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RESIDENTIAL ELECTRICITY DEMAND IN THE EUROPEAN UNION: THE ROLE OF BIOECONOMY

By

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ΔΠΜΣ ΣΤΗ ΒΙΟΟΙΚΟΝΟΜΙΑ

ΟΙΚΙΑΚΗ ΖΗΤΗΣΗ ΗΛΕΚΤΡΙΚΗΣ ΕΝΕΡΓΕΙΑΣ ΣΤΗΝ ΕΥΡΩΠΑΪΚΗ ΕΝΩΣΗ: Ο ΡΟΛΟΣ ΤΗΣ ΒΙΟΟΙΚΟΝΟΜΙΑΣ

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To my mother, for whom words are not enough.

To my father, who is always here.

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Planning and writing a dissertation about a matter that is important to society, the state, and academia is an important and challenging task. The researchers shall be able to do theoretical research, collect and, subsequently, analyze the available data in such a manner that they draw conclusions and contribute to the academic discussion concerning the subject they study.

Therefore, I would like to thank my supervisor Assistant Professor Michael Polemis for helping me focus on an up-to-date subject based on my previous academic experience and interests and, later, guiding me through the process of writing this dissertation.

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RESIDENTIAL ELECTRICITY DEMAND IN THE EUROPEAN UNION: THE ROLE OF BIOECONOMY

Keywords: bioeconomy, climate change, energy (electricity) consumption, energy efficiency, residential electricity demand, policy measures.

Abstract

Following the Kyoto Protocol, the 28 countries that are part of the European Union, among them Greece, are implementing a wide range of policy measures to tackle climate change and limit their greenhouse gas emissions. To achieve these, European countries must decrease their electricity consumption and make their buildings more energy-efficient. This thesis aims to investigate which factors affect residential electricity consumption and in which way. This could enable policymakers to design policy measures in a more energy-efficient and less carbon-intensive way in the bioeconomy framework. To find this out, a theoretical and empirical analysis of residential electricity demand in the EU has been carried out. Subsequently, the conclusions of this investigation are presented, and policy measures are suggested, to contribute to the overall discussion about electricity demand, energy efficiency, and climate change.

ΟΙΚΙΑΚΗ ΖΗΤΗΣΗ ΗΛΕΚΤΡΙΚΗΣ ΕΝΕΡΓΕΙΑΣ ΣΤΗΝ ΕΥΡΩΠΑΪΚΗ ΕΝΩΣΗ: Ο ΡΟΛΟΣ ΤΗΣ ΒΙΟΟΙΚΟΝΟΜΙΑΣ

Σημαντικοί Όροι: βιοοικονομία, κλιματική αλλαγή, κατανάλωση (ηλεκτρικής) ενέργειας, ενεργειακή αποδοτικότητα, οικιακή ζήτηση ηλεκτρικής ενέργειας, μέτρα πολιτικής.

Περίληψη

Έπειτα από τη Συνδιάσκεψη του Κιότο, τα 28 κράτη – μέλη της Ευρωπαϊκής Ένωσης, ανάμεσα σ’ αυτά και η Ελλάδα, εφαρμόζουν μια σειρά από μέτρα πολιτικής για να καταπολεμήσουν την κλιματική αλλαγή και να μειώσουν τις εκπομπές των αερίων του θερμοκηπίου. Για να τα καταφέρουν αυτά, οι ευρωπαϊκές χώρες πρέπει να μειώσουν την κατανάλωση της ηλεκτρικής ενέργειας και να κάνουν τα κτίριά τους περισσότερο ενεργειακά αποδοτικά. Ο στόχος αυτής της διπλωματικής εργασίας είναι να διερευνήσει ποιοι είναι οι κύριοι παράγοντες που σχετίζονται με την κατανάλωση ηλεκτρικής ενέργειας στον οικιακό τομέα. Έτσι, οι υπεύθυνοι θα μπορούν να χαράξουν πολιτικές οι οποίες να συμβάλλουν στη βελτίωση της ενεργειακής αποδοτικότητας και τη μείωση των εκπομπών των αερίων του θερμοκηπίου στα πλαίσια της βιοοικονομίας. Για τον σκοπό αυτό διεξήχθη μια βιβλιογραφική και εμπειρική ανάλυση όσον αφορά την κατανάλωση της ηλεκτρικής ενέργειας στον οικιακό τομέα στην Ευρωπαϊκή Ένωση. Στη συνέχεια, παρουσιάζονται τα αποτελέσματα αυτής της διερεύνησης και προτείνονται μέτρα πολιτικής, ως συνεισφορά στο διάλογο σχετικά με τη ζήτηση της ηλεκτρικής ενέργειας, την ενεργειακή αποδοτικότητα και την κλιματική αλλαγή.

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CHAPTER 1: INTRODUCTION

1.1 Energy and Climate Policy

It is an undeniable fact that energy consumption and greenhouse gases (GHG) emissions affect climate change and global warming. Therefore, climate change has become one of the most pressing issues of our time and plays a crucial role in the European Union's (EU) environmental policy. Reductions in energy consumption and CO_2 emissions are of crucial importance to preserve the planet for future generations. To mitigate climate change and reduce energy consumption, the EU has established a policy framework and binding targets for its Member States since its early days.

Following the Kyoto Protocol (1992), in December 2015, 195 countries all over the world, including Greece, adopted and then ratified the first universal, legally binding global agreement known as the Paris Agreement, which is the result of the United Nations Framework Convention on Climate Change (UNFCCC). The agreement sets out a global action plan to avoid dangerous climate change by limiting global warming to below 2^oC compared to pre-industrial levels and trying to limit it to 1.5^oC. Under this scope, governments agreed:

- on a long-term goal of keeping the increase in global average temperature to well below 2°C above pre-industrial levels,
- to aim to limit the increase of temperature to 1.5°C, since this would significantly reduce risks and the impacts of climate change,
- on the need for global emissions to peak as soon as possible, recognizing that this will take longer for developing countries. EU has set a target of reducing GHG emissions by at least 40% by 2030 compared to 1990 levels (IEA, 2016),
- to undertake rapid reductions thereafter following the best available science (European Commission).

EU has set targets for reducing its GHG emissions up to 2050 to achieve the transition to a low – carbon economy.

Europe 2020 is the EU’s agenda for jobs and growth for the current decade. It highlights the importance of smart, sustainable and inclusive growth as a way to strengthen the EU economy and prepare its structure for the challenges to appear in the next ten years. The main priorities of the agenda, which can make Europe a smarter, more sustainable, and more inclusive place to live are:

- smart growth, by developing an economy based on knowledge, research, and innovation,
- sustainable growth, by promoting resource-efficient, green and competitive markets,
- inclusive growth, through policies aimed at creating jobs and reducing poverty.

in the 28 Member States while reducing the impact on the natural environment (Eurostat, 2019).

EU’s climate and energy package for 2020 is one key priority of Europe 2020 and aims at making European countries more energy – efficient while reducing their GHG emissions, without harming their economic development based on the notion that more economic growth does not always lead to increased emissions (Bento and Moutinho, 2016). These goals must be achieved through:

- a 20% cut in GHG emissions compared to 1990,
- a 20% increase of the renewable energy, i.e. energy produced from renewable sources,
- a 20% improvement in energy efficiency.

Following this, the European Commission (EC) adopted in 2015 the 2030 Agenda for Sustainable Development to lead the global energy transition, putting the EU on the right path towards a sustainable future. The Agenda consists of a declaration, a set of 17 Sustainable Goals (SDGs) that are presented in Figure 1.1, and 169 targets (Eurostat, 2019). Therefore, the EU addressed in 2016 a revised package for 2030 called “Clean Energy Package for all Europeans”, which is comprised primarily of the elements described below:

- at least 40% cuts in GHG emissions compared to 1990 levels,
- at least 32% share for renewable energy, with specific provisions to foster public and private investment for the EU to maintain its global leadership on renewables, with a clause for a possible upward revision by 2023 (under the scope of the revised Renewable Energy Directive 2018/2001/EU),
- at least 32.5% improvement in energy efficiency, with a new Energy Performance of Buildings Directive (EPBD) which maximizes the energy-saving potential of smarter and greener buildings,
- the obligation for each Member State to draft National Energy and Climate Plans (NCEPs) for 2021 – 2030 describing how they will achieve their energy targets, and in particular the targets for 2030 on energy efficiency and renewable energy.

Also, the new rules, which must be in force by mid – 2019 and transposed into national laws within 1 – 2 years, make production, storage or selling of individuals' energy easier and reinforce consumer rights with more transparency on bills and greater choice flexibility, while increasing security of supply by helping integrate renewables into the grid and manage risks, and by improving cooperation among countries (European Commission, 2019; HAEE, 2019).

Source: Eurostat, 2019

Figure 1.1. The 17 Sustainable Development Goals

Greece, a Member State of the EU, developed its policy framework, under the scope of the Renewable Energy Directive (2009/28/EC), aiming at promoting renewable energy sources (RES) and diversifying the national energy mix, while reducing its CO_2 emissions. The package for 2020 sets the following national targets:

- a 20% cut in GHG emissions compared to 1990 levels,
- an EU Emissions Trading System (EU – ETS[1]) and a national target under the EU Effort Sharing Decision[2] to reduce GHG emissions outside the EU – ETS by 4% by 2020,
- an energy efficiency target of 24.7 million tonnes of oil equivalent (Mtoe) in primary energy consumption or 18.4 Mtoe of final energy consumption. At the same time, the intensity of primary energy consumption and final energy consumption in the Greek economy will be equal to 0.109 and 0.081 ktoe/€ respectively (CRES).
- a 20% renewable energy share in gross final energy consumption, beyond the 18% target set by the EU. This will be achieved through a variety of measures for energy efficiency as well as for enhanced penetration of RES technologies in electricity production, heat supply, and transport (IEA, 2017).

To achieve the last target, L. 3851/2010 ("Acceleration of the development of Renewable Energy Sources for tackling climate change and other provisions in matters of competence of the Ministry of Environment, Energy & Climate Change", Official Journal of the Hellenic Republic No 85, Issue A, 04/06/2010) sets the following specific targets:

- at least 40% of electricity demand must be met by renewable electricity, i.e. electricity generated from RES,
- at least 20% of heating and cooling must be met by renewables,

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[1] EU – ETS is the world's first international emissions trading system and works on the "cap and trade" system aiming at reducing GHG gases cost – effectively (European Commission). The EU – ETS covered sectors, i.e. all electricity producing plants with an installed capacity of more than 20 MW and a large share of the energy intensive industries, are obliged to reduce their emissions by 21% until 2020 compared to 2005 (Thema et al., 2013).

[2] The Effort Sharing Decision is part of the EU's climate and energy policy framework for 2020 and sets binding emissions targets for 2020 at national level, expressed as percentage changes from 2005 levels, according to each country's relative wealth. These targets concern emissions from sectors not included in the EU ETS, e.g. buildings and transport (EC).

- at least 10% of energy demand for transportation must be met by RES.

Several existing initiatives concerning long – term climate strategies (LTCS) are trying to make climate change a topic of immediate interest to European policymakers; from Article 4.19 of the Paris Agreement, which calls for the development of long – term low GHG emissions development strategies by all stakeholders, to Article 15 of the proposed EU regulation on the “Governance of the Energy Union and Climate Action” (EU/2018/1999), which requires that Member States develop by January 1st, 2020 long – term energy strategies of their own for 2050 and beyond. The strategies should contribute to the achievement of the net-zero emissions in the EU as early as possible, reaching eventually net – negative emissions. To support these processes, a project called “Climate Reckon 2050” has created a platform for dialogue among experts from the government and various research institutes. The goal of this platform is to exchange experiences among countries and identify common challenges and good practices to support effective national planning towards 2050.

Until 2019, almost half of the EU Member States are reported to have already developed national long – term climate strategies within the past ten years. Some countries are already revising their existing strategies to be updated in 2020 Taking into consideration the Paris Agreement’s objectives. For 2050, the EU aims at reducing its GHG emissions by 80 – 95% compared with 1990 levels and is currently discussing to strengthen this target and establish the ultimate target of net-zero emissions (Eurostat, 2019). The exiting strategies differ in terms of ambition, scope, design, stakeholders’ engagement, political ownership, and legal form; a fact which, according to a European Environment Agency’s (EEA) analysis, shows a lack of robust climate action in the EU (climate dialogue, 2019).

In this direction, the Greek Ministry of Environment & Energy presented in April 2012 a National Energy Plan: Roadmap to 2050 for Greece, which was developed by the National Committee for Energy Planning, established by L. 3438/2006 (“Composition of the National Energy Strategy Council – Arranging of matters of the Ministry of Development”, Official Journal of the Hellenic Republic 33, Issue A, 14/02/2006). According to the 2050 roadmap, the “Existing Policies” scenario (EP Scenario) will not result in the required reduction of CO_2 emissions by 2050 in the energy sector. The EP Scenario assumes a conservative policy implementation concerning both energy and the environment. It foresees a medium reduction of GHG emissions until 2050 by at least 40% compared to 2005 levels and a medium level of RES technology penetration and energy savings. The roadmap takes into consideration two alternative energy policy scenarios: (a) a scenario for maximizing RES measures (“RES Maximization Measures”) and (b) a scenario for minimizing the cost of environmental measures, whereas next to maximizing emission goals, the renewable energy deployment cost is also considered (“Minimum Cost Environmental Measures”). Based on these two scenarios, the roadmap sets out the following vision for the future Greek energy system:

- reduction of GHG emissions by 60% - 70% compared to 2005 levels by 2050,
- electricity production by 85% - 100% from RES using all commercially available and mature technologies,
- development of a 60% - 70% penetration of RES in gross final energy consumption,
- energy-saving measures which will lead to stabilization of energy consumption levels,
- the relative increase of the electricity consumption due to electrification of transport and greater use of heat pumps in the residential and tertiary sectors,
- reduction of oil consumption,
- increase of the biofuels’ use in the transportation sector by 31% - 34%,
- the dominant use of electricity in short-distance passenger transport and an increase in the share of public transport,
- more energy-efficient buildings and an increase of RES in them,
- development of decentralized production units and smart grids (IEA, 2017; WWF, 2017).

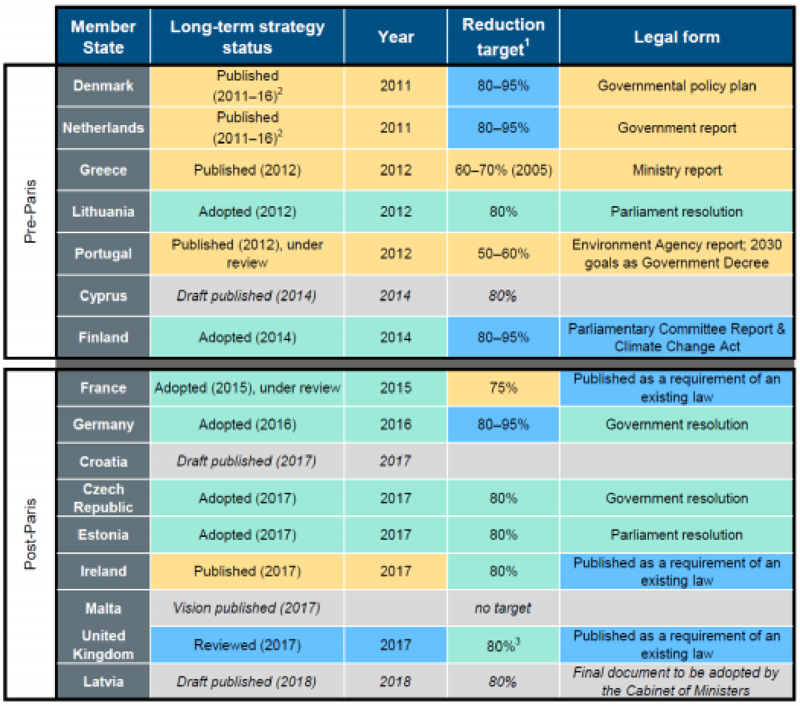
Other countries that have published or adopted LTCS, either before or after the Paris Agreement, according to Figure 1.2, include Denmark, Netherlands, Finland, Germany, and Ireland (climate dialogue, 2019).

Due to these climate and energy policies GHG emissions in 2017 were decreased by 21.7% compared to 1990 levels (Figure 1.3). A significant share of this reduction was reported between 1990 and 1994 (6.7%), mostly due to structural shifts in the economy, modernization of the industrial sector, and a shift from coal to gas. Between 1998 and

2007 emissions were reported to be fairly stable at around 92 – 94% of 1990 projections, despite increasing electricity consumption. The sharpest single-year decline in GHG emissions was reported in the period 2008 – 2009, due to the economic crisis. This crisis resulted in reduced industrial production, transport volumes, and energy demand. The further decline which was reported during the period 2010 – 2014 can be attributed to the rapid development of RES, the energy intensity in the EU economy and the aftermath of the economic crisis. Between 2005 and 2017, Luxembourg showed the highest share of GHG per capita emissions, followed by Ireland, Greece, Denmark, Belgium, and the United Kingdom. In contrast, five Member States (Latvia, Estonia, Lithuania, Bulgaria, and Poland) increased their emissions in the same period.

However, these strategies don’t just mitigate climate change; they also promote sustainable growth, which is one of Europe’s 2020 main objectives. For example, the deployment of RES and the promotion of energy efficiency contribute to the development of research and innovation and the creation of (green) jobs. The EU’s “20 – 20 – 20” targets are interlinked with other European goals for 2020, especially those concerning research and development (R&D) and employment. Furthermore, climate mitigation has additional environmental and health benefits, for example reducing air pollution at the local level and minimizing a series of health risks (Eurostat, 2019).

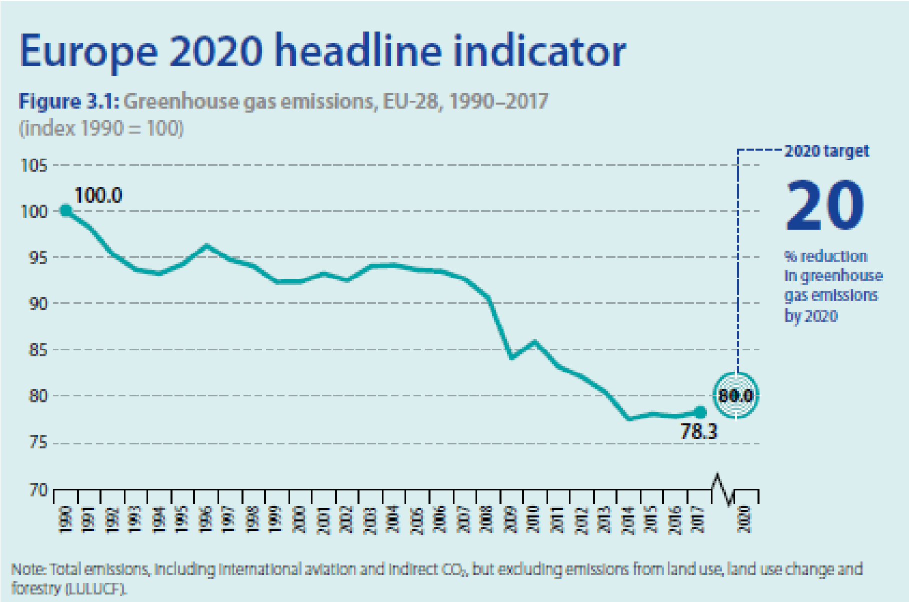
Both European and Greek legislation focus on electricity since electricity consumption plays a significant role in adapting to climate change in terms of adjusting to heating and cooling needs due to temperature changes. It is also important in mitigation planning since electricity is responsible for more GHG emissions than any other sector in Europe (Damm, Koberl et al., 2017).



	Member State	Long-term strategy status	Year	Reduction target^1	Legal form
Pre-Paris	Denmark	Published (2011–16)^2	2011	80–95%	Governmental policy plan
	Netherlands	Published (2011–16)^2	2011	80–95%	Government report
	Greece	Published (2012)	2012	60–70% (2005)	Ministry report
	Lithuania	Adopted (2012)	2012	80%	Parliament resolution
	Portugal	Published (2012), under review	2012	50–60%	Environment Agency report; 2030 goals as Government Decree
	Cyprus	*Draft published (2014)*	*2014*	*80%*	
	Finland	Adopted (2014)	2014	80–95%	Parliamentary Committee Report & Climate Change Act
Post-Paris	France	Adopted (2015), under review	2015	75%	Published as a requirement of an existing law
	Germany	Adopted (2016)	2016	80–95%	Government resolution
	Croatia	*Draft published (2017)*	*2017*		
	Czech Republic	Adopted (2017)	2017	80%	Government resolution
	Estonia	Adopted (2017)	2017	80%	Parliament resolution
	Ireland	Published (2017)	2017	80%	Published as a requirement of an existing law
	Malta	*Vision published (2017)*		*no target*	
	United Kingdom	Reviewed (2017)	2017	80%^{3}	Published as a requirement of an existing law
	Latvia	*Draft published (2018)*	*2018*	*80%*	*Final document to be adopted by the Cabinet of Ministers*

Source: https://climatedialogue.eu/

Figure 1.2. List of EU Member States' existing long - term climate strategies



Source: EEA; Eurostat, 2019

Figure 1.3. GHG emissions in the EU during the period 1990 – 2017

Compared to other environmental policies, policies that support renewable energy (REPs) support several targets other than pollution reduction, such as energy security, technological change, and energy efficiency, since REPs are often combined with measures that promote energy efficiency. In particular, a long-term and uncertain objective of REPs is energy security. This objective is considered uncertain since renewables are difficult to store and require backup capacity from fossil fuel plants. According to available literature, a suitable policy mix that combines policies to reduce pollution (e.g. emission trading schemes) with policies for learning (e.g. renewable energy production subsidies) and innovation (e.g. R&D subsidies) stimulates the search for new technological solutions rather than mere compliance with existing standards. Small local producers, environmental non – governmental organizations (NGOs), and potential entrants in the field of renewable energy technologies are most likely to support such policies (Nicolli and Vona, 2019).

1.2 Bioeconomy and climate change

According to the European Commission (EC, 2012), bioeconomy is “the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, bio-based products and bioenergy. Its sectors and industries have strong innovation potential due to their use of a wide range of sciences, enabling and industrial technologies, along with local and tacit knowledge”. Climate change and the increasing depletion of fossil fuels require an economy based on renewable energy sources. Therefore, a sustainable European bioeconomy is considered to be essential to build a future that is carbon neutral, in line with the objectives of the Paris Agreement.

Its main objective is to pave "the way to a more innovative, resource-efficient and competitive society that reconciles food security with the sustainable use of renewable resources for industrial purposes, while ensuring environmental protection". (EC, 2012). The concept of bioeconomy consists of 5 main targets:

- Ensuring food and nutrition security,
- Sustainable management of natural resources,

- Reducing dependence on non – renewable, unsustainable resources whether sourced locally or from aboard,
- Mitigation and adaptation to climate change,
- Strengthening of European competitiveness and job creation.

The third objective, i.e. to become less dependent on non – renewable, unsustainable resources whether sourced domestically or from aboard, is of crucial importance to deliver the EU’s energy and climate targets. Bioenergy (and, therefore, biomass), which is an important RES in the EU, is expected to remain a key component of the European energy mix in 2030 and contribute to the achievement of the EU’s 2020 and 2030 renewable energy targets.

Another objective of bioeconomy is the mitigation and adaptation to climate change, and a sustainable and circular bioeconomy is key for a GHG neutral Europe. A sustainable bioeconomy can reduce GHG emissions by promoting more resource-efficient and sustainable primary production practices, as well as by enhancing the ecosystems’ capacity to regulate climate (EC, 2018).

1.3 Renewable energy deployment

As mentioned before, under the initial Renewable Energy Directive (2009/28/EC), which promotes energy produced from RES, EU Member States have taken on binding targets at the national level for increasing the share of renewables in their energy mix by 2020. Overall, the EU is obliged to ensure that:

- renewable energy reaches a 20% share of gross final energy consumption[3] by 2020,
- at least 10% of its Member States’ fuels in the transport sector come from RES by 2020 (EC).

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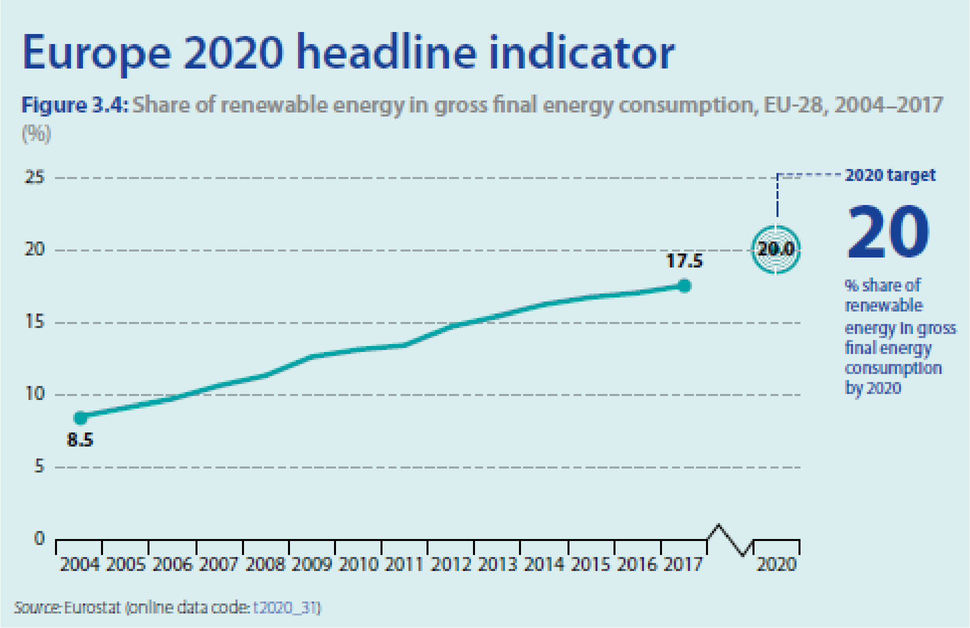
[3] Gross final consumption, according to Article 2F of Directive 2009/28/EC, refers to the energy commodities delivered for energy purposes to all end users (households, industry, transport, public services, agriculture, forestry and fisheries), including the electricity and heat consumption for electricity and heat production, and including electricity and heat losses in distribution and transmission (EEA, 2018).

Greece developed its policy framework under Directive 2009/28/EC, which set out a binding national target of 18% of renewable energy sources in gross final energy consumption for 2020. Greece raised its ambitions to a 20% overall share for 2020 and set the following targets, under Law 3851/2010 and the National Renewable Energy Action Plan (NREAP):

- electricity: at least 40% of electricity demand met by electricity generated from renewable energy sources,
- heating and cooling: at least 20% of heat consumption met by renewables,
- transportation: at least 10% of energy demand met by renewable sources (Ministry of Environment & Energy, 2010).

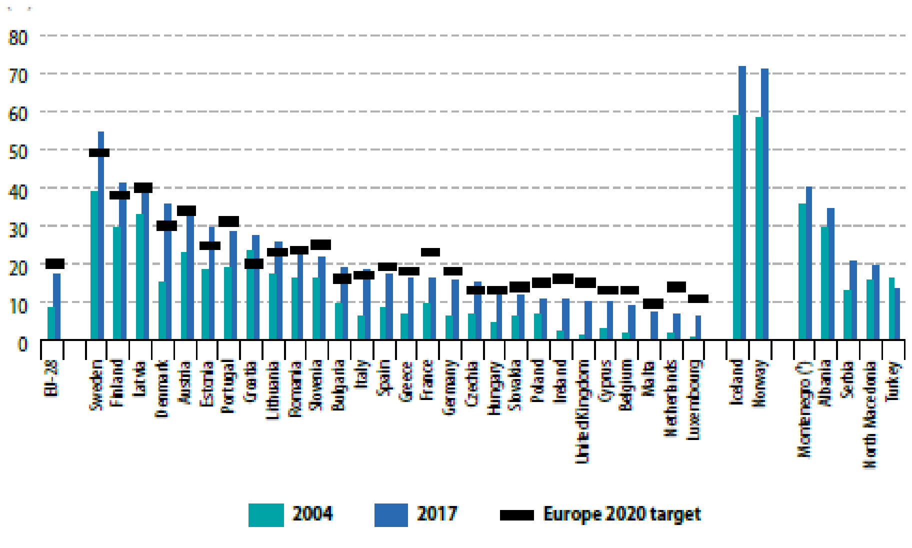
The share of renewable energy in the EU more than doubled during the period 2004 – 2017, reaching 17.5% of gross final energy consumption in 2017 (Figure 1.4). This increase can be attributed to technological development, the implemented support schemes for renewable energy technology, and the decreasing costs of renewable energy systems.



Source: Eurostat, 2019

Figure 1.4. Share of renewable energy in gross final energy consumption in the EU during the period 2004 – 2017

The share of renewable energy increased between 2004 – 2017 in all 28 countries (Figure 1.5), showing differentiation that reflect variations in natural resources' availability and energy - climate policies. Overall, the EU is right on track to reach its renewable energy target for 2020, but the pace of increase of the renewable energy share has decelerated since 2014 (Eurostat, 2019).



(¹) 2005 data (instead of 2004).

Source: Eurostat, 2019

Figure 1.5. Share of renewable energy in gross final consumption by country in 2004 and 2017

Specifically, Greece has large renewable energy resources, and the share of renewables has grown in wind and solar photovoltaics (PVs) in the last years (Figure 1.6) due to favorable feed-in-tariffs (FiTs)[4], notable progress of technology and continuously decreasing technology costs (IEA, 2017; Roberts et al., 2019). Also, Greece is developing competitive auctions for these renewables and market-based premiums to avoid large cost overruns, as the country transitions to a new support program, the feed-in premium (FiP)[5]

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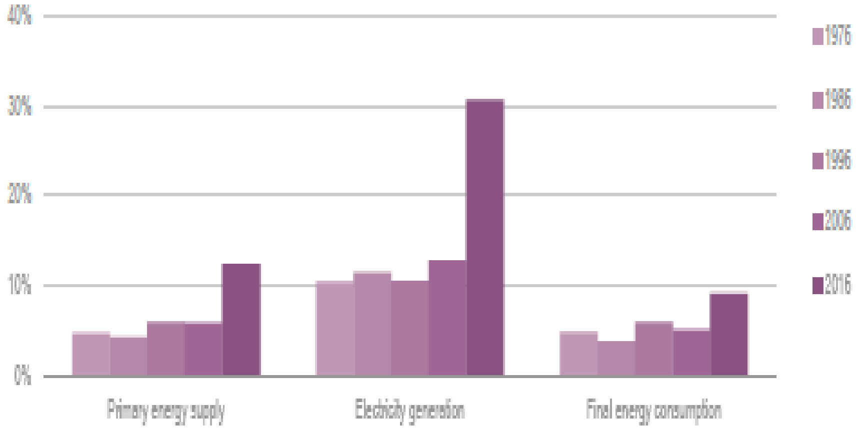
[4] A feed – in tariff (FiT) is an energy supply policy which focuses on supporting the development of new renewable energy projects by offering long – term purchase agreements for the sale of renewable energy electricity. These purchase agreements are typically offered within contracts ranging from 10 – 25 years and are extended for every kilowatt-hour of electricity produced (NREL).

[5] Under a feed – in premium (FiP) scheme, electricity from RES is typically sold on the electricity spot market and the payment level of the RES producers is based on a premium offered above the market price for electricity. The premium can either be constant, or it can vary based on a sliding scale (IENE, 2012).

program. Speeding up and simplifying complex licensing and permitting processes has also improved the situation for renewables.



Note: Data are provisional for 2016. The latest consumption data are from 2015.

Source: IEA, 2017

Figure 1.6. Renewable energy share of total primary energy supply, electricity generation, and total final consumption during the period 1976 – 2016

Due to the positive experience of competitive auctions and the fact that large islands are becoming interconnected to the Greek mainland system, wind power could increase its contribution and help Greece diversify its power mix, amid decreasing the costs of renewable energy source technology.

According to the existing literature, renewable energy may play an important role in both energy security and climate change-related problems (Ristinen and Krushaar, 2006; Sims et al., 2007). Additionally, RES could provide as much as half of the global energy needs by 2050 in a target-oriented scenario to prevent dangerous anthropogenic interference with the climate system (Krewitt et al., 2007).

1.4 Energy efficiency and energy consumption

Energy efficiency tends to improve when countries use new technologies, import less energy-intensive goods, and adopt better management practices (Mimouni and Tenimi, 2018). Under the Energy Efficiency Directive (2012/27/EU), the EU set a 20% energy savings target by 2020 compared to the projected use of energy in 2020, i.e. overall EU energy consumption should not exceed 1,483 Mtoe of primary energy[6] or 1,086 Mtoe of final energy. All Member States are obliged to use energy more efficiently at every stage of the energy chain (energy generation, transmission, distribution, and end-use consumption). Therefore, the EU has adopted a variety of measures to improve energy efficiency in Europe, including:

- a 1.5% reduction in national energy sales every year,
- energy- efficient renovations to at least 3% of buildings owned and occupied by governments per year,
- mandatory energy efficiency certificates accompanying the sale and rental of buildings,
- minimum energy efficiency standards and labeling for a series of products such as boilers, household electrical appliances, lighting and televisions (ecodesign),
- a preparation of National Energy Efficiency Action Plans every three years by EU countries,
- the planned rollout of close to 200 million smart meters for electricity and 45 million for gas by 2020,
- large companies conducting energy audits at least every four years,
- protecting the rights of consumers to receive easily free access to data on real-time and historical energy consumption,
- published guidelines on good practices in energy efficiency, which have already been published by the Commission.

Amending Directive 2018/2002/EU entered into force in December 2018 and established an EU energy efficiency target for 2030 of at least 32.5% (compared to projections) with a clause to be possibly revised upwards by 2023, if there are substantial cost reductions due to economic or technological progress. This means that energy

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[6] Primary energy consumption reflects the total energy demand of a country, referring to the consumption of the energy sector itself, losses during transformation and energy distribution, and the final consumption by end users. It excludes energy carriers used for non – energy purposes, e.g. petroleum not used for combustion but for plastics' production (Eurostat).

consumption in the EU should not exceed 1,273 Mtoe of primary energy and/or 956 Mtoe of final energy. In this amended Directive there are other measures, such as:

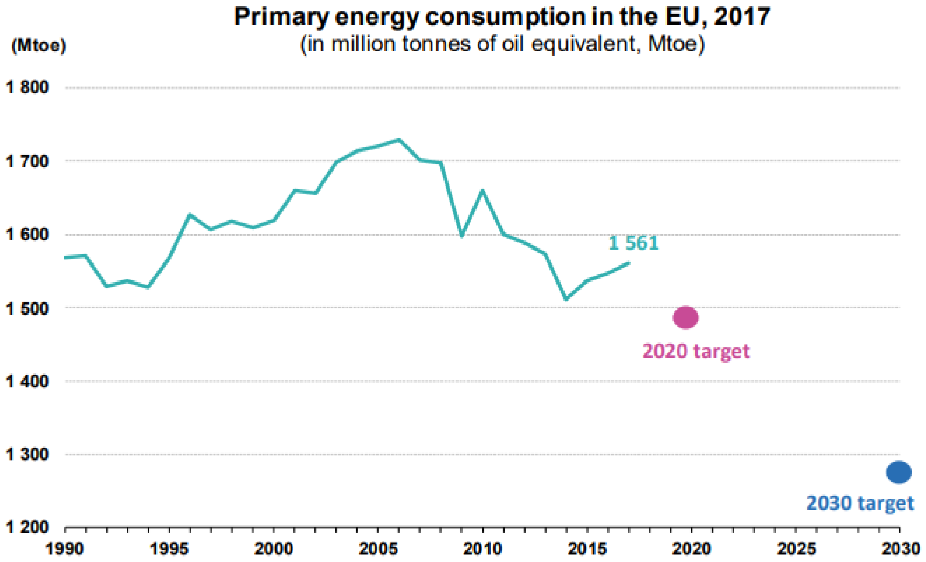
- new savings of 0.8% annually of final energy consumption,
- stronger rules on metering and billing of thermal energy by consumers, especially those living in multi-apartment buildings with collective heating systems, and with clearer rights to receive more frequent and more useful information on their energy consumption, while enabling them to better understand and control their heating bills,
- Member States are obliged to have in place transparent national rules, available to the public, on how the cost of heating, cooling and hot water consumption in multi-apartment and multi-purpose buildings with collective systems for such services is allocated,
- monitoring efficiency levels in new energy generation capacities,
- an updated Primary Energy Factor (PEF) for electricity generation of 2.1 (while the current one is 2.5),
- Energy Efficiency Directive must be reviewed by 2024 (EC).

In 2017, primary energy consumption in the EU was reported to be 5.3% above the efficiency target set for 2020. It has fallen by 0.4% since 1990 and 9.2% since 2005. However, primary energy consumption has shown significant fluctuations over the years. It peaked in 2006 (1,729 Mtoe, which equals to a 16.6% gap from the 2020 target), while it reached a record low in 2014 (1,511 Mtoe representing a 1.9% gap from the 2020 target). Over the period 2015 - 2017 the consumption rose again to 1,537 Mtoe in 2015, 1,547 Mtoe in 2016, and 1,561 Mtoe in 2017 (Figure 1.7).

The decreased primary energy consumption in 2011 and 2012 can be explained to some extent by reduced economic output, which is expressed by 0.4% of real Gross Domestic Product (GDP) in 2012. Warmer weather (climate) conditions in 2013 – 2014 are considered to have resulted in decreasing energy demand, despite real GDP increased by 1.8% in 2014. The recent uptick in economic activity has led to an increase in energy use. Although energy-efficient improvements have moderated this increase, reduction in energy intensity hasn’t kept primary energy consumption on a downward trend.

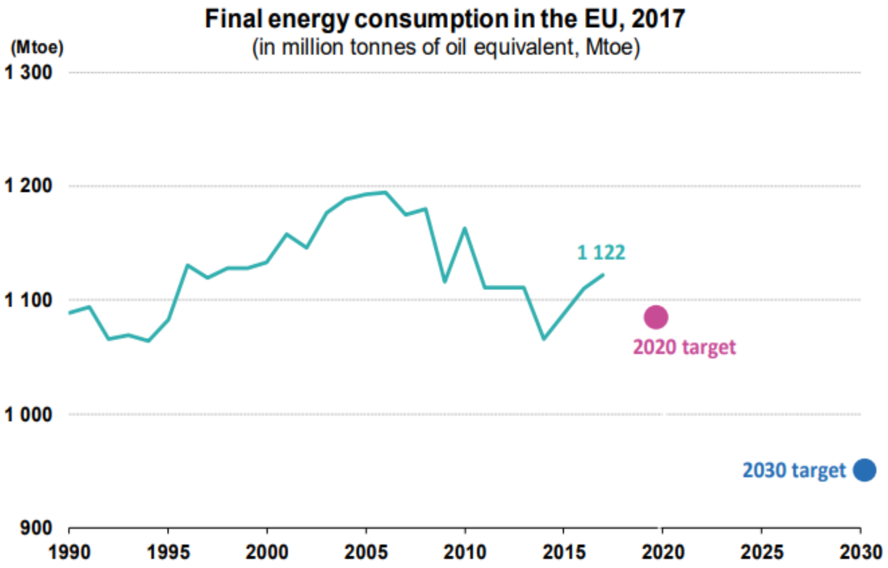
Therefore, if the EU wants to achieve its 2020 efficiency target, it has to reduce its primary energy consumption by another 5% in the period 2017 – 2020.

As far as final energy consumption is concerned, in 2017 it was 3.3% above the efficiency target for 2020. Final energy consumption in the EU, following the trend in primary energy consumption, reached a peak in 2006 (1,195 Mtoe) and decreased by 0.6% annually between 2006 and 2017 (1,122 Mtoe). Since the beginning of the new millennium, the lowest level of final energy consumption was recorded in 2014 (1,065 Mtoe, i.e. 1.9% below the 2020 target). During 2015 and 2017, it has increased again to 1,088 Mtoe in 2015, 1,110 Mtoe in 2016, and 1,122 Mtoe in 2017 (Figure 1.8). Compared to 2016, both levels of consumption increased by around 1%. Among the 28 Member States where final energy consumption declined between 2006 and 2017, only Greece showed a decline of more than 2% per year, more specifically -2.3%.



Source: Eurostat, 2019

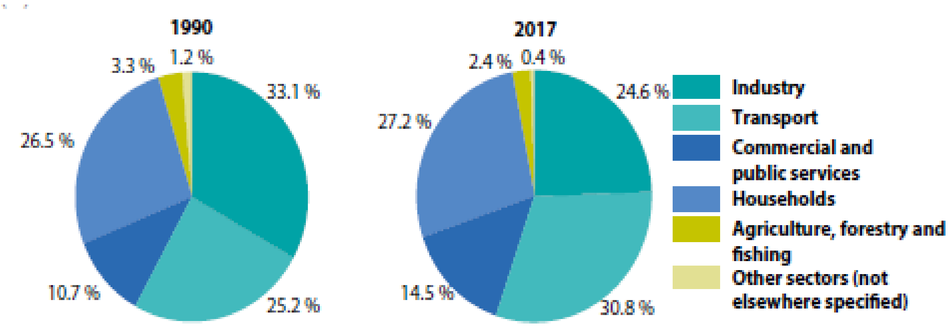
Figure 1.7. Primary energy consumption in the EU during the period 1990 – 2017



Source: Eurostat, 2019

Figure 1.8. Final energy consumption in the EU during the period 1990 – 2017

Between 1990 and 2017, final energy consumption followed different trends, which were reported for various economic sectors (Figure 1.9). Consumption was reduced in the sector of agriculture, forestry, fishing, and industry by 25.5% and by 23.6% in the industrial sector, while consumption in the residential sector increased by 5.1%. Energy consumption in the services and transport sectors also rose by 39.2% and 25.6% respectively. It is noteworthy that final energy consumption in all sectors increased in 2016 – 2017, reflecting an increase in economic activity and colder winter temperatures. These changes can be attributed to sector variations in energy efficiency improvements, but they also relate to a shift from energy-intensive industry to a more service-based economy. In 2017 most of the final energy was used in transport (30.8%), followed by households (27.2%), industry (24.6%), services (14.5%), while agriculture, forestry, and fishing accounted for 2.4% of final energy consumption (Eurostat, 2019).



Source: Eurostat, 2019

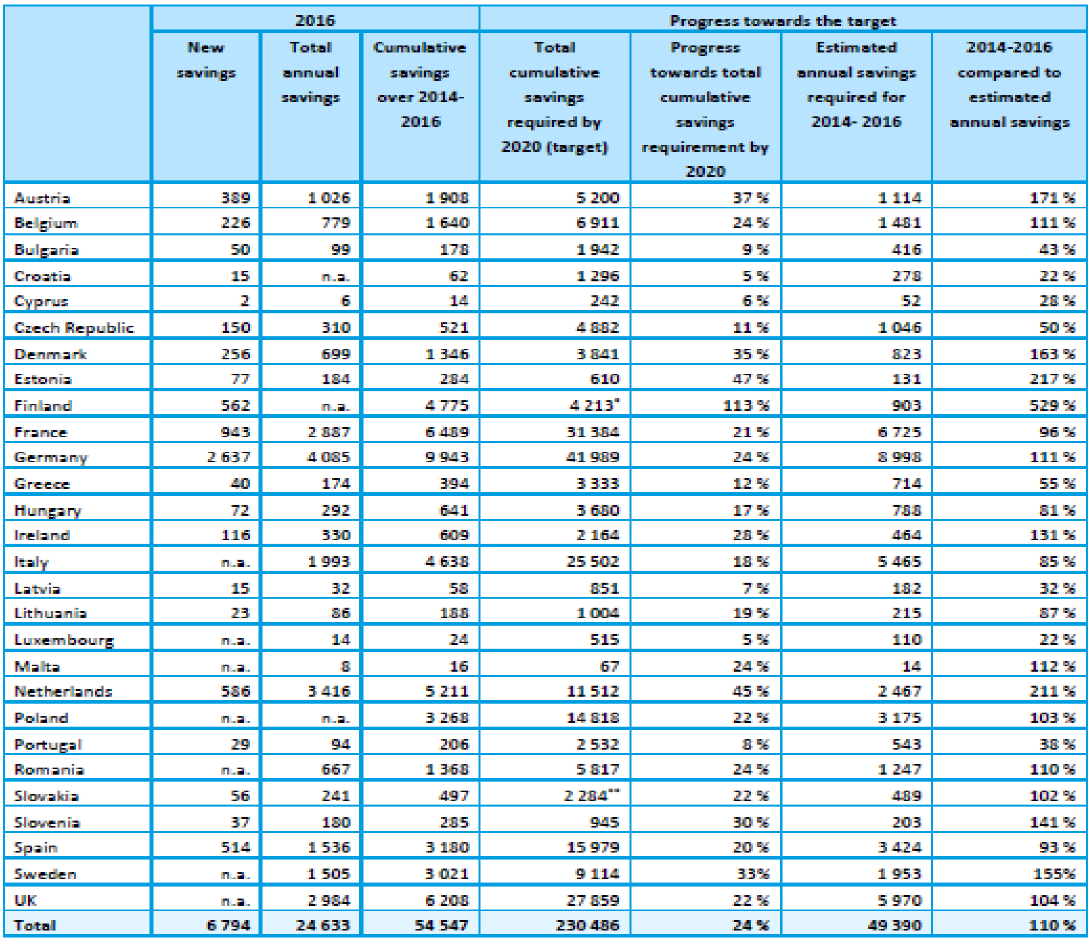
Figure 1.9. Final energy consumption by sector in the EU in 1990 and 2017

As a member of the EU, Greece was obliged to set a total final consumption (TFC) target for 2020 in compliance with the Energy Efficiency Directive. The target set by Greece was 18.4 Mtoe, which represented a 12% reduction in energy consumption levels in 2005. However, due to the 2009 economic crisis, TFC fell to 16.4 Mtoe in 2015, 11% below the 2020 reduction target.

Article 7 is a key component of Greece's compliance with the Energy Efficiency Directive. According to this article, all EU Member States have to ensure that annual energy savings of 1.5% are achieved by energy suppliers and distributors due to the implementation of energy efficiency policy measures. This Directive was transposed in the Greek legislation and, as stated in Article 9 of L. 4342/2015 (Official Journal of the Hellenic Republic 43, Issue A, 09-11-2015), Greece is obliged to achieve cumulative energy savings of 3,332.7 ktoe (38.8 TWh) by 2020 through the implementation of various energy efficiency policy measures, out of which the total for all new annual savings is 902.1 ktoe (10.5 TWh).

Implemented policy measures have not led to energy savings according to initial expectations due to the economic crisis, low public awareness, insufficient data, and lack of appropriate funding. Therefore, Greece achieved less than 60% of the required savings in 2016 (Table 1.1). This has created a need for Greece to achieve larger savings between 2017 and 2020 to comply with the aforementioned Article 7. As a result, in January 2017, considering the modeling and analysis from the Center for Renewable Energy Sources and Savings (CRES), Greece implemented an energy efficiency obligation program to provide 10% of the required energy savings (i.e. 333.2 ktoe) by 2020. The program obligates energy suppliers to obtain savings in line with an annual target, which is identified based on the market share of the obligated entity (IEA, 2017).

Table 1.1. Energy savings (ktoe) under Article 7 in the EU and the United Kingdom in 2016



	2016			Progress towards the target			
	New savings	Total annual savings	Cumulative savings over 2014-2016	Total cumulative savings required by 2020 (target)	Progress towards total cumulative savings requirement by 2020	Estimated annual savings required for 2014- 2016	2014-2016 compared to estimated annual savings
Austria	389	1 026	1 908	5 200	37 %	1 114	171 %
Belgium	226	779	1 640	6 911	24 %	1 481	111 %
Bulgaria	50	99	178	1 942	9 %	416	43 %
Croatia	15	n.a.	62	1 296	5 %	278	22 %
Cyprus	2	6	14	242	6 %	52	28 %
Czech Republic	150	310	521	4 882	11 %	1 046	50 %
Denmark	256	699	1 346	3 841	35 %	823	163 %
Estonia	77	184	284	610	47 %	131	217 %
Finland	562	n.a.	4 775	4 213*	113 %	903	529 %
France	943	2 887	6 489	31 384	21 %	6 725	96 %
Germany	2 637	4 085	9 943	41 989	24 %	8 998	111 %
Greece	40	174	394	3 333	12 %	714	55 %
Hungary	72	292	641	3 680	17 %	788	81 %
Ireland	116	330	609	2 164	28 %	464	131 %
Italy	n.a.	1 993	4 638	25 502	18 %	5 465	85 %
Latvia	15	32	58	851	7 %	182	32 %
Lithuania	23	86	188	1 004	19 %	215	87 %
Luxembourg	n.a.	14	24	515	5 %	110	22 %
Malta	n.a.	8	16	67	24 %	14	112 %
Netherlands	586	3 416	5 211	11 512	45 %	2 467	211 %
Poland	n.a.	n.a.	3 268	14 818	22 %	3 175	103 %
Portugal	29	94	206	2 532	8 %	543	38 %
Romania	n.a.	667	1 368	5 817	24 %	1 247	110 %
Slovakia	56	241	497	2 284**	22 %	489	102 %
Slovenia	37	180	285	945	30 %	203	141 %
Spain	514	1 536	3 180	15 979	20 %	3 424	93 %
Sweden	n.a.	1 505	3 021	9 114	33%	1 953	155%
UK	n.a.	2 984	6 208	27 859	22 %	5 970	104 %
Total	**6 794**	**24 633**	**54 547**	**230 486**	**24 %**	**49 390**	**110 %**

Source: EC, 2019

1.4.1 Energy efficiency and energy consumption in the residential sector

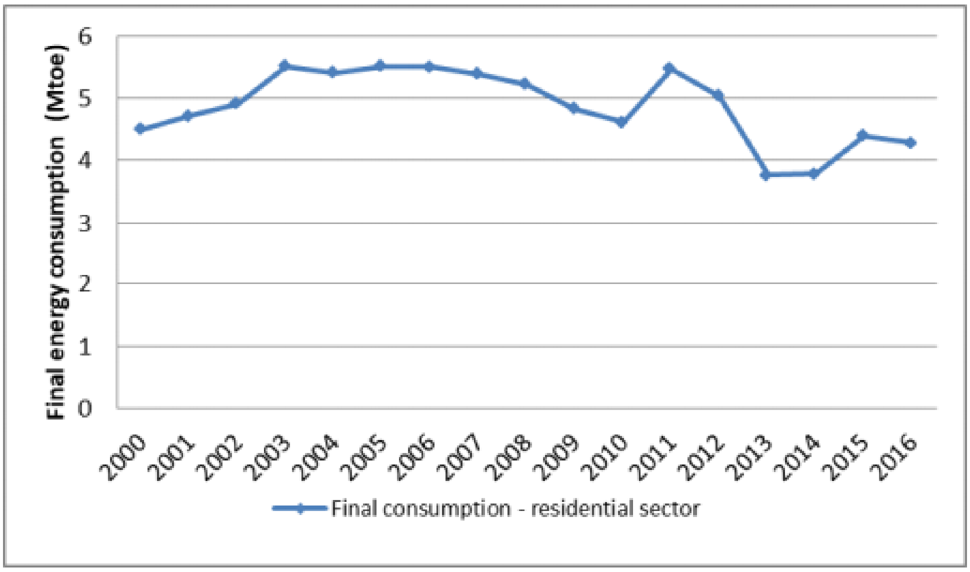
According to the U.S. Energy Information Administration (EIA), energy consumption in the residential sector can be defined as *"…all energy consumed by households excluding transportation uses"*. Residential energy consumption includes energy consumed to cover basic households' needs such as heating, cooling, lighting, and water heating (IEA, 2015). Residential energy consumption is affected by a variety of factors such as socioeconomic development (improvement of human comfort levels and entertainment activities, population, income), architectural design, geography, occupants’ behavior, culture, technological improvements, energy prices, energy access, weather (climate), households’ characteristics, appliances, and the shares of services met with different energy types (electricity, fossil fuels, etc.) as well as advances in energy efficiency (Allouhi et al., 2015; Gallo Cassarino et al., 2018, Bohlmann and Inglesi – Lotz, 2018).

Final energy consumption in the residential sector decreased by 9%, from 310 Mtoe in 2005 to 284 Mtoe in 2017. However, energy use rose by 7 % between 2014 and 2017 (with a 0.5% decrease in 2017). As mentioned before, this increase can be attributed to colder winter temperatures following the notably warm winter of 2014, given that space heating energy consumption accounts for around 2/3 of residential energy consumption, and a rise in economic activity. In 2017, the number of heating degree - days (HDD) was only slightly higher compared to 2016, and energy consumption declined by 0,5% every year. Although space cooling still accounts for a limited proportion of energy consumption, it has been growing rather fast in some countries, while the number of cooling degree – days (CDD) almost doubled in 2017 compared to 2014 (Tsemekidi – Tzeiranaki S., Bertoldi P. et al, 2018). The growing number of households and a bigger average surface area, that are indicators of the wealth effect, as well as lifestyle changes (e.g. the increasing penetration of new small appliances) could be additional factors that explain the recent increase in energy consumption.

In Greece, final energy consumption in the residential sector decreased by 5%, from 4.5 Mtoe in 2000 to 4.2 Mtoe in 2016.

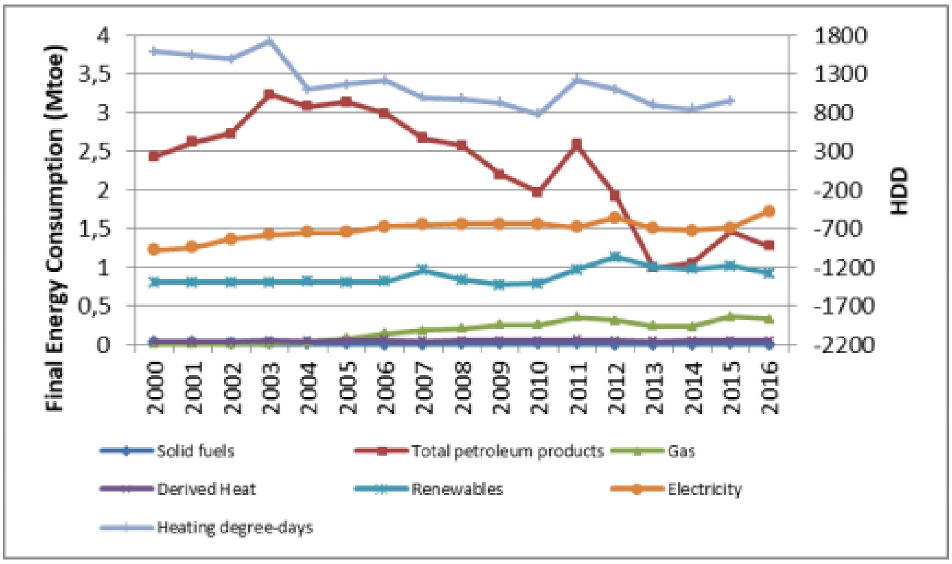
Residential sector intensity in terms of energy consumption per population decreased in the EU by 12% in the years 2005 – 2017, and almost 1 % in 2017 compared to the previous year (EC, 2019).

Although until 2006 residential final consumption was constantly increasing, the residential sector was one of the first sectors to sustain the effects of the economic recession in final energy consumption. This fact, combined with the energy efficiency measures that have been implemented since 2007, led to a decrease in final energy consumption (Figure 1.10). Energy consumption increased in 2011, mainly due to the colder winter and a new tax in heating oil, which was announced in the same year and was implemented in 2012, which led to the increase of heating oil cost by 50% (Figure 1.11). These facts led the consumers to procure the heating oil for the next years in 2011, a fact that increased final energy consumption.



Source: ODYSSEE, 2018

Figure 1.10. Final energy consumption in the Greek residential sector during the period 2000 – 2016



Source: ODYSSEE, 2018

Figure 1.11. Final energy consumption by fuel in the Greek residential sector during the period 2000 – 2016

Natural gas (36%) and electricity (24.1%) cover most of the EU's final energy consumption in the residential sector and are followed by RES (17.5%) – mainly biofuels, petroleum products (11.2%), derived heat (7.6%) and coal products (3.3%). Notably, in Denmark and Lithuania derived heat is the main energy generator in the residential sector, while solid fuels and petroleum products are mainly used by households in Poland and Ireland, respectively (Eurostat, 2019).

In Greece, the national energy mix of the residential sector has faced some changes during the period 2000 – 2013. From 2000 to 2006, petroleum products were the main fuels (more than 50%) used in the residential sector. After 2006, since the introduction of natural gas in the country's energy mix, the share of petroleum products in the mix of final energy consumption decreased. After 2012, due to the high cost of petroleum products, the main fuel that is consumed is electricity (40%). Moreover, in 2016, measures promoting RES led to an increase of the RES by 7%, from 17% to 24%, compared to the years 2000-2010.

Space heating is held accountable for the largest part of final energy consumption in households. In 2000, households consumed 3.1 Mtoe for space heating compared to 2.8 Mtoe in 2015, which represented a 13% reduction in energy consumption. Between 2000 and 2015, the energy share of electric appliances and lighting increased by 6% since they increased in both number and size. Energy consumption for cooking and hot water production remained almost constant during the years 2000 and 2015, while a slight increase in cooking was reported in the period 2013 – 2015.

As far as the residential energy efficiency index (ODEX) in Greece is concerned, it decreased regularly by 2% between 2000 and 2016 in average, mainly due to the efficiency measures that started to apply in 2000 and the economic crisis and the subsequent recession. Therefore, energy efficiency improved by 30% over this period (CRES, 2018).

1.5 Electricity production and consumption in Greece

1.5.1 Electricity market design

The update of the EU’s electricity market design, taking into consideration the technological changes and their integration in the last years as well as in the years to come, is one issue that plays a significant role in the “Clean Energy for all Europeans” package. The share of electricity produced by RES is expected to grow from 25% to more than 50% in 2030, therefore EU legislation is required to be updated to facilitate the integration of renewables into the grid, while ensuring that electricity will be delivered in sufficient quantities, taking into consideration the variations of renewable electricity. To address these issues, the EU updated its Electricity Directive (2009/72/EC) and Electricity Regulation (EC/714/2009), introduced a new regulation on risk preparedness, and enhanced the role of the Agency for the Cooperation of Energy Regulators (ACER). These new rules were formally adopted in May 2019 and EU Member States must transpose the new measures into national law in the next 1.5 years.

The new Electricity Directive and Electricity Regulation

The new electricity Directive and Regulation aims at adapting market rules to new market realities. These rules introduce a new limit for powerplants eligible to receive subsidies as capacity mechanisms. Furthermore, consumers are now placed at the center of the clean energy transition. These new rules enable the active participation of consumers while strengthening consumer protection.

Society is expected to benefit from trade between countries and competition by allowing electricity to move freely to where it is most needed. Trade and competition will be the drivers of investments that are essential to provide supply security and decarbonize the European energy system. Updating the design of the EU electricity market contributes to the EU's goal of being the world leader in energy production from RES by allowing more flexibility to accommodate an increasing share of renewable energy in the grid. The shift to RES and increased electrification is of utmost importance to achieving carbon neutrality by 2050.

The Regulation on Risk Preparedness

This Regulation obliges Member States to prepare plans for dealing with potential electricity crises in the future, while taking the necessary actions to prevent, prepare for and manage these situations. Member States are required to identify all possible electricity crisis scenarios, at national as well as regional level, and then design appropriate risk preparedness plans. All in all, this regulation ensures that markets can work effectively against electricity crises.

The Agency for the Cooperation of Energy Regulators (ACER)

ACER's main role was originally confined to coordination, advising, and monitoring. As the new market design rules foresee much more cross-border cooperation, the lack of regional cross-border oversight was seen as a potential problem with the risk of diverging decisions and unnecessary delays. In addition to coordinating the activities of national energy regulators, ACER has therefore been granted additional competences in those areas where fragmented national decisions of cross-border relevance are likely to lead to problems for the Internal Energy Market (EC).

1.5.2 Market shares

Electricity market liberalization is expressed by the market share of the largest generator in each country. For example, in Cyprus there was a total monopoly between 2007 and 2017, as 100% of its electricity was generated by the largest (and sole) generator. Four other Member States – Croatia, Estonia, France, and Slovakia – reported shares of at least 70%. In half of the 26 Member States (there is no available data for Bulgaria and Netherlands), the largest electricity generator provided less than 50% of the market, while the lowest share was recorded in Lithuania (14.2%).

An analysis revealed that, between 2007 and 2017, in 18 of the 24 member States (no available data for Bulgaria and the Netherlands; incomplete data for Luxembourg, Austria, and the United Kingdom), the market share of their leading electricity generator declined. Greece, Latvia, Malta, and Slovenia reported the largest reductions, since the largest generator lost at least 30% of its market share. In Cyprus, the market share of the largest generator hadn't changed during 2007 and 2013, while in Croatia, Hungary, Germany, and Poland this share increased. Among three of these five Member States, the share of the largest generator was almost stable during the period 2007 – 2017 (around 85% in Poland, 30% in Germany and 17% in Poland), while in Hungary it increased from 40.9% to 51.3%. In the United Kingdom, there was volatility due to mergers and demergers; these changes were reflected in the values of 15.3% in 2008, 51.7% in 2012, and 29.3% in 2013 (Eurostat, 2019).

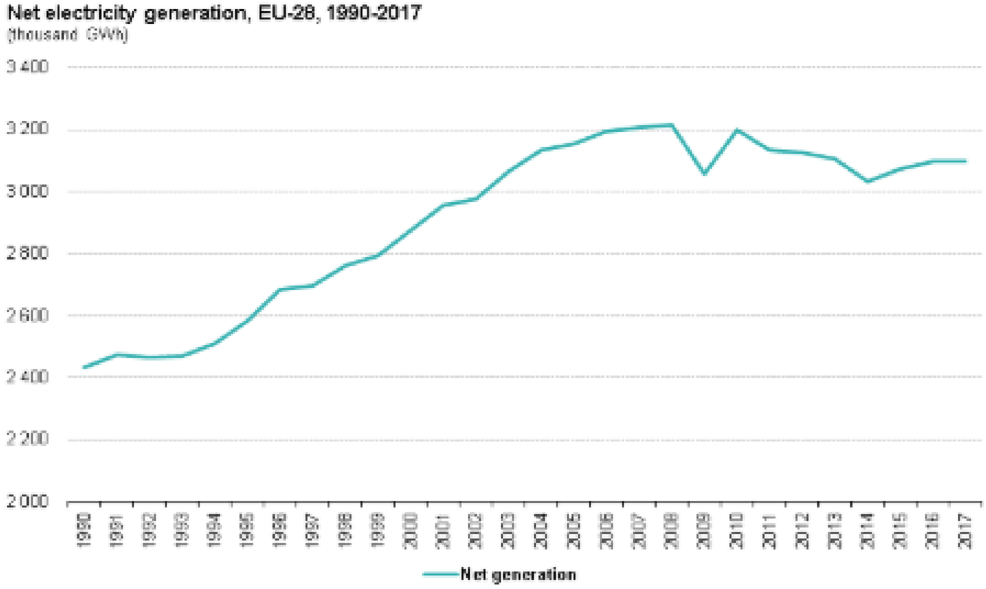
1.5.3 Electricity production

Total net electricity generation in the EU reached 3.1 million GWh in 2017, similar to the previous year, following an upward trend (Figure 1.12). Electricity generation was 3.6% lower than its 2008 peak when total output reached 3.22 million GWh.

Germany had the highest share of net electricity generation among all of the 28 Member States, accounting for 19.7% of the EU – 28 total generation and was followed by France (17.1%). Between 2016 and 2017, the largest increases per year were reported in Malta (97.5%), Latvia (18.5%), Estonia (7.8%), and Sweden (5.2%). On the contrary, in 8 Member States electricity production decreased in 2017; Croatia (-6.2%), Portugal (-2%), Finland (-1.8%) and Romania (-1.5%) faced the largest reductions.

During the period 2007 – 2017, an overall reduction of 2.2% in electricity generation was reported; a pattern which was repeated in 15 of the 28 member States. The largest decreases were registered in Lithuania (-69%), Luxembourg (-44.3%) and Malta (-26.4%), while Denmark, Hungary, Finland, the United Kingdom, and Greece also showed remarkable (double-digit) reductions. In contradiction, among the 13 Member States with the largest levels of generation, double-digit increases were recorded in Latvia, Portugal, Ireland, Sweden, Austria, and the Netherlands.

It should be noted that changes in electricity generation don't directly reflect variations in electricity consumption since they are also affected by changes in the energy products used for energy production and changes in electricity imports and exports (Eurostat, 2019).



Source: Eurostat, 2019

Figure 1.12. Net electricity generation in the EU during the period 1990 - 2017

Particularly in Greece, electricity demand (production plus net imports) decreased by 16% from 2008 to 2016 due to the economic crisis. Total electricity production was 48.8 TWh in 2016 (-18.9% since 2006) and net import 8.8 TWh, respectively (IEA, 2017). In 2018, electricity generation increased furthermore compared to 2016 and reached 50.8 TWh, a decrease of 20% since 2008 (HAEE, 2019).

When it comes to the national electricity generation mix, it is a fact that fossil fuels have traditionally been the largest energy generators and accounted for more than 70% of the total electricity produced in the previous years. However, their shares have decreased over recent years. This can be attributed to the decline of electricity consumption and the introduction of RES, especially wind power and solar PVs.

1.5.3.1 Renewable electricity production

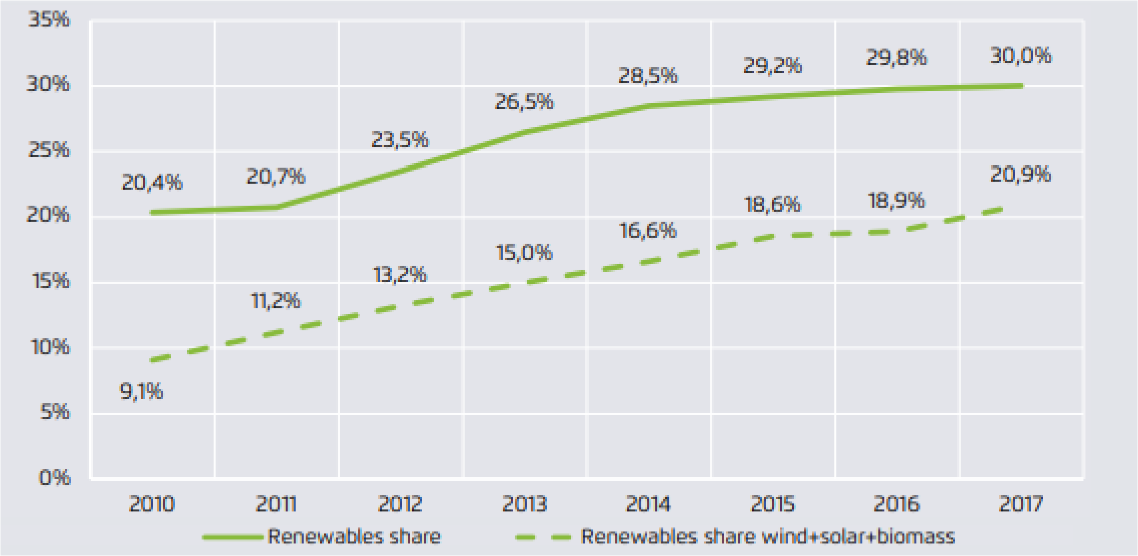
RES accounted for 30% of the EU's electricity generation for the first time in 2017. Wind, solar, and biomass accounted for 20.9% of the electricity mix in the EU, representing an average annual increase of 1.7% since 2010 (Figure 1.13). If this rate continues, then renewables could generate half of the EU electricity by 2030. This is considered to be sufficient to reach the current 2030 renewable target of a 27% share in final energy demand.

In 2017, wind power generation increased massively, due to onshore and offshore capacity additions and an above-average wind yield in the last quarter of the year. Wind generation increased by 58 TWh, solar by 9 TWh, and biomass by only 5 TWh. That led to wind, solar, and biomass surpassing coal generation for the first time. This is a notable progress, taking into consideration that coal generation was double these renewables. This is important to establish a sustainable European bioeconomy, since biomass plays a key role in it.

Although the deployment of RES has grown steadily, with approximately the same increase from 2011 to 2014, and from 2014 to 2017, it has become more geographically and technologically concentrated. Geographically, the largest part of that increase was reported in Germany and the United Kingdom, while in the other 26 Member States RES increased by 58% from 2011 to 2014 and 43% from 2014 to 2017. This could be partly attributed to the fact that some Member States have already reached their national 2020 targets. However, it could also reflect the existence of unnecessary high financing costs, particularly in Central and South-Eastern Europe, which prevent the translation of the decrease of renewable technology costs into really low - cost renewable energy projects (DiaCore, 2016; PriceTag, 2017).

Technologically, the increase has gotten more concentrated towards wind, since it accounted for 46% of the EU renewables growth from 2011 to 2014, and for 72% from 2014 to 2017, followed by biomass (15%) and solar, which is still lagging substantially.

In Denmark (74% of total electricity generation), Germany (30%) and the United Kingdom (28%) were recorded the largest penetration of renewables. On the contrary, in many countries the growth was anemic during the last ten years, for example in Bulgaria, the Czech Republic, France, Hungary, and Slovenia. Other countries had good growth rates at the start of the decade, but almost no growth during the last years, like Belgium, Greece, Italy, Portugal, and Spain. Also, there are six Member States that still had less than 10% of their electricity produced from RES in 2017: Bulgaria, Czech Republic, France, Hungary, and Slovakia.



Source: Eurostat, 2019

Figure 1.13. RES share as a percentage of gross electricity production

Taking this into consideration, deployment of RES could be sped up to achieve the 35% renewable target which is under consideration (Eurostat, 2019).

In 2018, the European Commission published the “Long Term Strategy” for the decarbonization of the European economy. To meet the renewable energy and energy efficiency targets for 2030 (32% and 32.5% respectively), renewable electricity must rise from 32% in 2018 to 57% by 2030. Taking this into account, as well as the electrification of the European economy, renewables’ annual deployment must increase by 84% from 2010 – 2018 to 2018 – 2030 (Eurostat, 2019).

Particularly in Greece, wind power generation increased from insignificant levels in the late 1990s to 5.1 TWh in 2016, a share that equals to 10.5% of the total electricity generation (HAEE, 2019). That seems rather logical since Greece has some of the most attractive sites for the use of wind energy in Europe. The national capacity target for wind energy is 7,500 MW until 2020, including 300 MW of offshore installations (EWEA, 2011). The installed capacity for wind energy has increased by 253 MW in 2018 compared to the figures at the end of 2017, making 2018 the second-best year for the national wind energy sector in terms of new installations after 2011.

Wind farms with a total capacity of 2,555 MW were installed in Greece by December 2018 compared to 2,047 MW and 2,302 MW installed by the end of 2016 and 2017 respectively. Of this 2,555 MW, 322 MW of wind turbines have been installed on the Non-interconnected islands (NIIs)[7] (HAEE, 2019).

Solar power has had more impressive growth since it increased from 0.16 TWh in 2010 to 3.9 TWh in 2016 (+25%) (IEA, 2017). Total installed solar power installed capacity accounted for 2,461 MW (2,140 MW in solar parks and 351 MW in small PV systems below 10 kWp that have been installed under the Special Photovoltaic Rooftop Programme) by the end of 2017. 159 MW of this 2,461 MW were installed in the NIIs, bringing Greece to one of the highest places globally in terms of PV contribution to total electricity demand (HAEE, 2019).

Hydropower has consistently been held accountable for the largest share of renewable electricity, facing substantial annual fluctuations. Hydropower production was 5.5 TWh in 2016, equal to 11.4% of total generation, and accounted for the largest share of renewable electricity. Greece also has a small share of electricity from biofuels, accounting for less than 1% of the total electricity generation (IEA, 2017).

Apart from solar power, including both small and large installations, which are relatively stationary over the last two years, biogas – biomass has also shown a small increase, i.e. 0.7% in 2016 (IEA, 2017). Greece has generally not exploited its biomass potential. It is noteworthy that biomass could cover even 20% of Greece’s total electricity needs (HAEE, 2019).

According to the NREAP’s third report, the penetration of RES in gross final energy consumption increased by 14% in 2014 compared to 2012, exceeding the penetration projected in the NREAP. As described in the second progress report the main reason for shifting the overall share of RES in the gross final consumption higher than expected was the use of RES for heating purposes, and specifically, in the residential sector (Ministry of Environment & Energy, 2016).

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[7] The majority of the Greek islands located in the Aegean Sea are not interconnected with the mainland’s electricity grid and have local autonomous systems. There are 32 such autonomous systems with a peak load demand ranging from 100 kW to 700 MW. Most of them are small isolated systems, while Crete and Rhodes are considered to be the biggest systems (Kelemenis and Tsachas, 2014).

Greece's share of renewables in gross final electricity consumption reached 24.5% in 2015, while the National Renewable Energy Action Plan's (NREAP) target was 26%, according to data from the NREAP's third progress report in 2016.

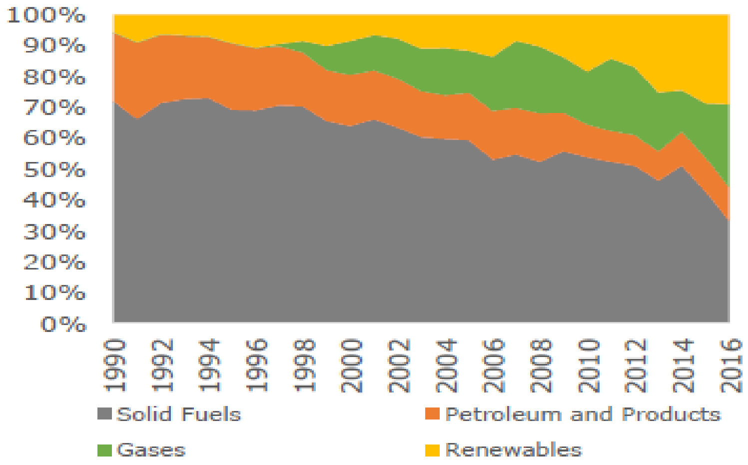
According to Table 1.2, the targets for heating and cooling by introducing RES with shares of around 26% were above the 2020 expected shares, while renewable transport was lagging with 1.4% against the 10% target. The RES electricity mix was notably different from the NREAP's projections, as the main share in the installed capacity was attained by solar PVs instead of wind farms, due to the national FiT program (IEA, 2017).

Table 1.2. Progress regarding RES deployment during the period 2011 – 2015

	2011 [%]	2012 [%]	2013 [%]	2014 [%]	2015 [%]
RES-electricity	20.23	24.43	26.47	26.85	25.90
RES-heating and cooling	13.82	16.48	21.24	21.92	22.09
RES-transport	0.74	1.06	1.04	1.37	1.43
Total RES	11.03	13.83	14.99	15.32	15.44

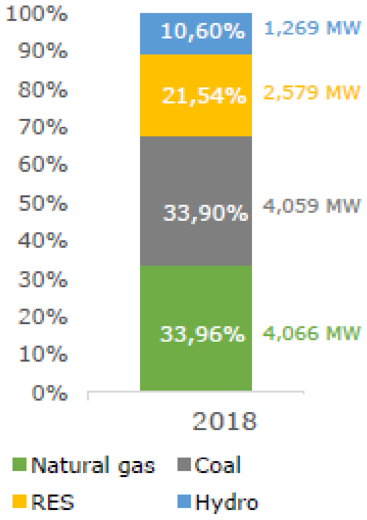
Source: IEA, 2017

In general, Greece has made progress in diversifying its electricity fuel mix (Figure 1.14), especially in the deployment of variable RES the deployment of renewable energy increased to almost 22% of total generation in 2018. In 2018, there was no dominant fuel in the electricity generation mix, since natural gas amounted to 33.96% of the electricity generation, coal to 33.9%, RES to 21.58% and hydroelectric stations to 10.6% (Figure 1.15) (HAEE, 2019).



Source: HAEE, 2019

Figure 1.14. Gross electricity generation (%) by fuel during the period 1990 - 2016



Source: HAEE, 2019

Figure 1.15. Gross electricity generation by fuel (% and MW) in 2018

So, it is evident that Greece's electricity mix has been diversified significantly in the last years through the penetration of natural gas and RES, due to the liberalization of the electricity market and the incentives given by the Greek state (Polemis and Dagoumas, 2013). A finding worth discussing is that the country's energy mix is different compared to the EU average; for example, the use of natural gas and solid fuels is higher, while the use of RES is lower and the use of nuclear power is non – existent (HAEE, 2019).

It should be noted that announcements for various renewable energy projects suggest further cost reduction soon and deployment will become less dependent on government intervention and support (IEA, 2017).

1.5.4 Electricity consumption

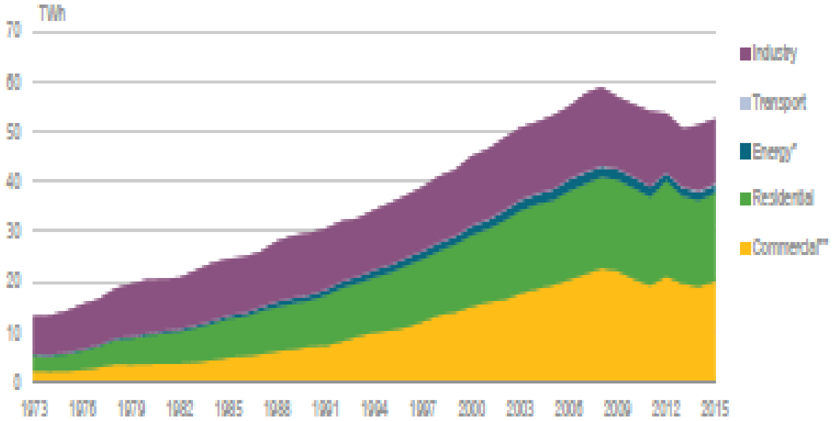
Electricity consumption plays a crucial role in adapting to climate change in terms of helping to adjust to heating and cooling needs as temperature faces changes. It is also important in mitigation planning as electricity accounts for more GHG emissions than any other sector in Europe. While for the different types of heating fuels (coal, oil, natural gas, biomass, etc.) higher temperatures equal less demand, this is not necessarily applied to electricity. A warmer climate might lead to a significant shift from electricity demand for heating services in winter to electricity demand for cooling services in summer, since cooling is mainly powered by electricity. However, the overall effect of this seasonal shift will be different for each country. Various socio-economic and technological factors (e.g. consumption habits), but also the climate zone, the extent of future climate change, and the form of adaptation measures which will be taken will determine the size of the effect mentioned above (Damn, Koberl, et al., 2017). Besides, electricity consumption can also be affected by other factors, such as the types of services (industry, agriculture, tourism etc.), weather (climate) conditions, and economic figures (electricity tariffs, average income, GDP) (HAEE, 2019).

Differences in welfare levels from country to country, electricity intensity of the national industries, the share of electricity use in space heating, penetration of air conditioning, efficiency of energy use, and climate conditions cam explain electricity consumption per capita variations (Damn, Koberl et al., 2017).

Electricity consumption in the EU increased by 0.7% (23 TWh) in 2017, which was the third year in a row that total European electricity consumption has increased. This increase was observed in all countries except the United Kingdom. In the period 2010 – 2014 there was a downward trend in consumption, but almost reached 2010 levels. In the same period there was a rise in European GDP, as it was reported to be 10% above 2010 levels. Between 2010 and 2017 the largest decline was reported in the United Kingdom (-9%), while Poland faced the biggest increase (9%) (Agora Energiewende and Sandbag, 2018). Following a similar pattern, electricity consumption increased by 0.2% in 2018, which is equal to 7 TWh. However, it remained 2% lower than in 2010 despite a 13% increase in GDP and a 2% increase in population since then. In Poland electricity consumption increased by 1.6% in 2018, which corresponds to 12% above 2010 levels. On the contrary, the United Kingdom reduced electricity consumption the most (Agora Energiewende and Sandbag, 2019).

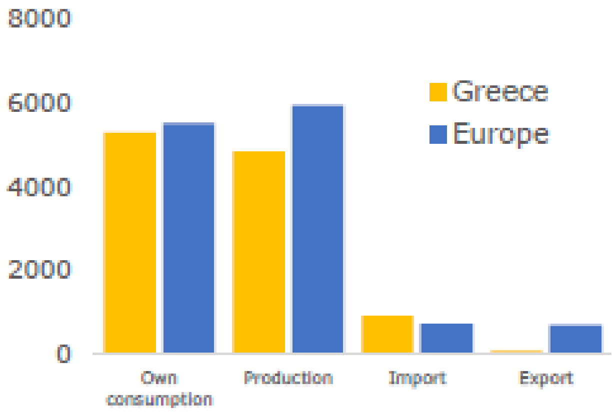
In particular, electricity consumption in Greece was increasing steadily until it reached a peak of 64.31 TWh in 2008, which was followed by five years of decline from 2009 to 2013 due to the economic crisis. Consumption has recovered slightly in recent years, and in 2015, Greece consumed 52.4 TWh of electricity (Figure 1.16) (IEA, 2017). In 2016, electricity consumption increased slightly compared to 2015 and reached 59.28 TWh (HAEE, 2019).

It is worth mentioning that, according to Figure 1.17, electricity consumption in Europe is completely covered by electricity generation and net exports are positive, while in Greece electricity imports cover the national deficit of electricity (HAEE, 2019).



Source: IEA, 2017

Figure 1.16. Electricity consumption by sector during the period 1973 – 2015



Source: HAEE, 2019

Figure 1.17. Electricity data per capita in Greece and Europe in 2017

Electricity consumption is expected to increase due to the electrification of the economy. The “Long Term Strategy 2050”, which was released by the European Commission in November 2018, indicates that electricity consumption is expected to rise by 18% by 2030. Electrification of the transport sector, heat, and industry are considered to be the main drivers (Agora and Energiewende, 2019). For example, the electric vehicle market is kicking off, as electric and plug-in vehicles amounted to 800,000 vehicles by the end of 2017 (Agora Energiewende and Sandbag, 2018).

1.5.5 Residential electricity consumption

Energy consumption in the residential sector across the world is affected by global warming. Energy patterns in buildings, including dwellings, are affected by climate change (Roshan et al., 2012; Roetzel and Tsangrassoulis, 2012), since it affects the mean and variance of major climate factors, such as temperature, humidity, solar irradiation, precipitation, wind speed and wind direction (De Wilde and Tian, 2011).

Residential heating and (especially) cooling requirements are highly dependent on the climatic parameters mentioned above (Chen et al., 2012). Climate change increases cooling loads and leads to unsatisfactory conditions in buildings. Also, global warming intensifies heat waves which lead to an increase in the electricity demand for cooling needs (Nejat et al., 2015).

As mentioned above, most of the final energy consumption in the residential sector is covered by natural gas (36%) and electricity (24.1%), while RES account for 17.5%, petroleum products for 11.2%, and derived heat for 7.6% of total energy consumption. A small share (3.3%) is covered by coal products (Eurostat, 2019).

Energy is used by households mainly to satisfy their heating needs, representing 64.1% of final energy consumption in the residential sector (Table 1.3). Electricity is used for lighting and the majority of electrical appliances (14.4% - excluding the use of electricity for powering the main heating, cooling, or cooking systems), while the share of electricity used for water heating accounts for 14.8%. Space and water heating represent 78.9% of total final energy consumption. Energy used for cooking devices amounts to 5.6% of final energy consumption, while space cooling and other end–uses run up to 0.3% and 0.9%, respectively.

The majority of energy products are used almost exclusively for space and water heating (from 93.6% of oil products to 100% of derived heat). Only electricity shows a broader use (59.1% for lighting, 25.5% for space and water heating, 11.2% for cooking, and 1.3% for cooling). Electricity covers 100% of energy needs for lighting and space cooling, but also 54.7% for other end-uses and 48.8% for cooking. Natural gas is used mainly for space and water heating (43.3% and 47.7%, respectively) and cooking (33.6%), while RES are used to cover 23.4% and 9.9% of the energy needs for space and water heating respectively, and 5.1% for cooking. It is worth mentioning that 11 of the Member States use mainly RES for heating their households, while 9 Member States use principally gas for this purpose (Eurostat, 2019).

Buildings were responsible for approximately 40% of final consumption and 60% of electricity consumption in the EU, while they accounted for 30% of total global final energy consumption in 2016 (IEA, 2017). About half of the residential buildings in the EU were built before the 1970s, with 25% built between 1970 and 1990 (Berardi, 2017).

In 2017, households were held accountable for 27.2% of final energy consumption (or 17.2% of gross inland energy consumption)[8] in the EU (Eurostat, 2019). During the years 2007 – 2017, electricity consumption in the residential sector increased by 0.1% (Figure 1.18). It increased at a much faster rate between 2007 and 2017 in Romania compared to

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[8] Gross inland energy consumption (or sometimes abbreviated as gross inland consumption) refers to a country's or region's total energy demand. It represents the quantity of energy which is necessary to satisfy inland consumption of the examined geographical entity (Eurostat).

the EU average, where the overall growth was 21.3%, while it increased by 18.8% in Bulgaria and by 16.6% in Malta.

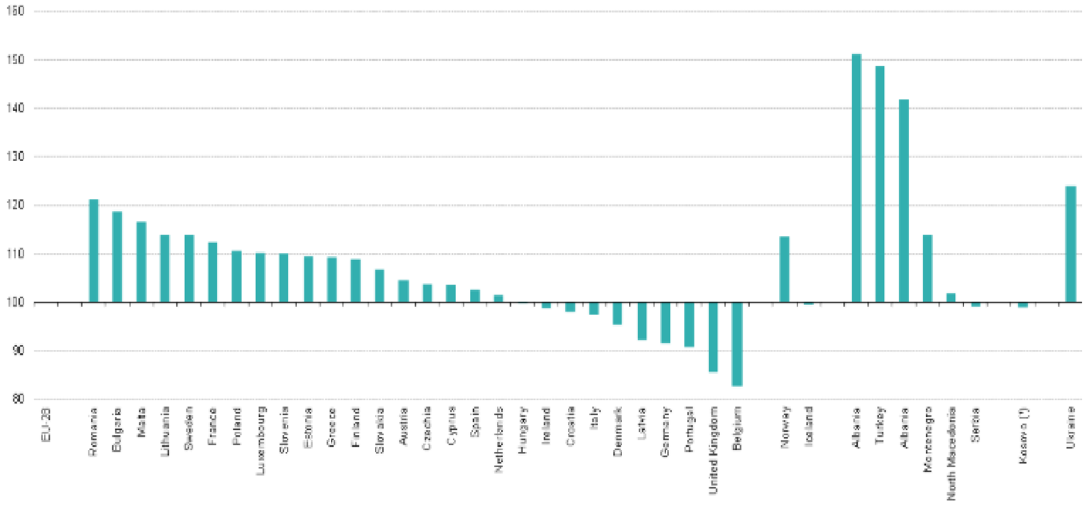
Table 1.3. Share of fuels in the final energy consumption in the residential sector by type of end-use in 2017

EU - 28	Total Residential/ Households	Space heating	Space cooling	Water heating	Cooking	Lighting & appliances	Other end-uses
Electricity	24.3%	3.4%	0.3%	2.8%	2.%	14.4%	0.7%
Derived Heat	7.8%	6.1%	0.0%	1.7%	0.0%	0.0%	0.0%
Natural gas	36.5%	27.6%	0.0%	7.1%	1.9%	0.0%	0.0%
Solid Fuels	3.3%	3.0%	0.0%	0.3%	0.0%	0.0%	0.0%
Oil & Petroleum Products	11.3%	9.0%	0.0%	1.6%	0.7%	0.0%	0.1%
Renewables & Wastes	16.8%	15.0%	0.0%	1.5%	0.3%	0.0%	0.1%
Total	**100.0%**	**64.1%**	**0.3%**	**14.8%**	**5.6%**	**14.4%**	**0.9%**

Source: Eurostat, 2019

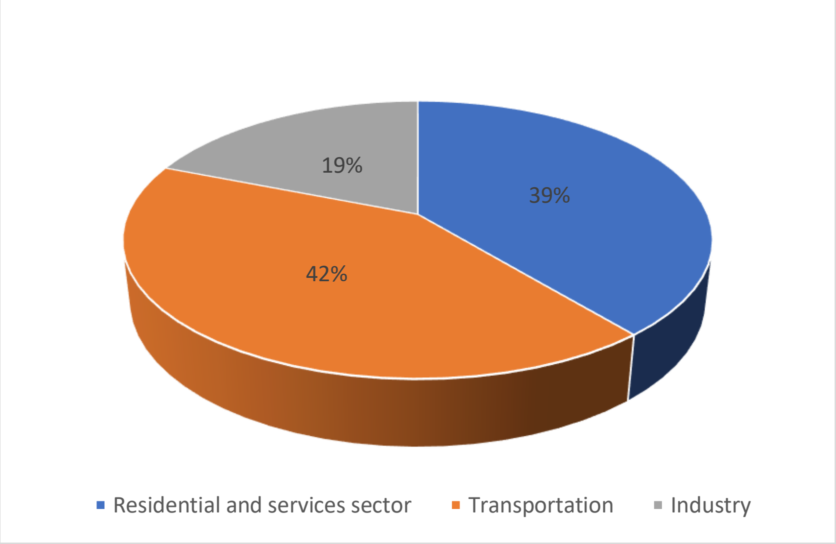
On the contrary, residential electricity consumption decreased in 9 Member States by less than 20% in general. Among these countries, electricity consumption decreased the most in Belgium (-17.2%), the United Kingdom (-14.4%), and Portugal (-9.2%) (Eurostat, 2019).

Particularly in Greece, there are 4,105,637 buildings (Table 1.4), and those that constitute the residential and services sector were responsible for 39% of total final consumption, as stated by 2016 data (Figure 1.19). The majority of residential buildings (55%) was built before 1980, and therefore have no thermal insulation, while, due to the economic crisis, the number of buildings built after 2010 with minimum requirements, represents only 1.5% of total residential building stock (Ministry of Environment & Energy, 2018).



Source: Eurostat, 2019

Figure 1.18. Residential electricity consumption in the 28 Member States of the EU in 2017



Source: Ministry of Environment & Energy, 2018

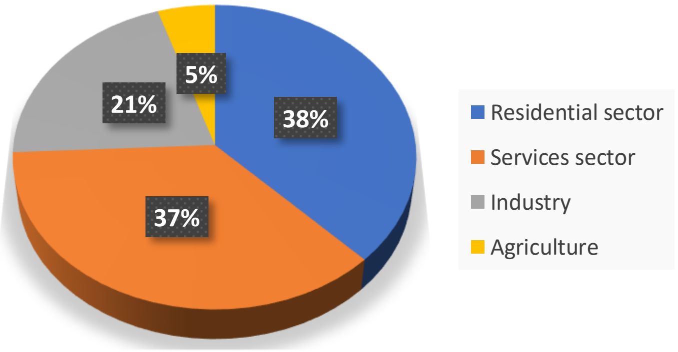
Figure 1.19. Total final consumption by sector in 2016

Table 1.4. Categorization of the Greek building stock.

Buildings		
Category	**Number**	**Rate**
Residential buildings	3,246,008	79.1%
Offices and stores	206,254	5.0%
Educational buildings	21,853	0.5%
Hospitals and clinics	1,973	0.0%
Hotels	43,516	1.1%
Total	**4,105,637**	**85.7%**

Source: Ministry of Environment & Energy, 2018

In 2016, buildings were held accountable for 74.2% of the total electricity consumed. Specifically, according to Figure 1.20 and Table 1.5, residential buildings, which include detached houses and apartments in blocks of flats and represent 79.1% of the national building stock, consumed 37.6% of electricity, while the services sector was held accountable for 36.6% of total electricity consumption (Ministry of Environment & Energy, 2018).



Source: Ministry of Environment & Energy, 2018

Figure 1.20. Electricity consumption by sector in 2016

Table 1.5. Distribution of the electricity consumption in Greece (2016)

Sector	Electricity consumption [GWh]
Industry	11.281
Residential sector	19.992
Services sector	19.445
Agriculture	2.407
Total	**53.126**

Source: Ministry of Environment & Energy, 2018

In this context, reducing electricity consumption seems to be essential because of its importance in energy demand. So, energy policies in Europe, as well as in most developed countries, have been focusing on reducing residential electricity demand (Innocent and Francois – Lecompte, 2018). Therefore, it is urgent to improve the energy performance of buildings, especially residential ones. Buildings that are energy – efficient provide higher levels of comfort and wellbeing for their occupants and improve their health by minimizing problems caused by a poor indoor climate, while they try to tackle energy poverty.

1.6 Policy measures in the residential sector

Energy efficiency and energy management are interlinked in terms of monitoring and controlling energy consumption in buildings. The main concern is focused on how to produce the required energy, as well as on how to improve energy efficiency while being able to meet the required demand, since energy consumption tends to increase at a global level (Abu Bakar et al., 2015). According to IEA (2018), energy efficiency is the key to ensuring a safe, reliable, affordable, and sustainable energy system for the future. Several policy measures have been implemented to enhance energy efficiency in the residential sector and decrease its electricity consumption. Building standards and mandatory energy labels for electrical appliances are the most common policy measures (Aydin and Brounen, 2019). As previously mentioned, European Directive 2002/91/EC on the Energy Performance of Buildings (EPBD) and EPBD recast (Directive 2010/31/EU and

Directive 2018/844/EU), which are part of the EU initiatives on climate change (commitments under the Kyoto Protocol) and security of supply (Dascalaki et al., 2012), as well as Energy Efficiency Directive (2012/27/EU), are the EU's main legislative instruments to promote the improvement of buildings' energy performance.

The main aspects of the EPBD recast are the following:

- All new buildings must be nearly zero-energy buildings (nZEBs)[9] after 31.12.2020, while new buildings occupied/owned by public authorities must be nZEBs after 31.12.2018,
- A common methodology for calculating the integrated energy performance of buildings must be implemented by all Member States. This methodology will use common benchmarks to calculate cost-optimal levels which will result in minimizing the life cycle cost of buildings,
- All existing buildings that undergo major renovations (25% of the building's surface or value) should meet minimum energy performance standards and not only those above 1000 m^2 as foreseen in EPBD, while national policies and specific measures should stimulate the transformation of refurbished buildings into nZEBs,
- Energy Performance Certificates (EPC) should be issued for building units that are rented out to new tenants and public buildings with a total useful floor area of 500 m^2,
- All EU Member States are obliged to introduce minimum energy use requirements for all HVAC technical building systems (Dascalaki et al., 2012).

Policies and measures that reduce energy consumption and promote energy efficiency in buildings are adopted by policymakers and public authorities around the world (Painuly et al., 2003; Bull et al., 2012; Mardookhy et al., 2014). These policies are different and

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[9] According to Article 2 of Directive 2010/31/EU, nZEB is a "building that has a very high energy performance. […] the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on – site or nearby" (Build Up, 2019). In other words, a nZEB is a low energy building which the yearly energy production balances yearly energy consumption through renewable energies (Harkouss et al., 2018).

can be generally divided into the following categories (Goeders, 2010, Atanasiu et al., 2012, Annunziata et al., 2013):

- Regulatory measures such as building regulations that have mandatory aspects and include minimum requirements to decrease the long – term energy demand of buildings (BREEAM certification, LEED, REPB/KENAK etc.). These codes set minimum energy performance requirements for energy use at the design stage.
- Electrical equipment standards, which set minimum requirements of energy efficiency.
- Soft instruments which consist mainly of voluntary standards, such as labels and user education (Allouhi et al., 2015), and aim to inform clients about the long – term energy use of buildings and appliances while raising public awareness.
- Economic incentives which are deployed to motivate building owners and occupants to renovate their residencies in a way that improves the buildings' energy efficiency. These incentives include energy savings performance contracting, tax exemptions/reductions, capital subsidies, grants, and subsidized loans (Goeders, 2010).

For example, the main policies in Greece are the Regulation on the Energy Performance of Buildings (REPB/KENAK) and the "Saving at home" programmes, which can be categorized as regulatory measures and economic incentives, respectively, and are subsequently presented.

Regulation on the Energy Performance of Buildings (REPB - KENAK)

In Greece, Regulation on the Energy Performance of Buildings became active in 2010 and replaced the national Thermal Insulation Regulation (TIR), which was introduced in 1980. According to REPB, energy audits are carried out and EPCs are issued to estimate the energy performance of buildings, i.e. the amount of energy needed to meet the energy demand associated with the typical use of a building.

This regulation requires more strict building thermal insulation regulation and more efficient HVAC installations through technical guidelines that define implementation (Droutsa et al., 2016). More specifically, an integrated energy design in the buildings' sector aims at improving the energy efficiency of buildings, energy savings, and environmental protection through specific actions:

- Conduction of a study on the energy performance of buildings. This study replaces the study on heat insulation and is carried out for every existing or new building over 50m^2, which must be renovated, and is based on a specific methodology including:
    - requirements to meet minimum standards on the design, building envelope and electromechanical installations, and
    - comparison with the reference building[10].
- Establishment of minimum requirements for energy efficiency in buildings,
- Energy Rating of Buildings through EPCs. The official national software, called "REPB - KENAK" which is designed by the Technical Chamber of Greece (TCG - TEE), is used for calculations generating EPCs. These certificates are an indicator of energy efficiency and could urge people to choose more energy-efficient alternatives (Aydin and Brounen, 2019). According to them, buildings are classified in nine energy categories taking into consideration their electricity consumption, from A$^+$ to G, where A+ stands for nZEBs and G for the most energy-intensive buildings. Also, they include general building data, annually calculated and actual, if available, final and primary energy consumption, CO_2 emissions, an optional evaluation of indoor environmental quality, breakdown of energy carriers and different end – uses, and up to three cost-effective recommendations for improving the building's energy performance with calculated energy savings and payback period. According to available statistics, 34% of the residential buildings are ranked in the lowest class, i.e. G, while only 3% of them are ranked in classes B to A$^+$ (Droutsa et al., 2016). This can be attributed to the fact that most buildings, about 60% of Greek national building stock, were constructed before the 1980s without any insulation and are equipped with energy-intensive heating/cooling and hot water systems. According to 2016

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[10] Reference building is a building with the same geometry, position, orientation, use and operating characteristics as the examined building, which also meets minimum standards and has specific technical characteristics (CRES, 2018). It is, by definition, an energy class B building.

data, only about 13% of Greek residential buildings dispose of an EPC (Gaglia, Dialynas and Argiriou et al., 2019).

- Energy inspections to buildings, boilers, and heating and air – conditioning systems (CRES, 2018).

So, Greece must adopt actions to exploit energy savings from the building sector through energy efficiency retrofit measures and the deployment of RES to upgrade the country's building stock and meet national targets. Households' indoor conditions and occupants' health can be improved by energy-efficient retrofit measures, since indoor temperatures don't rise as high in the summer while draughts and cold surfaces are minimized due to better insulation. However, it must be pointed out that their affordability is a factor that must be taken into consideration (Weber and Wolff, 2018).

According to the Ministry of Environment & Energy, only 1.2% of the buildings have been renovated between 2011 and 2016 to improve their energy performance, mainly by adding thermal insulation on the roofs and walls and by replacing windows, while the most efficient measure to reduce electricity consumption is the replacement of electrical boilers for domestic hot water (DHW) production. Also, it seems the deployment of RES, such as solar PVs for electricity production or solar collectors for DHW and space heating, can be energy and financial effective, considering the high availability of solar radiation and the continual reduction of their initial and operating cost. It is worth mentioning that solar collectors can lead to a more than 50% reduction of energy consumption for DHW (Gaglia, Dialynas and Argiriou et al., 2019).

"Saving at home" programme

"Saving at home" programme started in 2011 and aimed at providing financial incentives (including subsidies up to 70% and interest – free loans) for energy-saving interventions in dwellings that meet specific income-related criteria to reduce their energy needs, and subsequently, improve energy efficiency. Various types of houses were subsidized by this programme, such as single-family houses, individual apartments, and apartment blocks for the part of the block that relates to all the apartments in the building. The submitted proposals have to cover the following minimum requirement for them to be accepted:

buildings should be upgraded by at least one energy class or provide annual primary energy savings greater than 30% of the reference building's consumption.

51,659 applications were completed by June 2016 which translated to a total budget of €529 million. 83% of the completed applications involved the replacement of old window frames with more energy-efficient ones, 53.9% thermal insulation, and 71.6% upgrade of the existing heating system and DHW supply. The total area of the renovated residencies amounted to 5.2 million m^2 resulting in total annual primary savings of 853.6 GWh (CRES, 2018).

The programme was quite innovative, at least for Greece, since:

- public contribution was given to the residential sector for energy efficiency improvements for the first time,
- it was implemented through a revolving Fund called "Saving at Home Fund", which was the first Holding Fund established in Greece,
- after the repayment of the loans, this Fund can be used to increase the number of beneficiaries.

It can also be said that the programme was quite successful since:

- citizens did not have to pay in advance for the interventions and, therefore, more people could afford to carry out energy improvements in their dwellings,
- banks were co-financing 2/3 of the loans,
- maximum energy savings were achieved through ex – post and ex – ante energy inspections and interventions,
- people (or businesses) were motivated to become involved in the energy efficiency field,
- it led to the improvement of living conditions in cities and towns,
- it led to a public environmental awareness (Concerted Action Energy Efficiency Directive, 2015).

“Saving at home II” programme

This programme, which is the follow up of the aforementioned “Saving at home” program, started in 2018 and is funded by (a) the EU, through the European Regional Development Fund (ERDF), and (b) National Resources, through the Regional Operational Programmes (ROP) and Operational Programme “Competitiveness, Entrepreneurship, Innovation (OP CEI) of NSRF 2014 – 2020. Various measures are implemented to improve the energy performance of households that have low energy performance (category D or worse, based on EPCs) and belong to low – income owners who are not capable of fully funding on their own the energy upgrade of their households, or in which measures beyond the minimum required levels of energy performance will be implemented. The total public expenditure of the program amounts to €292.18 million (CRES, 2018).

The programme includes interventions such as:

- replacement of window frames with energy-efficient ones,
- installation or upgrade of thermal insulation,
- upgrade of the heating and cooling system. This can be achieved -for example- by installing solar thermal collectors or commercial solar heating and cooling installations),
- DHW system using RES, mainly solar thermal (Ministry of Environment & Energy).

According to the Ministry of Environment & Energy, as far as energy savings are concerned, the goal is to consume 32.5% less energy by 2030 compared to 2009 levels. Every year one “Saving” program is needed, knowing that in 2018 more than 70% of total electricity consumption concerns the building sector. As far as “Saving at home II” is concerned, 43,000 applications have been accepted corresponding to a total budget of €640 million, out of which 15,000 have already completed the interventions and have been subsidized and 24,000 are expected to complete the interventions and disbursements are forthcoming (energypress, 2019).

Regarding both programmes, it is worth mentioning that EPCs are issued before and after the interventions mentioned above to document the initial energy class of dwellings and to verify that the minimum energy performance improvements aimed by the programs have been achieved, i.e. household's upgrade by at least one energy class or annual primary savings exceeding 30%. A surprising finding is that the use of RES is limited, since only 22% of the buildings exploit solar thermal energy. Fuel oil and natural gas are used for heating and DHW production in old buildings, while for the new buildings constructed according to KENAK the trend is to use natural gas instead of oil (Droutsa et al., 2016).

These measures, apart from the reduction of energy consumption and tackling of energy poverty, have additional benefits: less family budget expenses, overall improvement of the occupants' quality of life through the improvement of thermal comfort and indoor air quality, and increase of the residences' value, since households are upgraded and have decreasing energy losses. They can also contribute to the decarbonization of the building sector by improving the buildings' insulation which reduces heating and cooling needs (IEA, 2016). Moreover, establishing such programs contributes to:

- the reduction of unemployment, since there is a substantial number of people that can be involved (especially engineers and people working in the banking field),
- raising peoples' awareness regarding energy saving and energy efficiency issues,
- the reduction of energy dependence, as well as the corresponding currency flows, from energy imports,
- the optimal and long – term use of natural resources (Concerted Action Energy Efficiency Directive, 2015; Ministry of Environment & Energy, 2018).

However, despite established financial incentives, the majority of people seem reluctant to invest in energy efficiency retrofits. This can partly be attributed to the fact that people generally lack information concerning sustainability retrofits in the residential sector. Besides, a significant number of citizens rents a house; renters are unlikely to invest, especially in "immobile" technologies such as solar PVs, since they can't recoup the full value of their investment if they move, and people who rent properties aren't particularly willing to invest in energy efficiency measures, since their benefits are enjoyed only by their tenants (Roberts et al., 2019).

1.7 Basic economic theory

This chapter ends with household production, which is behind everything that revolves around residential electricity demand.

The household production theory

In 1965, Becker developed the modern approach to household production and considered households to be small - scale factories or plants that use inputs, such as labor, capital, and raw materials, to produce some sort of home goods (Greenwood and Seshadri, 2005). The basic framework of household production theory can explain residential electricity demand (Alberini and Filippini, 2011; Filippini, 1999; Flaig, 1990). The household production theory states that households are both producers and consumers of goods. To maximize their utility, households attempt to efficiently allocate time, income, and goods and services they use and produce.

In our case, households consume energy because they must satisfy various needs (heating, cooling etc.) and are assumed to allocate their income to energy and other goods that meet these needs in a way that maximizes their satisfaction from total expenditure (Cialani and Mortazavi, 2018). This means that households combine electricity with household appliances to produce energy services such as heated rooms, lighting, and hot water. In the long term, households minimize their electricity consumption by employing the optimal level of capital equipment (Blazquez, Boogen, and Filippini, 2013).

CHAPTER 2: LITERATURE REVIEW

Various studies on modeling the residential electricity demand have been published since the early 1990s due to the implementation of new energy and environmental policies, climate change, and the development of new econometric tools. Donatos and Mengos (1991), Silk and Joutz (1997), Filippini (1999), Garcia – Cerrutti (2000), Lin (2003), Hondroyiannis (2004), Dergiades and Tsoulfidis (2008), Mohammadi (2009), Alberini and Filippini (2011), Wiesman et al. (2011), Blazquez et al. (2013), Salari and Javid (2016) are some of the most recent studies. Most of them, which are either top-down or bottom-up, have estimated the short – run and the long-run electricity demand using household-level data with imputed price and quantity data, detailed and often proprietary household-level data or aggregated state or regional data, while applying different methodologies (Fell et al., 2014). These studies focus mainly on three distinct issues: price responsiveness, appliance choice, and the effect of policies on energy demand, including the issue of rebound effect[11] (Krishnamurthy and Kristrom, 2015).

Residential electricity demand is different from country to country. Differences in a series of factors, such as socio-economic and demographic characteristics, building characteristics, electricity prices, and climate conditions, can explain these variations. Energy prices and income are two of the main determinants of electricity consumption for households. Socio-economic and demographic characteristics (education, income etc.) determine the way people live and their social classes, while they tend to influence residential electricity consumption behaviors (Salari and Javid, 2016).

According to Roman – Collado and Colinet (2018), who used the Logarithmic Mean Divisia Index (LMDI – I) method, the residential standard of living, as expressed by the income per capita, is a driver for residential electricity consumption.

Belaid (2017) used a structural equation modeling approach to assess various direct and indirect factors that determine residential energy consumption in France, and their impact on residential energy use, including dwelling characteristics, household attributes,

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[11] The rebound effect refers to the idea that energy efficiency improvements lead to an increasing demand for energy services, arising from reduction in the effective price of energy services resulting from those improvements (Barker et al., 2009). This effect is influenced by the level of environmental awareness, as a behavioral shift can lock – in or even accelerate the effect of energy savings projects (Polemis and Dagoumas, 2013).

climate conditions and behavior. Brounen et al. (2012) concluded that residential electricity consumption is affected by household composition, in other words family composition and income. Otsuka (2018) used a stochastic frontier function to investigate Japan’s determinants of residential energy demand and energy efficiency by considering the following variables: income, price, household size, urbanization, and climate conditions.

Particularly, as far as climate conditions are concerned, it is reported that the relation between electricity consumption and temperature is non – linear, since low or high temperatures are linked with higher electricity demand and intermediate temperatures correspond to lower electricity demand (Hekkenberg et al., 2009; Isaac and Van Vuuren, 2009; Moral – Carcedo and Vicens – Otero, 2005). Filippini and Hunt (2012) found that heating degree days, cooling degree days, income, price, population, average household size, and the share of detached houses are the main drivers of energy demand. Borozan (2018) confirmed that socio-economic factors, such as disposable income, and contextual variables, such as climate conditions, are important in energy consumption. So, it can be said that policymakers could develop better investment strategies if they would understand how these variables impact electricity demand (Zhou et al., 2014).

Also, Wiesmann et al. (2011) concluded that the effect of income on electricity consumption in Portugal is relatively low, especially once variables for dwelling characteristics, building stock, and appliances are introduced. Krishnamurthy and Kristrom (2015) found that electricity consumption in 11 OECD countries (including France, Netherlands, Spain, Sweden) is slightly affected by income, while it is affected more by average price changes. Cialani and Mortazavi (2018), using a dynamic partial adjustment model, concluded that in the EU, as far as climate conditions are concerned, heating degree days affect more electricity consumption compared to cooling degree days.

This thesis provides evidence on the relationship between electricity consumption in the residential sector in the EU and socio-economic conditions, energy and fuel prices, dwelling characteristics, and climate conditions. Therefore, we apply a panel VAR (pVAR) model and try to estimate empirically the main determinants of electricity consumption in the European Union (EU). So, we try to decompose the impact of the aforementioned factors on the residential electricity consumption proxied by the following variables: Gross Domestic Product per capita, price of electricity and natural gas, heating and cooling degree days, number of households, average household size and electrical appliances.

To do this, we use a panel dataset which consists of values of these variables in the 28 Member Countries of the EU over the period 1990 – 2017. This thesis aims to find the relations between these variables and residential electricity consumption to implement more effective policies to decrease electricity consumption in the bioeconomy framework.

This thesis differs from the related empirical literature since we try to examine how the determinants of electricity consumption possibly dynamically affect consumption at a European level.

CHAPTER 3: DATA AND METHODOLOGY

In this thesis, an annual panel set is used for the EU's 28 Member States (EU – 28) over a period that expands from 1990 to 2017. To assess the residential electricity consumption in the EU, country-level data were used combined with a model that consists of an observation equation.

For our analysis we used panel VARs' techniques; panel VARs follow the same logic of standard VARs and are a more suitable tool to address policy implications (Canova and Ciccarelli, 2013). In a pVAR framework, all variables are treated as endogenous and interdependent, dynamically as well as statically (Polemis, 2017). Moreover, this framework examines the dynamic relationships compared to the static results which come from the fixed effects model (Mamatzakis et al., 2013).

Our pVAR, following Canova and Ciccarelli (2013), takes the general form described below:

$$Y_{it} = A_{oi}(t) + A_i(l)Y_{it-1} + u_{it} \qquad (3.1)$$

where

$A_o(t)$ includes all the deterministic components of our data, i.e. constant terms, deterministic polynomial in time etc.

$A(l)$ is a polynomial in the lag operator, and

u_{it} stands for the error terms in the pVAR.

Thus, our model is given by the following equation:

$$lncnsm_{it} = A_{11}(t) + A_{11}(l)lncnsm_{t-1} + A_{12}(l)lngdpc_{t-1} + A_{13}(l)lnpel_{t-1} + A_{14}(l)lnpng_{t-1} + A_{15}(l)lnhdd_{t-1} + A_{16}(l)lncdd_{t-1} + A_{17}(l)lndwel_{t-1} + A_{18}(l)lnsurf_{t-1} + A_{19}(l)lnapp_{t-1} + u_{it} \qquad (3.2)$$

where

cnsm is the electricity consumption in the residential sector [GWh],

gdpc is the Gross Domestic Product per capita (€),

pel is the average price of electricity for households [€/kWh],

png is the average price of natural gas for households [€/GJ],

hdd and cdd are, respectively, the heating and cooling degree days,

dwel is the total stock of dwellings,

surf is the average surface area of dwellings (m^2),
app is the stock of electrical appliances,
u_{it} is the error term.

In this thesis, the average price was used for electricity, as suggested by Shin (1985), and natural gas. However, it is worth mentioning that the use of an average price could cause an endogeneity problem which, subsequently, could lead to inconsistent estimates and therefore to misleading conclusions (Ullah et al., 2018).

This potential problem could be addressed using instrumental variables techniques. The basic notion behind them is to decompose the variations in the endogenous (independent) variable through the use of instrumental variables by focusing on the variations in the endogenous variable that are uncorrelated with the model's error term and disregarding the variations that bias the estimation. One of the most widely used technique is two-stage least squares (2LS) estimation (Zaefarian et al., 2017), even though it leads to rarely statistically significant estimates (Semadeni et al., 2014). This technique corrects endogeneity and increases the likelihood of reporting coefficient estimates that are near their true values. By adding a third stage of regression, three-stage least squares (3LS) estimation could be deployed. Endogeneity which arises from simultaneity or reversed causality could also be tackled by using the lagged endogenous regressor technique. Endogeneity bias can be reduced by introducing a time lag between the independent and dependent variables (Zaefarian et al., 2017). In a panel data framework, a first – step or two-step Generalized Method of Moments (GMM) model could be used to overcome endogeneity issues due to reverse causality and provide consistent results. These dynamic panel data techniques use lags of the dependent variables as explanatory variables. These lagged values are therefore used as instruments to control this endogenous relationship (Ullah et al., 2018).

As far as natural gas is concerned, it should be noted that its average price shows significant fluctuations, which are attributed to the following factors:

- amount of natural gas production
- amount of stored natural gas
- natural gas imports and exports
- fluctuations in winter and summer weather conditions
- economic growth

- availability and prices of other fuels (EIA, 2019).

The income variable is measured as the Gross Domestic Product per capita (GDPC), which is used to measure and compare the living conditions across the EU-28 countries. Therefore, GDPC is considered to be a quality proxy for income, and, subsequently, welfare and economic growth of a country.

To capture the impact of the households on the electricity demand, the total stock of dwellings and their average surface area are included in the model.

Moreover, since electrical appliances, such as refrigerators, freezers, washing machines, dishwashers and TVs, play an important role in the electricity consumption of households, they are also a part of our analysis.

Two variables measure the effect of climate on electricity demand and are frequently used in many studies: heating degree days (HDD) and cooling degree days (CDD). These variables indicate the non – linear relationship between energy demand and temperature, based on the temperature of 18°C (Salari and Javid, 2016; Alberini and Filippini, 2011, Blazquez et al., 2013). More specifically, heating degree days and cooling degree days represent the number of degrees that a day's average temperature is below and above 18°C, which is the threshold temperature below which buildings need heating or cooling, respectively (Blazquez et al, 2013; Investopedia, 2019). Variables hdd and cdd are defined as follows (Moral – Carcedo and Vicens – Otero, 2005):

$$\text{hdd} = \sum_{t=1}^{nd} \max(0;\ \mathrm{T}* - \mathrm{Tt}) \qquad (3.3) \text{ and}$$

$$\text{cdd} = \sum_{t=1}^{nd} \max(0;\ \mathrm{Tt} - \mathrm{T}*) \qquad (3.4)$$

where

nd is the number of days of a particular year

T^* is the threshold temperature of cold or heat

T_t is the observed temperature on day t.

The selection of countries was based on the notion to analyze the residential demand for electricity in the European area, and the availability of public annual data. Therefore, the sample countries include the 28 Member States of the EU, i.e. Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the UK.

The data for these countries were extracted from three databases: the database of the European Statistical Office (Eurostat), the World Bank database, and the Odyssee database. Eurostat and the World Bank database are both available online; Eurostat provides high-quality data and statistics concerning the EU Member States, while the World Bank publishes data about countries around the world, enabling a direct comparison among countries. The database of the Odyssee project is managed by Enerdata and contains energy indicators and data on energy consumption. The Odyssee database includes, among others, data retrieved from national sources and Eurostat. Table 3.1 gives some details on the explanatory variables used in the analysis.

As mentioned before, we used a balanced panel data set of the EU's 28 Member States over the period from 1990 to 2017. It should be noted that there were missing data concerning some variables (GDPC, price of electricity and natural gas, stock of dwellings, surface area, and stock of appliances). Therefore, we imputed our data using the multiple imputation (MI) method (regression imputation, to be exact). According to Daniel Newman (2003) "MI is a procedure by which data are imputed several times (e.g. using regression imputation) to produce several different complete - data estimates of the parameters. The parameter estimates from each imputation are then combined to give an overall estimate of the complete – data parameters as well as reasonable estimates of the standard errors". Moreover, Paul Allison stated in 2000 that MI is one of the most appealing methods which is used to handle missing data in multivariate analysis. Also, he summarized the basic steps behind MI:

- an appropriate model is used to impute missing values
- after M imputations, M "complete" data sets are generated
- various standard complete – data methods are used to perform the analysis on each dataset
- a single point estimate is generated through average parameters' values
- calculation of standard errors (Williams, 2015).

Table 3.1. Definition of variables and descriptive statistics (1990-2017)

Variable	Unit	Abbreviation	Mean	Standard Deviation
Electricity consumption	GWh	cnsm	26,758.25	38,399.95
Gross Domestic Product per capita	€	gdpc	144,260.7	462,302.3
Stock of dwellings (permanently occupied)	Number	dwel	7,793.247	10,153.97
Average surface of households	m^2	surf	84.90995	20.64228
Price of electricity	€/kWh	pel	0.142524	0.0537046
Price of natural gas	€/GJ	png	13.24896	6.051926
Electrical appliances	Number of appliances	app	36,621.37	48,393.96
Heating degree days	Number	hdd	2,917.55	1,155.136
Cooling degree days	Number	cdd	98.84969	165.681

In our stationarity and cointegration analysis, we set the optimal lag length of the pVAR equal to one, ensuring that the residuals are white noise (Gaussian errors) (Polemis, 2017). In the end, Monte Carlo simulations are employed to estimate standard errors for the impulse response functions (IRFs) and the Variance Decomposition Analysis (VDC).

CHAPTER 4: RESULTS

In this chapter, the main findings of our pVAR analysis are portrayed. Firstly, our analysis focuses on the stationarity and cointegration tests of the employed variables, mainly on the performance of the unit roots. Subsequently, the main empirical results drawn from the IRFs and VDC analysis are discussed.

4.1 Stationarity and cointegration analysis

All the variables of the model were first examined for stationarity (in their logarithmic form) and their first differences were used when needed. To test for stationarity, we examine the existence of unit roots in a panel data framework using various econometric tests, such as Levin-Lin-Chu, Harris-Tzavalis, Breitung, Im-Pesaran-Shin W-test, ADF Fisher-type chi-square test and Hadri Lagrange test. Their results are presented in Tables 4.1 and 4.2. As mentioned before, we deployed a lag of one and we subtracted cross-sectional means when applicable.

Table 4.1. Unit root tests' results

Variable	**Levin-Lin-Chu t-test**	**Harris-Tzavalis**	**Breitung test**	**Im-Pesaran-Shin W-test**	**ADF Fisher-type chi-square**	**Hadri z-statistic**
lncnsm	-3.0830	0.8927	2.7316	-0.9284	66.8102	33.9070
lngdpc	-0.3300	0.1722	-0.5828	-8.9633	341.8523	8.7326
lnpel	-1.6355 **	0.4184	-2.0194 ***	-5.1743	161.0471	13.7699

Table 4.1. Unit root tests' results

(cont.)

lnpng	-3.0329	0.3352	-2.6597	-5.6245	140.2953	11.2739
lnhdd	-9.8816	0.1219	-6.3537	-11.2019	279.4479	5.4199
lncdd	-13.6730	-0.0075	-7.3613	-14.9403	403.6663	3.1093
lndwel	-2.3079 ***	0.3916	-4.3172	-5.3609	206.2149	14.2663
lnsurf	-6.2406	0.4128	-3.5739	-8.7088	289.8090	10.2662
lnapp	-4.1809	0.4169	-6.4140	-6.1386	200.5521	14.9204

Under the null hypothesis, stationarity tests assume a unit root. On the contrary, the Hadri Lagrange test assumes the absence of a unit root.

Significant at ***1% level, **5% level, *10% level respectively.

Table 4.2. Unit root tests' results (first differences)

Variable	**Levin-Lin-Chu t-test**	**Harris-Tzavalis**	**Breitung test**	**Im-Pesaran-Shin W-test**	**ADF Fisher-type chi-square**	**Hadri z-statistic**
dlncnsm	-11.6414	-0.0336	-5.7287	-12.9773	357.9724	2.8565
dlngdpc	-1.1e+02	-0.4172	0.0305	-72.8017	1,565.0719	-0.4262
dlnpel	-18.7447	-0.4671	-1.9690 ***	-23.9072	814.2749	-2.7031

Table 4.2. Unit root tests' results (first differences, cont.)

dlnpng	-19.5011	-0.4745	-2.3497	-24.2886	835.9306	-3.2870
dlnhdd	-14.8937	-0.4620	-9.9751	-21.8517	716.6785	-3.5737
dlncdd	-23.3290	-0.4775	-11.3820	-28.4490	1,023.0569	-3.6765
dlndwel	-15.9023	-0.4226	-8.6543	-24.5195	871.5219	-2.1008
dlnsurf	-15.2031	-0.4102	-7.6231	-24.6101	847.9925	-1.3040
dlnapp	-12.3596	-0.3994	-9.0741	-19.5320	629.8256	-3.0768

Under the null hypothesis stationarity tests assume a unit root. On the contrary, the Hadri Lagrange test assumes the absence of a unit root.

Significant at ***1% level, **5% level, *10% level respectively.

According to the results of the first five unit root tests, the null hypothesis can be rejected for all variables almost at every level. Finally, we test the null hypothesis that panels are stationary using the Hadri Lagrange test. We strongly reject the hypothesis that there is no cointegration for all variables, reinforcing the results of the other tests.

In other words all the variables, which are stationary and therefore should not be included in the cointegration equation, are integrated of order I(1).

Since all variables are I(l) series, we proceed with the panel cointegration test. This test by Khodzhimatov (2018), which is based on Wang and Wu (2012), is a cointegration regression that uses fully modified ordinary least squares, dynamic ordinary least squares, and canonical correlation regression methods. The results are shown in Table 4.3. According to them, the null hypothesis of no cointegration is rejected at 1% level and, subsequently, there is a structural relationship between the variables.

Table 4.3. Panel cointegration test

Variables	beta
lncnsm	
lngdpc	0.63
lnpel	-0.02
lnpng	0.04
lnhdd	0.11
lncdd	0.02
lndwel	0.10
lnsurf	0.18
lnapp	0.02

Under the null hypothesis the test assumes no cointegration (b=o).

4.2 pVAR analysis

Our previous analysis reveals that there is a structural relationship between our variables, and now we estimate the coefficients of the p-VAR (Table 4.4). To improve our estimation, we used “GMM-style” instruments as proposed by Holts-Eakin et al. (1988). This method replaces missing values with zeroes, which results in more efficient estimates. For our analysis we used 2 instrument lags.

According to the estimations, the price of electricity plays an important role in residential electricity consumption and has a positive sign, whereas the price of natural gas has a negative value. This could be attributed to the fact that natural gas is an important fuel in the residential sector in many European countries. Besides, we see that an increase of heating degree days, i.e. days with the temperature below 18^oC, will increase electricity consumption, while an increase in cooling degree days will result in a slight decrease of consumption. This means that climate conditions in the European territory make people less tolerant in cold than in heat, therefore they consume more electricity to satisfy their heating needs.

Table 4.4. Estimation of the coefficients.

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]
lncnsm lncnsm L1.	.9056108	.0239433	37.82	0.000	.8586829
lngdpc L1.	-.0006534	.0166801	-0.04	0.969	-.0333458
lnpel L1.	.031574	.0230841	1.37	0.171	-.01367
lnpng L1.	.-.0304208	.0129648	-2.35	0.019	-.0558313
lnhdd L1.	.0050493	.0631651	0.08	0.936	-.1187521
lncdd L1.	-.0032168	.0019666	-1.64	0.102	-.0070713
lndwel L1.	.0096504	.0115264	0.84	0.402	-.0129409
lnsurf L1.	.0581713	.0411789	1.41	0.158	-.0225379
lnapp L1.	.0010971	.0072726	0.15	0.880	-.0131569

It is also noteworthy that households' conditions, mainly the number of appliances and households' surface, also affect the levels of consumption, while the stock of dwellings also plays a role in the residential electricity consumption.

4.3 Impulse response functions (IRFs)

Since our main focus is to examine how residential electricity demand responds to shocks (innovations) on itself and the variables in equation 4.2, we move with the IRF extraction, using 200 Monte Carlo simulations, and the results are presented in Figure 4.1. The response of electricity consumption to its own innovation is downward sloping and positive across all ten years. Furthermore, it is evident that the response of cnsm to price innovations:

(a) in the case of natural gas, negative across all years. There is a downward trend in the very short-run, i.e. during the first two years, then a stabilization is observed, and from the sixth year, there is an upward trend.

(b) in the case of electricity, positive in the first seven years (with a downward trend) and then negative until the tenth year. It is worth mentioning that there is a downward pattern across all years. These findings are also confirmed by the coefficient estimations.

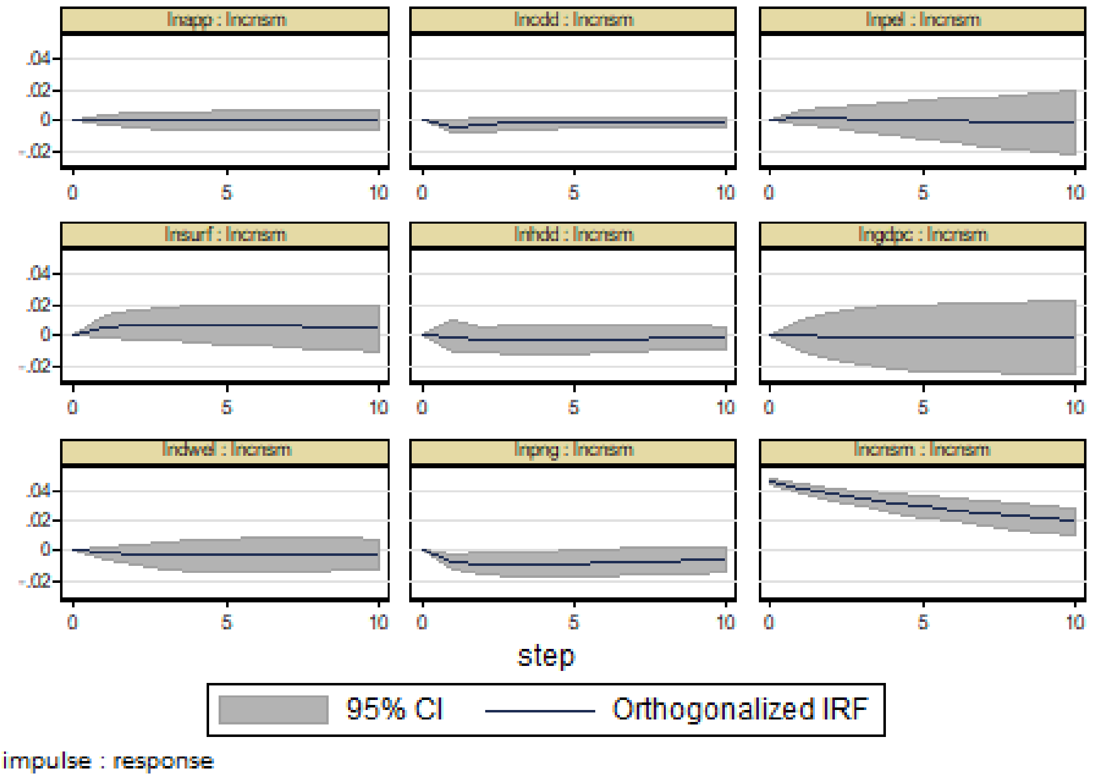

Figure 4.1. Impulse response functions (IRFs) for electricity consumption (lncnsm) to one standard deviation shock

As far as climate conditions are concerned, the response of electricity consumption to hdd innovations is negative across all years. In cdd innovations, electricity responds negatively in all ten years. It is worth mentioning, that, although the response is generally negative, there is an upward trend between the second and fourth year.

In the case of GDPC innovations, electricity consumption responds slightly positively in the very short - run, i.e. the first two years, and then the response is slightly negative and stable.

When it comes to households' conditions, consumption responds positively across all the years in shocks in dwellings' surface, which is an indicator of the household's size. Notably, the trend is down after the fourth year. This supports the logical thought that the bigger a household is, the more people live in it and the more electricity they consume. A quite surprising finding is that electricity consumption seems to not respond in appliances innovations and is stable around zero level. Finally, consumption tends to react slightly positively to dwelling stock innovations in the first year and slightly negatively during the remaining years. One would expect a positive reaction since by several residents, electricity consumption should increase. Since this is not our case, this could mean that houses are more energy-efficient and consume less energy.

4.4 Variance decomposition analysis (VDC)

Finally, we proceed with the VDC analysis and the results are shown in Table 4.5. According to them, 4.63% of the forecast error variance of electricity consumption can be explained by disturbances in the price of natural gas, while disturbances in the price of electricity explain only 0.007% of the variation in electricity consumption. These findings support our previous results from both the pVAR estimations and the IRFs. GDPC explains only 0.08% of the variation in consumption, while our previous analysis supports this finding since the response of electricity is not significant.

When it comes to climate conditions, hdd is found to affect more electricity consumption compared to cdd (0.43% and 0.29% respectively). This is not supported by the IRFs, which showed that a standard deviation shock in cdd explains better the response of electricity consumption. Finally, when it comes to households' conditions, disturbances in surface area and number of appliances explain 3.29% and 0.001% of electricity consumption’s variation, as confirmed by the IRFs graph, while the stock of dwellings explains 0.49% of consumption variation.

Table 4.5. Variance decompositions for the model

Variables	**Periods**	**lncnsm**	**lngdpc**	**lnpel**	**lnpng**	**lnhdd**	**lncdd**	**lndwel**	**lnsurf**	**lnapp**
lncnsm	10	0.9069958	0.0008252	0.0007999	0.0462941	0.0042458	0.0029087	0.0049664	0.0329464	0.0000176

CHAPTER 5: DISCUSSION AND CONCLUSIONS

Global challenges like climate change, coupled with a growing population, force policymakers in the EU to seek new ways of producing and consuming in a way that respects the ecological boundaries of our planet. At the same time, it is crucial to achieving sustainability by implementing innovative measures and strategies relating to the use and consumption of products (in our case, electricity), while ensuring the prosperity of European people. All these led to the introduction of a new term: bioeconomy.

Our analysis tries to contribute to the overall discussion concerning electricity demand in the residential sector while taking into consideration the importance of energy efficiency and mitigation of climate change in the bioeconomy framework. More specifically, we attempt to estimate the main factors that drive residential electricity demand in the EU.

Initially, we used various econometric tests (Levin-Lin-Chu, Harris-Tzavalis, Breitung, Im-Pesaran-Shin, Fisher-type test, Hadri Lagrange test) to test if there is a unit root. Our tests revealed that there is a unit root, therefore we proceeded with the cointegration analysis. The results reveal that there is a structural relationship between our sample variables.

Taking into consideration the fact that, according to OECD (2008), income is expected to increase in the following decades and energy demand is anticipated to follow an upwards trend, our analysis should be informative in this direction. This is supported by the IRFs in the short - run, which showed that the response of electricity consumption is positive in GDPC innovations, which is a quality proxy of income, during the first two years. Then, it becomes slightly negative. VDC analysis showed that GDPC innovations explain only a little electricity consumption fluctuation, while, according to our pVAR analysis, GDPC is not significant and is slightly negative. This can be confirmed by the existing literature, which states that the effect of income, expressed here by GDPC, has a low impact on electricity consumption once other variables, e.g. appliances, are introduced.

Prices of electricity and natural gas seem to also affect the level of residential electricity consumption. Electricity consumption seems to be more susceptible to natural gas price innovations compared to electricity prices. Also, residential consumption responds negatively to natural gas price innovations, while it responds positively to electricity price innovations in the first seven years, and then slightly negatively. These results are supported by both the IRFs and VDC analysis. These are expected results since (a) most EU Member States' final energy consumption is covered by natural gas and (b) natural gas and electricity are substitute goods. Taking into consideration that natural gas is a fossil fuel, therefore a non-renewable source of energy, EU policymakers should take action towards the promotion of RES.

Both the IRFs results and the VDC analysis also reported that the bigger the households are, which means that more people live in them, the bigger the electricity consumption is. Therefore, it is important to take into serious consideration the dwellings' characteristics if policymakers want to design more effective policies. These policies must "simultaneously lower emissions and lower the economic strain on people – by making sure that everyone can get a good job in the new economy; that they have access to basic social protections like health care, education and daycare; and that green jobs are good, unionized, family-supporting jobs with benefits and vacation time" (Klein, 2019).

But this is not enough. Our previous analysis showed that temperature plays an important role in electricity consumption. According to IRFs, electricity consumption responds negatively to both hdd and cdd innovations. In the case of cdd, it is worth mentioning that, although the response is generally negative, there is a trend upwards between the second and fifth year. VDC analysis shows that electricity consumption is affected negatively by hdd innovations and hdd ones. Our pVAR analysis revealed that consumption is affected positively by heating degree days which is expected since electricity in the EU is mainly used for the dwellings' heating needs, and not the cooling ones. Taking into consideration that electricity is mainly used for the dwellings' heating and cooling needs, it is also of utmost importance to design a low energy consuming (and low–carbon) heating and cooling system, which will be energy - efficient and flexible enough to adapt to future climate conditions' changes. Besides, governments could give financial incentives to all people, and not just the poorer ones, to install -for example- solar panels, use electricity from biomass or renovate their home in an energy-efficient way.

It is noteworthy that IRFs showed that innovation in the number of electrical appliances, such as refrigerators, freezers, washing machines, dishwashers and TVs, seem to affect almost not at all the electricity consumption, while VDC analysis confirmed that their effect on the electricity consumption is almost non-significant. This, however, does not mean that people, especially those who have old technology appliances, should not invest in energy-efficient appliances. And this finding should not prevent policymakers from taking the appliances' characteristics into account when designing new energy efficiency policies.

Variations of electricity consumption are explained to a large extent by dwellings stock and surface innovations, as reported by the VDC analysis. According to IRFs, the surface is positively affected by surface innovations during the ten years, and positively affected by dwelling stocks only in the first year (then slightly negatively). Therefore, considering that the population is expected to increase, policymakers should revise national technical guidelines and support the construction of timber buildings. Wood is a material with good thermal insulating capacities, which, compared to concrete, results in less electricity consumption and better indoor living conditions.

To have a better understanding of the dwelling characteristics and design better policies, persons per household should be included. Although the surface is an indicator of a dwelling's size, residential electricity demand is affected not only by its surface, but also by the number of people living in it. Also, in a future analysis, maybe it would be a good idea to include a variable representing RES or energy efficiency. Also, due to technical problems, (a), we could not perform the Akaike Information Criterion (AIC) in unit root analysis to select the optimal value of the p-VAR, and the lag length of one was chosen after the results of simple regressions (b) didn't impose a variables' decreasing ordering, from the most exogenous to the least one as suggested in the empirical literature (Greene, 2003) concerning VDC analysis. Therefore, these issues should be considered in future analysis.

Also, this thesis wants to point out that, from the prospect of bioeconomy, it is crucial, for the sustainability of our environmental, economic and social system to reform the European renewable energy legislative framework. This will lead to the promotion of electricity from RES, which can lead to a reduction of GHG emissions and provide affordable electricity while creating green jobs and stabilizing economic growth (Belaid and Youssef, 2017).

This new framework should support and promote more the creation of more energy communities[12] in Europe. These communities support renewable electricity generation and consumption, while mitigating GHG emissions and tackling energy poverty. Besides, they:

- promote the active participation of citizens and the use of local resources,
- lead to reduced costs of the energy vectors procurement,
- result in supply, which is of better quality and more reliable (Ceglia et al., 2020),
- promote the concept of cooperation between stakeholders.

Finally, it must be highlighted that when we talk about bioeconomy, we must also take into serious consideration innovative measures and strategies which will result in a more sustainable, energy-efficient residential sector while respecting our planet's limited resources and boundaries. Renewable electricity in the residential sector, especially when it comes from biomass, can lead to a more sustainable future, therefore it is of utmost importance to be supported by policymakers. In this direction could help the reformation of the renewable energy legislative framework in the EU. More green jobs are expected to be created which also leads to unemployment reduction, the prosperity of European citizens, and promotion of research and development (R&D). By upgrading national building guidelines and promoting the use of timber constructions, building innovations will arise while decreasing the use of electricity for heating and cooling needs. Also, giving all people incentives to increase the energy efficiency of existing and new buildings by using low energy consuming systems/ appliances and renewable electricity results in decreasing GHG emissions and further research and development. If such measures would be implemented, then our future would be more environmentally, economically, and socially sustainable which is the center of bioeconomy.

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[12] Energy Communities are a set of energy services (private, public or mixed) located in a specific area in which end – users (citizens, firms, public authorities, etc.) cooperate to satisfy their needs by using energy generation solutions that support RES (Ceglia et al., 2019).

APPENDIX

Abbreviations

EU	European Union
EC	European Commission
UNFCCC	United Nations Framework Convention on Climate Change
CO_2	Carbon dioxide
GHG	Greenhouse gas
IEA	International Energy Agency
RES	Renewable energy sources
EU - ETS	European Union Energy Trading System
CRES	Center for Renewable Energy and Savings
REP	Renewable energy policy
LTCS	Long – term climate strategies
EEA	European Environmental Agency
SDG	Sustainable Development Goal
NGO	Non – governmental organization
NECP	National Energy and Climate Plan
PV	Photovoltaic
FiT	Feed-in-tariff
NREAP	National Renewable Energy Action Plan
R&D	Research and development
MW	Megawatt
GW	Gigawatt
TW	Terawatt
ktoe	Kilotoe (kilotonnes of oil equivalent)
Mtoe	Megatoe (millions of tonnes of oil equivalent)

TPES	Total primary energy supply
TFC	Total final consumption
kwh	Kilowatt-hour
TWh	Terawatt hour
EIA	Energy Information Administration
GDP	Gross Domestic Product
ACER	Agency for the Cooperation of Energy Regulators
MoU	Memorandum of Understanding
HAEE	Hellenic Agency for Energy Economics
PPC	Public Power Cooperation
RAE	Regulatory Authority of Energy
HTSO (in Greek: DESMIE)	Hellenic Transmission System Operator
LAGIE (in Greek)	Operator of the Electricity Market
IPTO (in Greek: ADMHE)	Independent Power Transmission Operator
HEDNO (in Greek: DEDDHE)	Hellenic Electricity Distribution Network Operator
ATHEX	Athens Stock Exchange
HenEx	Hellenic Energy Exchange
CHP	Combined Heat and Power
EPBD	Energy Performance in Buildings Directive
nZEB	nearly Zero Energy Building
EPC	Energy Performance Certificate
HVAC	Heating, ventilation and air conditioning
REPB (in Greek: KENAK)	Regulation on the Energy Performance of Buildings
TIR	Thermal Insulation Regulation
TCG (in Greek: TEE)	Technical Chamber of Greece
LMDI - I	Logarithmic Mean Divisia Index
DHW	Domestic hot water
ERDF	European Regional Development Fund

ROP	Regional Operational Programme
OP CEI	Operational Programme “Competitiveness, Entrepreneurship, Innovation”
NSRF 2014 – 2020 (in Greek: ESPA 2014 - 2020)	National Strategic Reference Framework 2014 - 2020
GDPC	Gross Domestic Product per capita
HDD	Heating degree days
CDD	Cooling degree days
pVAR	Panel VAR
IRF	Impulse Response Function
VDC Analysis	Variance Decomposition Analysis
R&D	Research and Development

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