of the analysis.

It is essential to notice also that the decomposition has been carried out in rolling base years' form, i.e. the effects are calculated in step of one year. This approach has the advantage to allow to detect the path followed year by year and to aggregate results in sub periods or in the entire period (Granel 2003; O'Mahony 2013). On the other hand, it encompasses cumulative errors (Granel, 2003).

To be more specific, results are presented in Table 3.1 in the form of aggregate results, expressing the change occurred between 1971 and 2013 and between sub – periods. The sub – periods have been selected in order to reflect how the variables changed as a consequence of main events which characterised the energy and economic situation of Italy. Some examples are the of 1973 oil and the 1979 energy crises, the economic crisis occurred in the early 1990s and in 2007, the ratification of the Kyoto Protocol and the introduction of the massive incentives with respect to renewable energy.

	ΔC_{tot}	ΔC_{pop}	ΔC_{ypc}	ΔC_{emc}	ΔC_{ffse}	ΔC_{repe}	ΔC_{int}	ΔC_{rsd}
1971 - 1979	1,2229	1,0414	1,3233	1,1156	1,0025	0,9964	0,7964	0,0000
1980 - 1989	1,0805	1,0042	1,2366	1,0692	0,9741	1,0038	0,8322	0,0000
1990 - 1995	1,0308	1,0022	1,0645	0,9861	0,9878	0,9944	0,9975	0,0000
1996 - 2006	1,1221	1,0274	1,133	0,8835	0,9989	0,9885	1,1049	0,0000
2007 - 2013	0,7607	1,0316	0,8866	1,003	1,0093	0,9108	0,9021	0,0000

	ΔC_{tot}	ΔC_{pop}	ΔC_{ypc}	ΔC_{emc}	ΔC_{ffse}	ΔC_{repe}	ΔC_{int}	ΔC_{rsd}
1971 - 2013	1,1516	1,1139	1,8142	1,031	1,0578	0,8967	0,5827	0,0000

Table 3.1. Decomposition of Italy's CO_2 emissions – aggregate results

To continue, results are presented in form of accumulated Figure 3.1 for the entire period, allowing to understand the overall contribution to the change of carbon emissions given by all the factors considered.

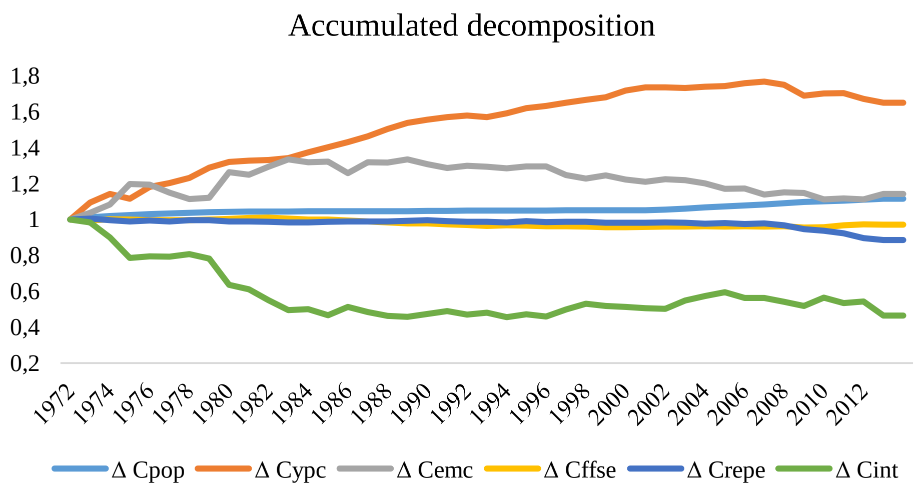

Figure 3.1. Accumulated decomposition of Italy CO_2 emissions. Author's own elaboration. Data source: OECD/IEA

At a first glance, it is possible to state that the major positive impact can be associated to the affluence effect (C_{ypc}), followed by the emission coefficient effect (C_{emc}). Besides, it can be noted that the trend followed by the emission coefficient effect has been a decreasing one, especially from the late 1980s. Indeed, it has reached the population effect (C_{pop}), reducing progressively the impact on emissions. Therefore, the influence produced by population and the emission coefficient effect is relatively small with respect to economic growth. Among the factors which produce a negative effect on emissions, the prevalent one is the intensity effect (C_{int}), followed by the renewable energy penetration effect (C_{repe}) and, lastly, by the fossils fuels substitution effect (C_{ffse}).

Results can be deeper analysed as follows.

First of all, the dominant factor in determining CO_2 emissions Italy is GDP per capita, despite the two oil shocks that hit the world in the 1970s. During this years, in fact, Italy's GDP experienced the higher growth rates among the period considered. After a slightly decrease in carbon emissions in the first years of the 1980s, they started to follow a steady positive trend, so as GDP. Emissions trend seems to be influenced by the 1990s and 2000s crises. In 1993 and starting from 2007, they dropped significantly, together with GDP. Of course, not all the movements faced by emissions can be explained with GDP trend, since there are negative effects on emissions which, during the period considered, influenced the quantity of CO_2 released in the atmosphere.

With respect to the affluence effect, it is interesting to mention a research question that analysts tried to investigate in recent years, i.e. is it possible to growth economically without increasing emissions? This phenomenon is referred to with the term decoupling[87]. While in march 2016 the IEA issued a report about an analysis on world decoupling, proving that it has been reached, a study conducted on Italy shows the opposite. Andreoni and Galmarini (2012), with their decomposition analysis of energy consumption at sectoral level, showed that the main driver of carbon emissions within the period 1998 – 2006 has been GDP, despite all the measures trying to counterbalance this positive effect. Focusing on this aspects, should, therefore, being a priority for the country. Reaching a decoupling situation will substantially help to reduce the increase in emissions, allowing to reach country and European level objectives. Moreover, Italy is a country which need to recover from the crisis and the increase in GDP is one of its main targets. Of course, if economic growth will still be linked with emissions, it would be a non - sustainable from an environmental point of view.

As for the contribution of the emission coefficient effect, it can be seen that it was quite relevant in the first years of the analysis, while it decreased steadily starting from the late 1990s. It signals a reduction on the carbon content of the fossil fuels considered, drove by the relative carbon emissions decrease associated with oil[88]. This results are consistent with policies adopted by Italy after the ratification of the Kyoto Protocol and subsequently to some laws and directives issues by the country itself and the European Union. Indeed, starting already from 1997, Italy promoted policies aimed at enhancing fuel quality, by decreasing the percentage of

[87] This means breaking the link between bad effects on environment and economic growth
[88] Author's own elaboration. Data source: IEA

benzene and other aromatic hydrocarbons in fuel gasoline (Agenzia delle dogane e dei monopoli). Moreover, after a 1991 directive the country began to introduce technologies to reduce emissions produced by vehicles. After that, to comply with the Kyoto Protocol and the 2009 European directive, Italy started to promote research and development activities in the abatement technologies field (ENEA, 2011). Notwithstanding, application of such technologies is still limited and Italy is lagging behind many other OECD countries in terms of innovation and performance (OECD, 2013). To conclude, it is possible to assert that part of this result can be ascribed to the latest financial crisis: as a consequence, not only emissions, but also consumption[89] of fossil fuel diminished in a consistent manner, helping observing a decrease in the effect produced by the emission coefficient effect.

To conclude the analysis of the positive determinants of carbon emissions, the analysis shows that population has always had a limited effect on CO_2 emissions. Only after 2002, when Italy started to face a dramatic population growth, also the effect associated with population increased, but it remained low relatively to GDP.

When considering, on the other hand, the factors that have a negative effect on emissions, it is possible to assert that fossil fuel substitution effect and the renewable energy penetration effect do not play a relevant role in reducing CO_2 emissions. Nonetheless, some interesting consideration can be made with respect to renewable energy, since their trend shows aspects that are worth – analysing. In fact, as Figure 3.1 clearly demonstrate, only starting from the late 2000s, energy produced by renewable energy started to increase its influence on the aggregate. This is consistent with what has been already explained in the chapter one about the introduction of policies[90] aimed at promoting the use of renewable resources for the production of energy. In fact, Italian own initiative and the commitment to meet the standard set at European level, allowed to had this strongly positive results in a relatively short time period. Although, renewable energy penetration effect deserves special attention, since it is believed they will play a critical role in achieving the reduction in emissions by 50% within 2050. Governments, included the Italian one, have recognised that, therefore they began to introduced a wide range of policies and measures in order to promote the use of renewable energy (IEA).

[89] Energy consumption (TPES) and CO_2 emissions are the two component of the emission coefficient effect
[90] Green Certificates System, Conto Energia, Biofuels use targets

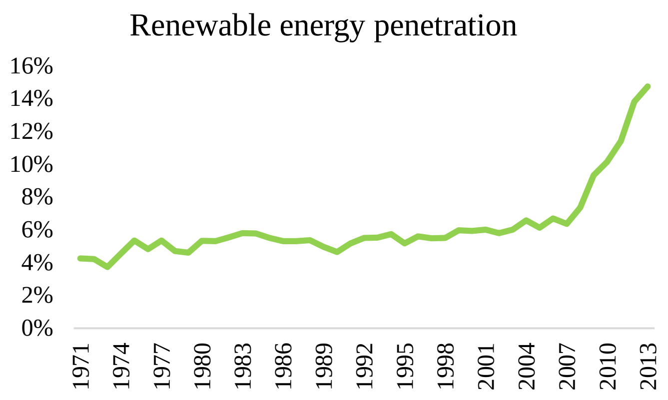

Figure 3.2 Renewable energy penetration. Calculated as renewable energy TPES/total TPES. Author's own elaboration. Data source: IEA/OECD

Figure 3.2 give an idea about the trend tracked by the penetration of renewable resources, calculated as the ratio between renewable resources TPES and total TPES. After many years in which the contribution of renewable resources was fairly constant, it was only during last decade that the trend experienced a sudden and noteworthy increase. Without the aforementioned incentives introduced by the government, this results would have not been achieved. As underlined by a report issued by KPMG in 2011, despite being crucial as for environment protection and despite their positive effects[91] on the energy market, they do not possess a cost advantage over alternative, non-renewable sources. Despite that, they are, for the moment, the least problematic solution to face the environmental issue in our country. Moreover, they are cost efficient, but not sustainable. It simply means that when the full cost[92] to bear to produce energy from renewable resources is compared to the one sustain in the case of more conventional sources, the first is still meaningfully higher.

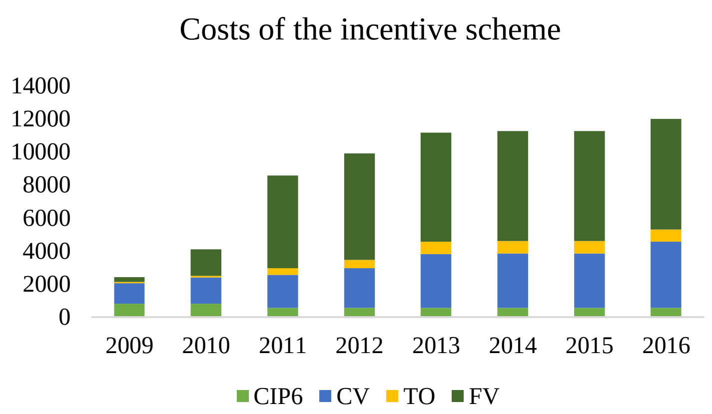

Figure 3.3 Costs of the incentive scheme for renewable resources in Italy, expressed in million euros. Data source: GSE

[91] Some of this effects have been already described in chapter one: renewable resources deployment can boost energy efficiency, they can help to reduce energy dependence (thus increasing energy security) and they can help diversifying the energy mix of a country

[92] Considering also returns on invested capital

Figure 3.3 give a picture of the costs sustained by the country to support the incentive scheme aimed at promoting renewable resources use, which includes FV, that stands for photovoltaic, CO that means green certificates, TO that is the *"tariffa omnicomprensiva" and Cip6*[93]. It is important to notice that almost the total amount of the incentives is paid by the final consumer through the electricity bill[94] (ENEA, 2013). Furthermore, Assoelettrica in 2012, estimated that within 2013 and 2020 Italy will provide about 200 billion euros to support these incentive schemes. As GSE (2014) these costs are only partially covered by the revenues obtained by selling electricity on the market[95], It is a signal that in future years, the costs the final consumers will have to bear will increase dramatically, confirming that the actual scheme to promote the use of renewable energy is not sustainable, also in light of the relative minor impact of these component to the reduction of CO_2 emissions.

Nonetheless, their future role cannot be ignored, not only because CO_2 emissions[96] need to be reduced, but also because fossil fuels are non – renewable sources and it will be necessary to progressively substitute them with renewables ones. Several studies tried to understand their future potential, by underlining that renewable energy could be the most appropriate long term solution for the environmental issues. Connolly et al. (2016), construct a model to understand if a pathway toward a 100% renewable energy system in Europe within 2050 is possible, concluding that, indeed, it can be attained. The analysis was divided into nine steps toward the final result and they determine that, for each step accomplished, primary energy supply and CO_2 emissions both decrease. On the other hand, energy costs rise, since many technological change are needed in order to allow an intensive penetration of those sources. The higher costs associated with renewable energy introduction is one of the main issue related to the topic. As Moriarty and Honnery (2016) highlighted, those costs are also associated with the flow and the intermitted[97] nature of renewable resources. To be more specific, they are a flow rather than a stock, with the consequence need of energy storage systems. Moreover, future renewable resources output will be mostly electric, so that a reconfiguration of existing grids and conversion to non - electric energy will be necessarily. They also underlined that costs for the maintenance of ecosystem services[98] will rise. For Italy this costs are represented also by the heavy incentive

93 *"Tariffa ominicomprensiva"* and cip6 are other two incentives instrument within the Italian framework
94 The major part of the final consumers is represented by small and medium enterprises (78%), while only the 22% is represented by households (Assoelettrica, 2013)
95 According to GSE revenues obtained in 2014 where equal to 2.420 millions euros
96 As the analysis presented suggest, their impact on Italian environment is still limited and it can be observed only in recent years. Since the Italian renewable energy have the right potential, the country has to continue over this path, trying to increase the effect of these fundamental resources
97 Typical characteristic of wind and solar
98 They are those benefits that ecosystems provide to humankind. Some examples are the production of food and water and the control of climate and disease) (Millenium Ecosystem Assessment)

system required to promote renewable resources use. Nevertheless, they are not only the most promising long term solution to the problems already mentioned but, for Italy, their expansion can represent a chance, also to promote growth and sustainable development. Besides, the promotion of this resources, should be incentivized considering that Italy has not significant fossil fuels and does not use nuclear power.

To continue, it can be stated that also the effect produced on emissions by energy intensity is worth noting. As explained in the previous chapter, it represents the quantity of energy needed by a country to produce a unit of GDP. Energy intensity can be seen as a rough indicator of energy efficiency[99], but it has to be underlined that a change in energy intensity can be due to a variety of other factors, not only energy efficiency. Some examples are economic development, changes in the industrial and economic structure, lifestyle habits and climatic condition (ENEA, 2015).

The trend of energy intensity in Italy has followed, for most of the period considered, the trend of GDP per capita, with the exception of the years between the late 1970s and early 1980s, when a positive growth rate of GDP was accompanied by a decrease in energy consumption. The consequence was, of course, a decrease in energy intensity. After that period, the contribution of energy intensity to the reduction of carbon dioxide emissions remained constant. The change in this trend began in the mid - 2000, together with the introduction of the energy efficiency measures[100], already presented in chapter one. In the period between 2005 and 2013, energy intensity decrease by a rate of nearly 13%[101]. During this period of time, when the growth rate of GDP was negative, the one of energy intensity was even lower and when the GDP growth rate was positive[102], the one of energy intensity was negative. Even if 2014 and 2015 has not been included in this analysis, data recorded by ENEA prove that in 2014 energy intensity further decreased, to recover in the following year, due to a relevant increase in energy consumption (+ 3.2 % with respect to 2014). This relatively positive results can be explained by several factors, first of all the few domestic energy sources. Furthermore, the deep commitment of several industrial sectors[103] for the production and spread of energy efficiency technologies played a role (ENEA, 2011), together with the mild climate condition which characterized the country (EEA, 2013; ENEA, 2011) and the introduction in the energy system of renewable

[99] Since energy intensity is a ratio, a decrease of this indicator can signal better energy efficiency in the country considered (ENEA, 2011)
[100] White certificates, 55% tax deduction, thermal account
[101] Author's own elaboration. Data source: IEA
[102] GDP recorded a positive growth rate in 2006 and 2011
[103] Some examples are: household appliances and home automation, lighting, boilers, motors, inverters and smart grid, buildings and automotive (ENEA, 2011)

resources. Data on TPES demonstrate how, during the period considered, the share[104] of renewable energy consumed by the country increased, while the use of coal and oil progressively diminished. This helped at enhancing energy efficiency[105]. When analysing the influence by sectors, as reported in Figure 3.2, it is possible to notice that the main contribution to the decrease in energy intensity was given by the industrial sector. Despite its highest energy intensity, it registered a major and significant decreasing trend starting from 2003.

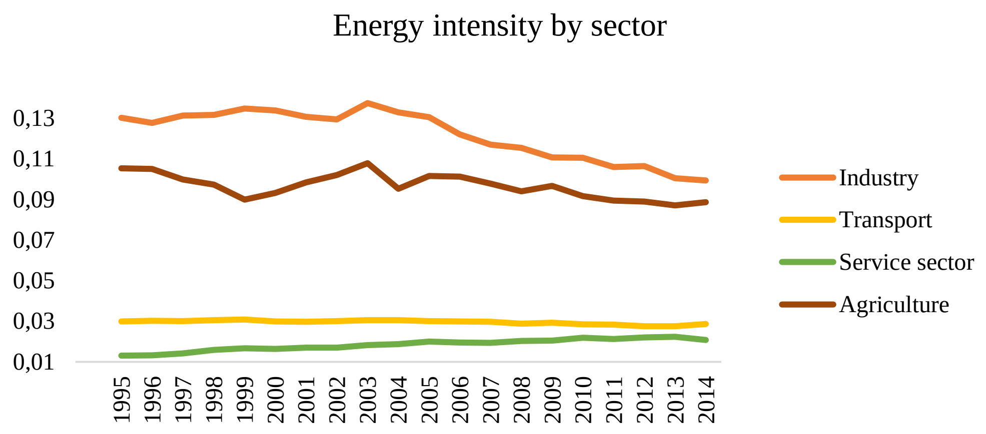

Figure 3.4 Energy intensity by sector, unit measure koe/€2005p. Author's own elaboration. Data source: Odyssee

Moreover, it has to be underlined that Italy is one of the best performing country in terms of energy intensity, also thanks to all the reasons stated above. At European level, in 2014 it was ranked third, as for energy intensity, after Great Britain and France (PwC, 2015). Plus, it has a consumption of energy per unit of GDP lower also than many other OECD countries (OECD, 2013). Despite this good performance, during the 2000s energy intensity in Italy declined at a rate lower than the one of many OECD countries (OECD, 2013) and the advantage with respect to worst performing European countries is getting lower[106] (ENEA, 2015).

Nevertheless, the potential in terms of energy savings of Italy are still many and they would entail a positive economic return, for both Italy and the single consumer. Chapter one already underlined the positive effects that could derive from a focus on actions and measures designed to boost energy efficiency.

[104] This extremely positive trend started in 2010. On the other hand, for many years the consumption of renewable resources has been fairly constant

[105] The reasons behind this conclusion can be found in the first chapter of this work.

[106] According to a study about Italian energy efficiency published by ENEA in 2015, over the last two decades Italy has shown a primary energy intensity lower than the average of the 28 European Union countries and of the ones belonging to the Euro Area. In 1995, the distance between Italy and these two groups was of 40 toe/M€, while in 2013 it was of about 20 toe/M€

3.3 Policy implications

Chapter one already gave an overview about the measures adopted over the last decades by Italy in order to comply with Kyoto Protocol and European Directives, but also about the policies adopted by its own initiative. The reasons behind these decisions is clear: contrast the climate change and environmental degradation, together with promoting the sustainable development of the country.

An important prerequisite for the formulation of the most effective policies to reduce emissions, is a proper understanding of the main determinants of CO_2 emissions itself. Once identified the problems, as this chapter has already done, it is possible to design the most suitable solutions. In order to do that, it is useful to divide the determinants factors into three categories: scale effects, technological effects and structural effects (Ma and Stern, 2008) and as shown by Table 3.2.

ΔC_{pop}	ΔC_{ypc}	ΔC_{emc}	ΔC_{int}	ΔC_{ffse}	ΔC_{repe}
Scale	Scale	Technological	Technological	Structure	Structure

Table 3.2 Determinants effect by type

Usually, policy makers, to limit emissions do not intervene over the scale effects, since it would entail to put constraints on population and economic growth (Ma and Stern, 2008; O'Mahony 2013). Even if the role of GDP as for the increase of air pollution is relevant and unequivocal, precedence is typically given to social and economic growth objectives. It has to be beard in mind that Italy needs to recover by the Great Recession, which necessitate an acceleration of economic growth, and that population is expected to grow even further in the next years (Eurostat), causing a boost on emissions.

Decoupling economic growth from carbon dioxide emissions can be a solution to pursued an increase in GDP, without having, as a consequence, a rise in emissions too. During last decades, even thanks to the Kyoto agreement on 1997, the need to break the link between economic growth and emissions has been clear at national and international level. In fact, several measures have been implemented in order to achieve this ambitious objective (Andreoni and Galmarini, 2012; Bento and Moutinho, 2015; PwC, 2015). Tapio et al. (2006) described this phenomenon with the term immaterialization, defining it as the decoupling of both material production (TPES) and consumption from economic production. Immaterialization favour lower intensity development in the economy, helping making mitigation less expensive. More than a few ways can be adopted to guide quality or nature of economic growth toward energy and emissions extensive forms, such as economic development, spatial development, transport policy and lifestyles. Anyway, integration among policies, programmes and individual actions is also necessary (O'Mahony, 2014). On the other hand, Andreoni and Galmarini (2012) stated the main typical forces on which to focus in the attempt to allow economic development without further damaging the environment. Those leverages are technological progress, innovations, enhancing productivity and efficiency. While many countries at international level have achieved significant results with regard to decoupling (World Resource Institute), Italy, as already mentioned, has not. Therefore, is should be one of its priorities to focus on this fundamental objective.

As for renewable energy usage, their role in reducing CO_2 emissions is well known. Not surprisingly the commitment in investing and promoting their use towards incentives is spread both at national, European and at international levels and has kept on increasing over last years. The introduction of these incentives turned out to be fundamental: as already mentioned, one of the most interesting aspects of the analysis is that the trend showed in Figure 3.2 can be explained by the introduction of related incentives and policies. Italy's commitment in this field is not recent, in fact, its first National Energy Plan was released in 1981. It was then followed by several laws, aimed at spread and continue the usage of renewable resources into the national energy system (IRENA, 2012). Also with the ratification of the Kyoto Protocol, Italy and the European Union have found themselves further committed and the effect was the release of an integrated policy for energy and environment. In 2009, was indeed released the climate and energy package called 202020, with which the European Union set, as a target, the rise of the share of the renewable energy over total consumption. A work conducted by Dogan and Seker (2016) actually explains how, by increasing the share of renewable energy and decreasing the one of non - renewable, CO_2 emissions should decline. They, therefore, argued that the European Union should focus their efforts on the goal set. As a matter of fact, it requires each Member States to issue a National Renewable Energy Action Plan (NREAP) which states the way in which the objectives set will be achieved. Italy delivered this document in 2010 and it listed the measures already described in chapter one. Several subsequent decrees then modified the NREAP, providing the evolution and development to the related regulation.

Now, there will be a deeper focus on why incentives[107] are so important for the development of the sector and on their drawbacks, together with an insight on the main issues related to the regulation that is aimed at applying the policies.

First of all, an analysis conducted by KMPG in 2011 will result helpful in highlighting the main issues related to the development of energy resources in the country (i.e. crucial role

[107] Green certificates system, "conto energia", biofuels target

played by incentives, costs, legislative framework)[108]. To begin with, the relevant role of incentives can be justified by the failure in achieving the grid parity, which can be defined as the parity of the energy production costs from renewable resources and conventional ones. Moreover, the expansion of this resources, strongly depend not only on the presence of suitable sites, but also on the profitability of the incentives. As a matter of fact, it is a sector in which returns against large initial investments are certain. On the other side, when deciding to implement those investments at industrial level, some difficulties arise, i.e. complex authorisation procedures and problems in attaining funds from banks. To continue, the situation is complicated by the confuse legislative framework, given that every Region can decide the regulation about licensing requirements with respect to their territory, which sometimes are in contrast with the national regulation. As a consequence, long waits are necessary to obtain the investments, discouraging the investments themselves. The requirement of a smoother regulation, more homogeneous nation - wide is, therefore, suggested. Furthermore, policy makers should find a balance between making the development of renewable energy sustainable and to keep on encouraging investments, guaranteeing a certain profitability.

Additionally, the costs of the incentive scheme charged to the consumers is high[109], making the incentives used an unsustainable system in the medium – long term, since costs are expected to further increase, also in view of the context of reduced public spending.

As for the reduction of the costs associated with the incentives, the government already moved some steps in the right direction, revising the incentives related to the production of renewable energy. In particular, it decided to reduce the incentives issued in relation to photovoltaic, wind and biomass, together with decreasing the installable capacity for all three categories[110]. Changes like that have been introduced also to bring the costs of the incentives in line with the falling costs of the technologies[111]. Besides, with respect to photovoltaic, the incentives will also be gradually reduced, since the major costs over last years were associated with the heavy installation of the photovoltaic technology. (OECD, 2013; KPMG, 2011).

Once again, the analysis emphasised how it is important, for Italy, to concentrate on technology, facilitating the development of renewable energy and finding the rightest balance between benefits and costs. Progressively moving toward its growing use is essential, especially looking at the future, where non – renewable resources will exhaust.

[108] Costs, legislative framework,
[109] In 2010 total costs of the incentives were estimated to be 3.6 billion euros (KPMG, 2011)
[110] It has to be noticed that, in some cases, the installed capacity is not fully exploited
[111] Just to make an examples, once installed a photovoltaic technology, companies are able to achieve economies of scale

The fossil fuel substitution effect, as figure 3.1 demonstrates, gives only a minor contribution to avoidance on carbon emissions, which has increased slightly during last years considered by the analysis. The trend could change by helping to move energy consumption toward more low carbon intensity fuels, contributing also to improve energy efficiency (O' Mahony).

The last point touched, will regard to the effect produced by energy intensity and, of course, the policies that can guarantee a good performance of this determinant factor. In particular, the focus will be on the importance related to energy efficiency, considering, among all other positive effects, also the role it plays in reducing energy intensity, which has the main negative effect on carbon emissions. As already anticipated, Italian performance with respect to energy intensity is relatively positive, since in recent years has experienced a decreasing trend, also when compared to the rest of European countries and OECD countries. Moreover, in 2016 the CCPI estimated that Italian energy intensity is one third below G20 countries average. The importance of acting on energy intensity especially by means of energy efficiency improvement, is something well recognised, both at national and European level. To help countries to reach significant targets in term of cost-effective energy efficiency, the European Union and the Italian government have started to issue and implement several measures and policies. At European level, a continuing evolving variety of directives set targets and action plans over last decade. The most recent objective, is an increase of 20% in energy efficiency to be reached within 2020. Furthermore, according to the Energy End-Use Efficiency and Energy Services Directive (ESD) (2006/32/EC), member states have to submit the national energy efficiency action plans (NEAAP). In 2014 Italy delivered its NEAAP, which set out the target to be reached within 2020 and give a picture of the Italian energy situation, together with results already reached. This work clearly describes why the focus on energy efficiency is fundamental for Italy. First of all, it is the most cost – effective way to reduce carbon emissions. Moreover, it could help mitigating the weaknesses which characterized the Italian energy market, such as the high energy costs[112] and the dependence on energy imports. Energy efficiency will also contribute to the achievement of the 2020 package targets and to the use of investments as a leverage to improve growth and employment. Measures the country has already adopted for the achievement of energy efficiency objectives[113] have been described in chapter one: they are white certificates, thermal account and tax deduction.

[112] Italian energy prices are among the mst expensive in Europe and the difference becomes even greater when compared with United States. Some of the reasons are the reliance on gas, especially for electricity generation (while other countries in Europe use more nuclear and coal) and the incentives for the use of renewable resources for the production of electricity.

[113] The NEEAP specifies the targets related to energy efficiency: save 15.5 Mtoe of final energy per year within 2020 (20 Mtoe of primary energy), avoid the emission of about 55 $MtCO_2$ per year and avoid to import 8 million tonnes of fossil fuels per year.

In chapter one have been also already provided some data regarding the results achieved (Table 1.3), while above is presented Table 3.2 which summarises the main targets in terms of energy efficiency to be reached by sector within 2020, with a specification of the related instruments.

Energy efficiency targets for 2020 (Final and primary energy, Mtoe/year)							
Sectors	Planned measures for 2011 - 2020					Final energy consumption	Primary
	Regulatory Standards	White Certificates	Tax deductions	Measures and investments for mobility	Thermal Account	Expected savings	Expected savings
Residential	1.6	0.15	1.38	1.97	0.54	1.31	3.67
Services	0.2	0.1			0.93	0.07	1.23
Public authorities	0.1	0.04			0.43		
Private	0.1	0.06			0.5		
Industry		5.1				1.36	5.10
Transport	3.43	0.1				0.47	5.5
Total	5.23	5.45	1.38	1.97	1.47	3.21	15.50

Table 3.3 Energy efficiency targets for 2020 in Mtoe/year. Source: NEAAP 2014

The energy strategy of the country is, therefore, still concentrated on this area: not only Italy is a world leader in energy efficiency, but it is putting the base to continue follow this path, promoting a strong improvement of energy efficiency. Even if Table 3.3 only describes results in terms of energy savings, of course acting on energy efficiency will contribute in several other ways to enhance the Italian energy situation. Among these, since efficiency is one of the major components of energy intensity, it can be assumed that, in next years, the latter will continue to decrease, thus lessening emissions.

This latter chapter gives a clear and comprehensive picture not only of the trend followed by CO_2 emissions, but also of its components. It turns out to be useful mainly because, with one single instrument, it is possible to understand the main driver of emissions, enabling to construct the proper policies to incentivize the negative effects and to overcome the causes of emissions. Moreover, it allows to recognise to what extend every single determinant factor should be influence by policy makers and the potential benefits that could be reached. From the analysis presented it results that the main driver of emissions is a factor on which is not possible to directly intervene (i.e. GDP per capita), which is something that holds also for population. Indeed, it would not be possible to slow down economic growth or to limit population rise. The possible solution is to try to decouple economic growth from environmental pollution, as some other countries managed to do. The leverage that Italy can use involve technological development and improvement of innovation and energy efficiency. Energy efficiency resulted to be a fundamental force on which to act to reduce emissions, since it has the advantage of enhancing also energy intensity, the determinant with the main negative effect on carbon dioxide emissions. Furthermore, it is not only necessary to act on the factors that, as for now, seem to be the main forces behind emissions. Italy should give importance also to the incentives to promote renewable energy, especially in view of the fundamental role they will play in the future and of the surge in renewable energy penetration that follows the introduction of the aforementioned incentives.

CONCLUSION

The aim of this work is not only to give a comprehensive picture of the Italian energy situation, but primarily to try to understand what are the main drivers of CO2 emissions in the country, their past trend and what can influence their future impact on the environment. This kind of analysis is indeed essential in order to recognise the future development of Italian emissions and to construct the proper policies on which to focus, in view of the future results Italy should achieve in terms of pollution and environment.

The first step has been the one to underline weaknesses and strengths of the country, attempting to deeply explain the main elements which distinguish and characterize the Italian energy market. What emerged from this preliminary view was that Italy is, for some aspects is a forerunner, while for some other it is still lagging behind. As it has already been described, the country displayed good performances with respect to energy efficiency, renewable resources usage promotion and for the commitment it has manifested during last decades to the reduction of CO2 emissions. Nonetheless, there is still room for improvement and development, especially in light of the need to further decrease emissions and energy consumption, to stimulate energy security and to diminish the energy dependence rate.

The focus has been given to the reduction of carbon dioxide emissions, which are the main contributor of GHG. In order to better understand which tools it should be acted on trying to reduce them, it has been used an extended Kaya Identity, that has allowed to disentangle all the factors that contributes to the compose CO2 emissions. The novelty of the analysis performed is that it includes also renewable resources, allowing taking them into account separately from non-renewable ones. This choice was driven by the fact that it is one of the areas on which the country concentrated its efforts in recent years and on which a lot of resources have been devoted to.

Furthermore, renewable resources usege is at the centre of the environmental debate and of the policy measures decided at national and European level, also in light of their fundamental future role in reducing pollution. It is, therefore, interesting to analyse what is the actual contribution their implementation had in the country.

The application of the Kaya Identity to Italy has provided some interesting results, giving a broad image of the main forces behind CO2 emissions. Moreover, it has been possible to observe the role played, within this context, by renewable energy penetration.

Results of the decomposition analysis, considering a period from 1971 to 2013, indicated that, nowadays, the main contributor to the increase of emissions is the affluence effect, i.e. GDP per capita, while the major negative influence on the increase in emissions is the intensity effect, namely the ratio between GDP and energy consumption. It is interesting to notice that the main contribution to the CO_2 emissions increase is given by a determinant that cannot be directly controlled by policy instruments. Of course it represents a limit to pollution reduction and it makes more complex to find the rightest ways to decrease emissions. This is true especially when considering the priority need to recover from the recent economic crisis and the consequent major attention given by policy makers to GDP growth, rather than the reduction of pollution. The possible solution could be trying to break the link that tie these two variables, by mean of measures aimed at decoupling them. Examples encompass technological progress, innovation and productivity and efficiency improvement.

On the other hand, the relevant factor as for the reduction of carbon emissions appeared to be energy intensity, which began to have a decreasing trend from the mid - 2000, together with the strong introduction of energy efficiency measures. This result proves that the country should focus on further decreasing energy intensity, also by acting on energy efficiency, which could help reducing energy consumption and, consequently, also energy intensity.

The last worth - noting determinant factor that deserves attention is renewable resources penetration. The decomposition analysis presented showed that, despite it increased over last years, their contribution is still very limited. Moreover, Italy should concentrate its efforts also in spreading the usage of these energy sources also in the areas where their application is still narrow. Indeed, it can be notice that the share of renewable energy consumption over primary energy consumption increased in recent years, but this trend is mostly related to their use in the electric sector, while it is still limited in the thermal and transport sectors. Furthermore, the cost associated with the implementation of renewable energy is relatively high, especially when confronted with the results achieved in terms of emissions reduction.

To conclude, this work helped to underline weaknesses and strengths of the Italian carbon emissions situation, by highlighting that the major contributor is a factor that does not depend on policy measures. Additionally, it is clear that the country has to concentrate on enhancing technological development, innovation and energy efficiency. Italy should also continue to focus its attention on the role played by renewable resources, with a special consideration of the way they are promoted and of the trade - off between costs they will required and benefits they will bring

APPENDIX A

	Δ C_{tot}	Δ C_{pop}	Δ C_{ypc}	Δ C_{emc}	Δ C_{ffse}	Δ C_{repe}	Δ C_{int}	Δ C_{rsd}
1971 - 1972	1,0592	1,0057	1,0310	1,0264	0,9965	1,0004	0,9984	0,0000
1972 - 1973	1,0703	1,0068	1,0640	1,0117	0,9975	1,0052	0,9849	0,0000
1973 - 1974	1,0102	1,0066	1,0481	1,0458	1,0072	0,9915	0,9169	0,0000
1974 - 1975	0,9566	1,0060	0,9733	1,1139	0,9983	0,9915	0,8862	0,0000
1975 - 1976	1,0786	1,0050	1,0659	0,9966	0,9969	1,0056	1,0078	0,0000
1976 - 1977	0,9725	1,0043	1,0213	0,9554	0,9993	0,9945	0,9988	0,0000
1977 - 1978	1,0171	1,0036	1,0287	0,9641	1,0003	1,0069	1,0145	0,0000
1978 - 1979	1,0463	1,0029	1,0565	1,0069	1,0042	1,0010	0,9756	0,0000
1979 - 1980	1,0040	1,0021	1,0322	1,1428	1,0040	0,9924	0,8525	0,0000
1980 - 1981	0,9735	1,0013	1,0071	0,9860	1,0041	1,0001	0,9750	0,0000
1981 - 1982	0,9861	1,0006	1,0035	1,0452	1,0020	0,9977	0,9400	0,0000
1982 - 1983	0,9860	1,0004	1,0113	1,0402	0,9948	0,9973	0,9446	0,0000
1983 - 1984	1,0166	1,0002	1,0320	0,9847	0,9943	1,0002	1,0057	0,0000
1984 - 1985	1,0002	1,0003	1,0277	1,0038	1,0010	1,0029	0,9655	0,0000
1985 - 1986	1,0036	1,0001	1,0285	0,9345	0,9946	1,0020	1,0476	0,0000
1986 - 1987	1,0566	1,0001	1,0318	1,0613	0,9945	1,0001	0,9700	0,0000
1987 - 1988	1,0113	1,0005	1,0414	0,9983	0,9944	0,9993	0,9785	0,0000
1988 - 1989	1,0467	1,0008	1,0331	1,0182	0,9952	1,0043	0,9949	0,0000
1989 - 1990	1,0117	1,0008	1,0190	0,9730	0,9993	1,0034	1,0167	0,0000
1990 - 1991	0,9978	1,0010	1,0144	0,9775	0,9946	0,9943	1,0166	0,0000
1991 - 1992	0,9939	1,0004	1,0080	1,0136	0,9963	0,9965	0,9794	0,0000
1992 - 1993	0,9923	1,0006	0,9909	0,9942	0,9955	0,9998	1,0114	0,0000
1993 - 1994	0,9886	1,0002	1,0213	0,9917	1,0035	0,9977	0,9747	0,0000
1994 - 1995	1,0596	1,0000	1,0288	1,0096	0,9977	1,0060	1,0163	0,0000
1995 - 1996	0,9925	1,0003	1,0126	1,0013	0,9956	0,9955	0,9874	0,0000
1996 - 1997	1,0078	1,0005	1,0178	0,9518	1,0003	1,0011	1,0383	0,0000
1997 - 1998	1,0262	1,0003	1,0159	0,9792	0,9987	1,0000	1,0327	0,0000
1998 - 1999	1,0134	1,0002	1,0154	1,0183	0,9964	0,9950	0,9883	0,0000
1999 - 2000	1,0073	1,0005	1,0366	0,9769	1,0004	1,0003	0,9935	0,0000
2000 - 2001	0,9988	1,0007	1,0170	0,9867	1,0014	0,9991	0,9940	0,0000
2001 - 2002	1,0168	1,0021	1,0004	1,0150	1,0014	1,0022	0,9956	0,0000
2002 - 2003	1,0399	1,0055	0,9961	0,9939	0,9997	0,9978	1,0472	0,0000
2003 - 2004	1,0203	1,0075	1,0082	0,9836	1,0034	0,9941	1,0237	0,0000
2004 - 2005	1,0033	1,0060	1,0035	0,9697	0,9976	1,0047	1,0225	0,0000
2005 - 2006	0,9831	1,0041	1,0159	1,0011	1,0008	0,9940	0,9678	0,0000
2006 - 2007	0,9825	1,0061	1,0085	0,9661	0,9992	1,0034	0,9995	0,0000
2007 - 2008	0,9720	1,0077	0,9819	1,0121	1,0015	0,9895	0,9793	0,0000
2008 - 2009	0,8935	1,0057	0,9399	0,9971	0,9923	0,9787	0,9762	0,0000
2009 - 2010	1,0186	1,0042	1,0128	0,9634	1,0033	0,9911	1,0455	0,0000
2010 - 2011	0,9786	1,0038	1,0020	1,0067	1,0092	0,9858	0,9713	0,0000

REFERENCES

Acaravci A. and Ozturk I., 2010. *On the relationship between energy consumption, CO2 emissions and economic growth in Europe*. Energy 35 (12), 5412–5420. Consulted on 13th July 2016

Aliprandi F., Stoppato A. and Mirandola A., 2015. *Estimating CO2 emissions reduction from renewable energy use in Italy*. Renewable Energy 96, 220–232. Consulted on 29th July 2016.

Andreoni V. and Galmarini S., 2012 *Decoupling economic growth from carbon dioxide emissions: A decomposition analysis of Italian energy consumption*. Energy 44 (1):682–691. Consulted on 15th September 2016.

Andreoni V. and Galmarini S., 2016. *Drivers in CO2 emissions variation: A decomposition analysis for 33 world countries*. Energy 103 (15) 27–37. Consulted on 9th September 2016.

Ang B. W. and Zhang F. Q., 2000. *A survey of index decomposition analysis in energy and environmental studies.* Energy 25 (12) 1149–1176, 2000. Consulted on 16th August 2016.

Ang B.W. and Liu F.L., 2001: A new energy decomposition method: perfect in decomposition and consistent in aggregation. Energy 26 (6), 537–548. Consulted on 9th August 2016.

Ang B.W. and Liu F.L., 2007. *Negative-value problems of the logarithmic mean Divisia index decomposition approach.* Energy Policy 35 (1), 739 - 743 Consulted on 31st August 2016.

Ang B.W., Choong W.L., 2015. *Energy security: Definitions, dimensions and indexes.* Renewable and Sustainable Energy Reviews 42, 1077-1093. Consulted on 28th July 2016.

Ang, B.W, Liu F.L. and Chew E.P., 2003: *Perfect decomposition techniques in energy and environmental analysis*, Energy Policy 31, pp. 1561–1566. Consulted on 18th August 2016.

Ang, B.W., 2004: *Decomposition analysis for policymaking in energy: which is the preferred method?* Energy Policy 32, 1131–1139. Consulted on 16th August 2016.

Ang, B.W., 2005. *The LMDI approach to decomposition analysis: a practical guide*. Energy Policy 33, 867–871. Consulted on 18th August 2016.

Annicchiarico B., Bennato A. R. and Zanetti Chiniy E., 2014. *150 Years of Italian CO2 Emissions and Economic Growth*. CEIS Research Series, 320. Consulted on 13th July 2016

Bardazzi R, Pazienza M. and Tonini A., *European energy and climate security*. Springer, 2016. 267-270. Consulted on 27th July 2016.

Camarero M., Picazo - Tadeo A. and Tamarit C., 2012. *Are the determinants of CO2 emissions converging among OECD countries?.* Economics Letters 118 (1), 159–162. Consulted on 9th September 2016.

Castro Camioto F. Fernando Morales H., Barberio Mariano E. and Do Nascimento Rebelatto D. A., 2014. *Energy efficiency analysis of G7 and BRICS considering total-factor structure.* Journal of Cleaner Production 122 (20) 67–77. Consulted on 25th July 2016.

Cerdeira Bento J. P. and Moutinho V., 2015. *CO2 emissions, non-renewable and renewable electricity roduction, economic growth, and international trade in Italy.* Renewable and Sustainable Energy Reviews 55, 142-15. Consulted on 26th September 2016.

Cerdeira Bento J. P., 2014. *The determinants of CO2 emissions: empirical evidence from Italy.* MPRA Paper No. 59166. Consulted on 13th July 2016.

Chiaroni D., Chiesa V., Franzò S., Frattini F. and Toletti G., 2015. *Introducing a new perspective for the economic evaluation of industrial energy efficiency technologies: An empirical analysis in Italy, 2015.* Sustainable Energy Technologies and Assessments 15, 1 – 10. Consulted on 25th July 2016.

Chung H. S. and Rhee H C., 2000 *A residual-free decomposition of the sources of carbon dioxide emissions: a case of the Korean industries,* Energy 26 (1) 15-30. Consulted on 1st September 2016.

Connolly D., Lund H., Mathiesen B.V., 2016. *Smart Energy Europe: The technical and economic impact of one potential100% renewable energy scenario for the European Union.* Renewable and Sustainable Energy Reviews 60, 1634–1653. Consulted on 29th September 2016.

Deloitte, 2015. *European energy market reform – country profile: Italy.* Deloitte, Zurich. Consulted on 14th July 2016

Dogan E. and Seker F., 2016. *Determinants of CO2 emissions in the European Union: The role of renewable and non-renewable energy.* Renewable Energy 94, 429–439. Consulted on 4th October 2016.

ENEA, 2011. *Rapporto annuale efficienza energetica.* ENEA, Rome. pp 16 – 17. Consulted on 21th September 2016.

ENEA, 2011. *Tecnologie di cattura e sequestrazione della CO_2.* ENEA, Rome. Consulted on 19th September 2016.

ENEA, 2015. *Energy Efficiency trends and policies in Italy.* ENEA, Rome. Consulted on 21st July 2016.

ENEA, 2015. *Rapporto annuale efficienza energetica*. ENEA, Rome. Consulted on 20th September 2016.

European Commission, 2013. *Member States' Energy Dependence: An Indicator-Based Assessment, 2013.* Occasional Papers n 145, pp 137 – 147. Consulted on 31st July 2016.

Granel F., 2003. *A Comparative Analysis of Index Decomposition Methods.* Energy Economics 25(1) 39-69. Consulted on 9th August 2016.

Greenpeace, *Le ricadute economiche delle energie rinnovabili in Italia – Analysis by Althesys Strategic Consultant, 2014.* Greenpeace, Milano. Consulted on 11th October 2016.

GSE, 2015. *Rapporto statistico – energia da fonti rinnovabili 2014*. GSE, Rome. pp 3 – 33. Consulted on 31st July 2016.

GSE, 2016. *Energia da fonti rinnovabili in Italia Dati preliminari 2015.* GSE, Rome. Consulted on 30th July 2016.

Hoffrén J., Luukkanen J. and Kaivo-Oja J., 2000. *Statistical Decomposition Modelling on the-Basis of Material Flow Accounting.* Journal of Industrial Ecology. Consulted on 1st September 2016.

Hogan P. et al., 2012. *Tracking Emissions and Mitigation Actions: Current Practice in China, Germany, Italy, and the United States.* CPI Working Paper, 35-46. Consulted on 19th July 2016.

IPCC, 2000. *Emission Scenarios – Special Report, 2000.* Cambridge University Press, Cambridge. Chapter 3, section 1. Consulted on 1st September 2016.

IPCC, 2012. *Special Report on Renewable Energy Sources and Climate Change Mitigation* Cambridge University Press, Cambridge. 3 – 27. Consulted on 29th July 2016.

IRENA, 2012. *30 years of Policies for wind energy. IRENA,* Abu Dhabi, 101 – 107. Consulted on 4th October 2016.

ISPRA, *2013 Italy Climate Policy Progress Report*, 2013. ISPRA, Roma. Consulted on 21st July 2016

Jorgenson D.W. and Griliches Z., 1971. *Divisia index numbers and productivity measures,* Review of income and wealth 17 (2), 227 – 229. Consulted on 25th August 2016.

Karmellos M., D. Kopidou and D. Diakoulaki., 2015. *A decomposition analysis of the driving factors of CO2 (Carbon dioxide) emissions from the power sector in the European Union countries.* Energy 96 (1), 680 – 692. Consulted on 9th September 2016.

Kaya Y. and Yokobori K., 1997. *Environment, energy, and economy: Strategies for sustainability.* United Nations University Press, Tokio, Chapter 13. Consulted on 1st September 2016

Kaya Y., Yamaji K. and Akimoto K., *Climate Change and Energy: Japanese Perspectives on Climate Change Mitigation Strategy, 2015,* ICP Series on Climate Change Impacts, Adaptation, and Mitigation, Japan. Chapter 1. Consulted on 1st September 2016.

Klessmann C. et al., 2013. *Policy options for reducing the costs of reaching the European renewables target*. Renewable Energy 57, 390 – 403. Consulted on 11th October 2016.

Kopidou D., A. Tsakanikas and D. Diakoulaki, 2015. *Common trends and drivers of CO2 emissions and employment: a decomposition analysis in the industrial sector of selected European Union countries.* Journal of Cleaner Production 112. Consulted on 9th September 2016.

KPMG, 2011. *Investing in renewables – trends, opportunities and prospects*. KPMG Advisory, Milan. Consulted on 28th September 2016.

Lester R. K. and Finan A., 2009. *Quantifying the Impact of Proposed Carbon Emission Reductions on the U.S. Energy Infrastructure*. IPC Working Papers 6, *1 – 5*. Consulted on 1st September 2016.

Ma C. and Stern D., 2008: *Biomass and China's carbon emissions: A missing piece of carbon decomposition*. Energy Policy 36 (7), 2517-2526. Consulted on 2nd May 2016

Marinella D., Favero A., Galluccio G. and Rogate C., *Strategies and Research Towards LCS in Italy, 2010. CMCC Research Paper No. 102.* Consulted on 19th July 2016.

Marrero G. and Ramos-Real F., 2013. *Activity Sectors and Energy Intensity: Decomposition Analysis and Policy Implications for European Countries (1991–2005)*. Energies 6, 2521-2540. Consulted on 2nd May 2016

Mercan M. and Karakaya E., 2015. *Energy Consumption, Economic Growth and Carbon Emission: Dynamic Panel Cointegration Analysis for Selected OECD Countries.* Procedia Economics and Finance 23, 587 – 592. Consulted on 13th July 2016

Ministero dello sviluppo economico, 2016. *Rapporto Annuale 2016.* Direzione Generale per la Sicurezza anche ambientale delle attività minerarie ed energetiche - Ufficio Nazionale Minerario per gli Idrocarburi e le Geo risorse (DGS UNMIG), pp. 99 – 121. Consulted on 28th July 2016.

Ministry for the Environment, Land and Sea, 2006 *Italian Report On Demonstrable Progress Under Article 3.2 Of The Kyoto Protocol.* Ministry for the Environment, Land and Sea, Rome. Consulted on 19th July 2016

Ministry for the Environment, Land and Sea, 2013. *Sixth National Communication under the UN Framework Convention on Climate Change Italy.* Ministry for the Environment, Land and Sea, Rome. Consulted on 19th July 2016. Consulted on 19th July 2016

Ministry of Economic Development, 2013. *National Energy Strategy*. Ministry of Economic Development, Rome. 32 – 85. Consulted on 20th July 2016

Ministry of economic development, 2014. *Italian Energy Efficiency Action Plan, 2014*. Ministry of economic development, Rome. 10 – 32. Consulted on 31st July 2016.

Ministry of Economic Development, 2015. *La situazione energetica nazionale nel 2014.* Ministry of Economic Development, Rome. Consulted on 27th July 2016.

Ministry of Economic Development, 2015. National Energy Balance 2014. Ministry of Economic Development, Rome. Consulted on 27th July 2016

Ministry of Economic Development, 2016. *La situazione energetica nazionale nel 2015.* Ministry of Economic Development, Rome. Consulted on 27th July 2016.

Moriarty P. and Honnery D., 2016. *Can renewable energy power the future?.* Energy Policy 94, 3 – 7. Consulted on 29th September 2016.

Nachmany M. et al., *Climate Change Legislation in Italy - An Excerpt from the 2015 Global Climate Legislation Study, 2015.* Consulted on 19th July 2016

OECD/IEA, 2011. *Co – generation and renewables. Solutions for a low carbon energy future.* Internatinal Energy Agengy, Paris. Consulted on 28th September 2016.

OECD/IEA, 2013. *Environmental performance review – Italy*. OCSE, Paris. 89 – 93. Consulted on 19th September 2016.

OECD/IEA, 2013. *Rapporti dell'OCSE sulle performance ambientali – Italia*. OCSE, Paris. Consulted on 4th October 2016.

OECD/IEA, 2015. *CO2 Emissions from Fuel Combustion Highlights*. OECD/IEA, Paris. Consulted on 9th September 2016.

OECD/IEA, 2015. W*orld* CO_2 *emissions from fuel combustion: Database documentation.* OECDI/IEA, Paris. Consulted on 9th September 2016.

OECD/IEA, *World energy balance 1960 – 2015. OECD, Paris* Consulted on 9th September 2016.

PwC, 2015. *Low Carbon Economy Index 2015.* Consulted on 20th September 2016.

Qualiano A., 2007. *Geopolitical Constraints of the Italian Security of Energy Supply.* International Association for Energy Economics. Consulted on 28th July 2016.

Raupach R. M. et al., *2007. Global and regional drivers of accelerating CO2 emissions.* PNAS, Cambridge. Consulted on 1st September 2016.

Rosa A. E. and Dietz T., 2012. *Human drivers of national greenhouse-gas emissions.* Nature Climate Change 2, 581–586. Consulted on 1st September 2016.

Sofia Teives Henriques and Karol J. Borowiecki, 2014. *The Drivers of Long-run CO2 Emissions: A Global Perspective since 1800,* 2014. Discussion Papers on Business and Economics, University of Southern Denmark. Consulted on 2nd May 2016

Sustainable Development Foundation, 2014. *Dossier Clima 2014 – Verso i nuovi impegni di riduzione della* CO_2 *per l'Italia*. Sustainable Development Foundation, Rome. Consulted on 18th July 2016

T. O'Mahony, *Decomposition of Ireland's carbon emissions from 1990 to 2010: an extended Kaya identity*, Energy Policy, vol. 59, . 573–581, 2013.Consulted on 12th April 2016.

Tapio, P., Banister, D., Luukkanen, J., Vehmas, J. and Willamo, R. 2007: Energy and transport in comparison: Immaterialisation, dematerialisation and decarbonisation in the EU15 between 1970 and 2000, Energy Policy 35, 433-451.Consulted on 26th September 2016.

UNFCC, 2013. *Italian report on demonstrable progress under article 3.2 of the Kyoto Protocol*, UNFCC, Bonn. Consulted on 20th July 2016

Wang, C., Chen, J. and Zou, J., 2005: Decomposition of energy-related CO2 emission in China: 1957–2000, Energy 30 (1), 73-83. Consulted on 27th July 2016.

Wei Li and Qing-Xiang Ou, 2013. *Decomposition of China's Carbon Emissions Intensity from 1995 to 2010: An Extended Kaya Identity*. Mathematical Problems in Engineering Volume 2013. Consulted on 2nd May 2016

Winzer C., 2012. *Conceptualizing energy security. Energy Policy 46, 36 – 48.* Consulted on 28th July 2016.

Zhang, F.Q. and Ang, B.W., 2001: *Methodological issues in cross-country/region decomposition of energy and environment indicators*, Energy Economics 23 (2), 179–190.Consulted on 29th August 2016.

WEBSITES

Agenzia delle dogane e dei monopoli, https://www.agenziadoganemonopoli.gov.it/portale/, Consulted on 19th September 2016.

Avvenia, *Efficienza Energetica: primo combustibile del mondo, 2016.* http://www.avvenia.com/efficienzaenergeticaprimocombustibiledelmondo/. Consulted on 25th July 2016.

EEA, Energy intensity, 2013. http://www.eea.europa.eu/data-and-maps/indicators/total-primary-energy-intensity-1/assessment. Consulted on 20th September 2016.

EEA, Energy intensity, 2015. http://www.eea.europa.eu/data-and-maps/indicators/total-primary-energy-intensity-2/assessment. Consulted on 20th September 2016.

EEA, Renewables successfully driving down emissions in Europe, 2015. Last update 21st June 2016. *http://www.eea.europa.eu/highlights/renewables-successfully-driving-down-carbon.*Consulted on 29th July 2016.

ENEA, 2012. *Economic analysis of energy efficiency programs in Italy. http://www.enea.it/it/pubblicazioni/EAI/anno-2012/n.-2-marzo-aprile-2012/economic-analysis-of-energy-efficiency-programs-in-italy.* Consulted on 21st July 2016.

ENEA, Intensità energetica, http://www.enea.it/. Consulted on 20th September 2016.

European Commission, 2013. *The EU Emissions Trading System (EU ETS).* https://ec.europa.eu/clima/policies/ets/index_en.htm. Consulted on 20th July 2016.

European Commission, *2020 climate & energy package. http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm*. Consulted on 20th July 2016.

European Commission, Energy unit conversion calculator, https://ec.europa.eu/energy/intelligent/projects. Consulted on 13th September 2016.

European Commission, The EU Emissions Trading System (EU ETS), http://ec.europa.eu/clima/policies/ets/index_en.htm. Consulted on 6th September 2016.

European Commissions, *2030 climate & energy framework, http://ec.europa.eu/clima/policies/strategies/2030/index_en.htm.* Consulted on 20th July 2016.

Eurostat, Primary energy consumption, http://ec.europa.eu/eurostat/statistics-explained/index.php/Consumption_of_energy#Consumption. Consulted on 29th July 2016

Eurostat, http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_production_and_imports. Consulted on 1st August.

GSE, *White Certificates, http://www.gse.it/en/White%20Certificates/Pages/default.aspx*. Consulted on 20th July 2016.

IEA, Balance Definitions, https://www.iea.org/statistics/resources/balancedefinitions/#tpes. Consulted on 4th September 2016.

IEA, *Decoupling of global emissions and economic growth confirmed, 2016. https://www.iea.org/newsroomandevents/pressreleases/2016/march/decoupling-of-global-emissions-and-economic-growth-confirmed.html.* Consulted on 15th September 2016.

IEA, Policies and Measures, http://www.iea.org/policiesandmeasures/pams/italy/name-21684-en.php. Consulted on 2nd September 2016.

Istat, Energy Balance, http://dati.istat.it/Index.aspx?DataSetCode=DCCV_BILENERG&Lang=en. Consulted on 25th July 2016

Millenium Ecosistyem Assessment, http://www.millenniumassessment.org/en/index.html, Consulted on 28th September 2016.

ODYSEE – MURE, http://www.odyssee-mure.eu/. Consulted on 26th July 2016

UNFCC, Kyoto Protocol, http://unfccc.int/kyoto_protocol/items/2830.php, 2014. Consulted on 26th July 2016