STUDY ON RENEWABLE ENERGY SOURCES IN THE AOOS BASIN – BEYOND HYDROPOWER EXPLOITATION

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Towards a truly sustainable energy future in Northern Pindos

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Cover photo

Aoos river, running through the rocky gorge that is formed within its first kilometers in Greece, before reaching Konitsa.

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THE "ENERGY LANDSCAPE" OF GREECE

The Greek energy system is different from most EU Member States energy systems, as, apart from the mainland, it comprises of a large number of autonomous island systems and is highly dependent on conventional fuel imports (higher than the EU average). Lignite is, in fact, the main fossil fuel produced in Greece and is almost exclusively used for electricity generation. In this Chapter some main facts and figures regarding the structure of the electricity system, as well as the energy production and consumption, are presented.

Installed Capacity and Electricity Generation in Greece

Regarding the Greek electricity generation mix in the Interconnected System of the country (mainland) in 2017, lignite, a significant domestic fossil fuel resource in Greece and an important component of the country's energy security, overpassed Renewable Energy Sources (RES) and hydroelectric production after the latter's dominance in 2016 energy mix. More specifically, lignite production in 2017 increased by 9.97% (1,486 GWh) compared to 2016, as opposed to the sharp decline of 23.26% (- 4517 GWh) of 2016 compared to 2015 (RAE, 2018). Similarly, natural gas production continued the upward trend of the last two years and amounted to 15,400 GWh (against 12,500 GWh in 2016 and 7,300 GWh in 2015), rising up to 23.06% of the total power production. The hydroelectric production declined from 4,800 GWh in 2016 to 3500 GWh in 2017 (by 28.62%), following the downward course of the previous year. RES production and Combined Heat and Power Production (CHP) continued the upward course of the previous year and was equal to 10,600 GWh, recording an increase of 3.67% compared to 2016. Production by other fuels in the Interconnected System of the country was at zero level for a third consecutive year. The numbers indicate the importance of lignite and natural gas in security of supply for Greece. Overall, domestic production showed an increase of 7.91% compared to 2016. The share of energy sources for electricity generation in Greece for the year 2017 are presented in Figure 1.

Table 1 and Figure 2 present the monthly fluctuation of actual generation by fuel, reflecting seasonal demand changes, as well as the impact of stochastic factors and regulatory measures. In 2017, electricity demand showed a very strong increase in percentage points during January and February (12.3% and 6.8%, respectively, compared to the corresponding months of the 2016). This was related to the electrification of heating, along with the great drop in temperature and the intense weather deterioration during these two months, in comparison with the corresponding months of the previous year, which on the contrary, were the warmest of the last 100 years in Greece. On the other hand, a significant reduction in electricity demand (of 6.2%) was noted in December 2017 compared to December 2016. This was mainly due to the relatively mild temperatures, which prevented - to a certain extent - the frequent use of electric heaters.

Overall, lignite production experienced a sharp fluctuation between 1080 GWh and 1708 GWh on a monthly basis. A significant decline in lignite production was marked in May and September of 2017, following the respective decline in demand, the same months. The maximum value of lignite production was recorded in January 2017 and was equal to 1708 GWh. Lignite units greatly contributed to covering demand during the crisis of natural gas in January and February of 2017, although some of them were out of service due to planned work of annual maintenance, some of them faced serious damages and some others had poor performance due to extreme weather conditions and poor lignite quality (ADMIE, 2017a).

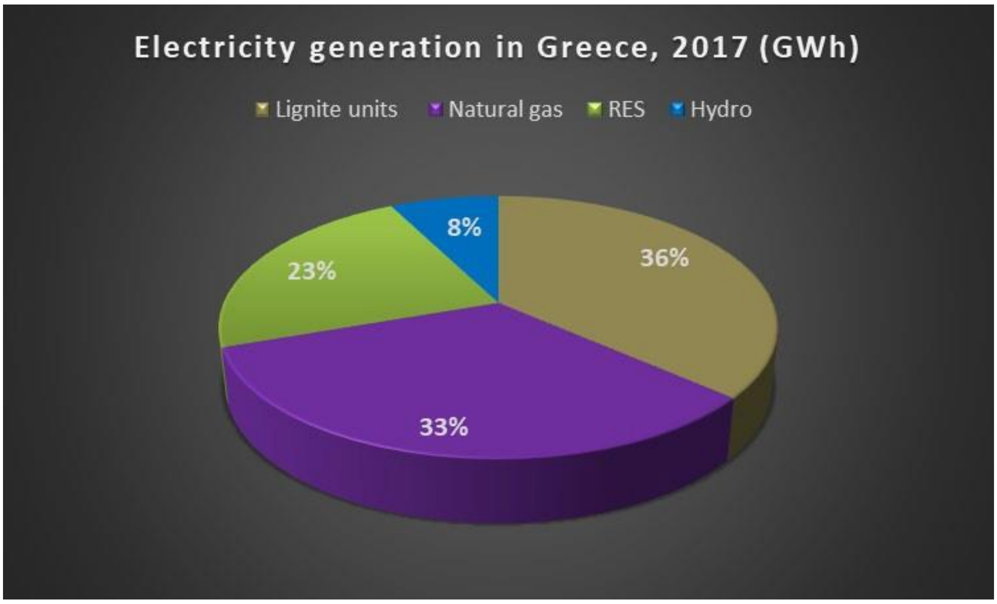


Figure 1. Share of energy sources for electricity generation in Greece, in 2017 (ADMIE, 2018).

Natural gas production presented a significant increase in 2017, showing great variations, with monthly levels varying between 764 GWh (in March) and 2001 GWh (in January). The highest production from natural gas units was marked in January 2017, during the gas crisis. During this period, the National Natural Gas System Operator (DESFA S.A.), due to restrictions in delivering liquefied natural gas, upgraded the alarm level from Level 0 (Normal Operation Level) to Level 2 (Alert Level) in the national gas system (ADMIE, 2017b; RAE, 2018). The management of this energy crisis under the coordination of the Regulatory Authority for Energy (RAE) in Greece, as the Competent Authority, along with the assistance of all institutions and market participants, had excellent results in terms of security of supply, as any interruption of power supply to consumers was prevented, even marginally (RAE, 2018).

Hydroelectricity presented lower levels compared to 2016, ranging from 146 GWh in April 2017 to 658 GWh in January 2017. During the winter gas crisis of 2017, the water reserves of hydroelectric plants were intensively used, in order to meet electricity demand. This resulted in the depletion of water reserves, which was reflected in a reduced production during the months after the gas crisis.

RES production[1], as a stochastic factor depending on climatic conditions, presented expected seasonal fluctuations, ranging from 681 GWh in November (due to low winds and lower sunshine) to 1168 GWh in

[1] It is noted that RES do not include big hydropower stations; hydroelectric stations with capacity less than 15MW are operating under the legislation applied for RES in Greece.

August 2017, maintaining high levels from April till August. The extreme weather conditions occurred mainly in January 2017 resulted in a relatively reduced production this month.

Table 1. Monthly electricity production in GWh by generation fuel in Greece in 2017 (RAE, 2018)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Lignite	1,708	1,573	1,331	1,129	1,080	1,215	1,466	1,346	1,202	1,460	1,529	1,347	**16,387**
Natural Gas	2,001	1,240	764	764	972	1,417	1,500	1,603	1,223	1,111	1,422	1,361	**15,397**
Hydro	658	214	218	146	210	284	406	362	214	196	234	315	**3,457**
RES	770	839	959	838	960	729	988	1,168	772	839	681	1,022	**10,564**
TOTAL	**5,137**	**3,867**	**3,272**	**2,878**	**3,222**	**3,644**	**4,359**	**4,479**	**3,411**	**3,606**	**3,886**	**4,044**	**45,805**

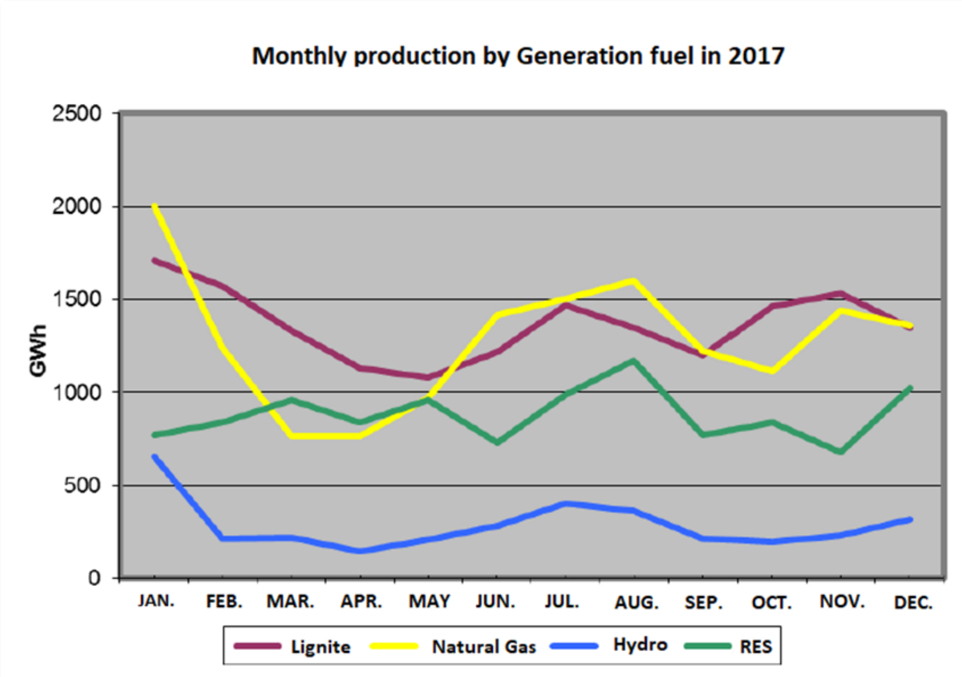


Figure 2. Monthly electricity production by generation fuel in Greece in 2017 (RAE, 2018)

Figure 3 illustrates the evolution of electricity generation in Greece the past -approximately- 40 years, including the net result of imports-exports. As shown, the dominance of lignite has decreased over the last decade. More specifically, electricity generated from lignite fell from 31 TWh in 2012 to 17 TWh in 2017, mainly due to growth of renewable generation by wind and solar, more extensive use of natural gas, increased energy imports and a lower overall electricity demand, as result of the economic crisis (Roumpos et al., 2018).

As regards installed capacity, Table 2 presents the evolution of installed capacity by fuel in Greece the past 3 years, based on Monthly Energy Balance Reports of the Transmission System Operator - ADMIE S.A. (ADMIE, 2016; 2017c; 2018). As shown, a slight drop in the lignite installed generation capacity was noted between 2015 and 2016, by 3%, while also the final closure of the oil generation units of PPC (730 MW) took place. For the same period, installed generation capacity of RES presented a small increase (by 2%), while also a higher increase of RES installed capacity (of 5%) was noted between 2016 and 2017. In 2017, RES amounted to a total of 5,138 MW, which is the result of the increase in wind farm capacity. Moreover, hydropower plants increased their installed capacity by 5% between 2016 and 2017. In 2017, the total installed capacity, including renewables, reached 17,128 MW.

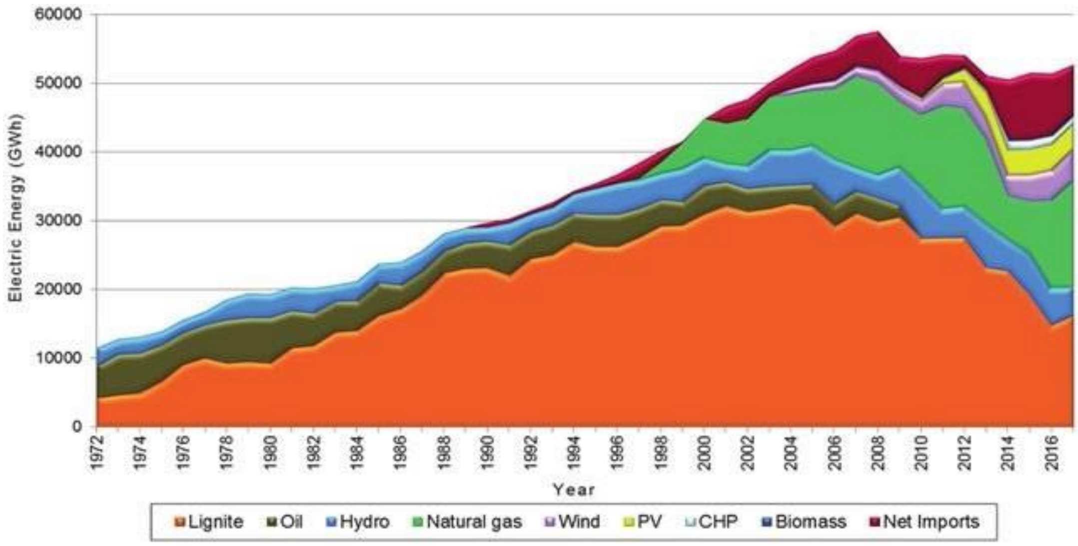


Figure 3. Evolution of electricity generation by fuel in the Interconnected System of Greece since 1972, including the net result of imports-exports (Roumpos et al., 2018).

Table 2. Installed capacity by type of fuel in Greece (ADMIE, 2016; 2017c; 2018)

FUEL	Installed Capacity 2015 (MW)	Installed Capacity 2016 (MW)	Installed Capacity 2017 (MW)
Lignite	4,462	4,337	4,337
Natural Gas	4,642	4,482	4,482
Oil	730	0	0
Hydro	3,017	3,017	3,170
RES+ high eff. CHP	4,763	4,871	5,138
TOTAL	**17,615**	**16,708**	**17,128**

Renewable Energy Production in Greece

As shown in Table 3 and Figure 4, the installed capacity of RES units (excluding large hydroelectric plants) is constantly increasing since 2012, with a total increase of 64% within 7 years (2012 - 2018), mainly due to the installation of new biomass units and the installation of new wind power plants. At the end of 2018, the installed capacity of RES units amounted to 5828 MW, showing an increase of 5.5% compared to 2017. The new biomass units added a capacity of 21 MW (33.9% increase compared to 2017) and the new wind power plants a capacity of 235 MW (increase of 9% compared to 2017), as shown by the breakdown by technology. In fact, as regards the two technologies (wind power plants and biomass/biogas stations), a stable investment activity in these sectors seems to have been established since 2017.

Furthermore, it should be noted that, in the light of a change in the institutional framework with the Law 4414/2016, a remarkable increase in the development of small hydroelectric stations started appearing in 2017, with an increase of their installed capacity by 3.4% compared to 2016, as well as an increase of 3.9% in the period 2017-2018. As regards PV technology, the installed capacity of PV units increased by 40 MW in 2018 (1.8% compared to 2017), due to the completion of many projects of the pilot competitive process (which was carried out by RAE at the end of 2016) and to the inclusion of the selected projects in the country's electrical system.

Table 3. Installed capacity of RES units (MW) - excluding big hydroelectric plants - between 2012 and 2018 (RAE, 2018; DAPEEP, 2013; 2014; 2015; 2019).

	2012	2013	2014	2015	2016	2017	2018
Biomass	45	47	47	52	58	62	83
small Hydro <10 MW	213	220	220	224	223	231	240
PV on roofs <10 KW	298	373	375	376	375	375	375
PV	1,238	2,210	2,221	2,229	2,230	2,230	2,270
Wind	1,753	1,810	1,978	2,089	2,370	2,625	2,860
TOTAL	**3,547**	**4,660**	**4,841**	**4,970**	**5,256**	**5,523**	**5,828**

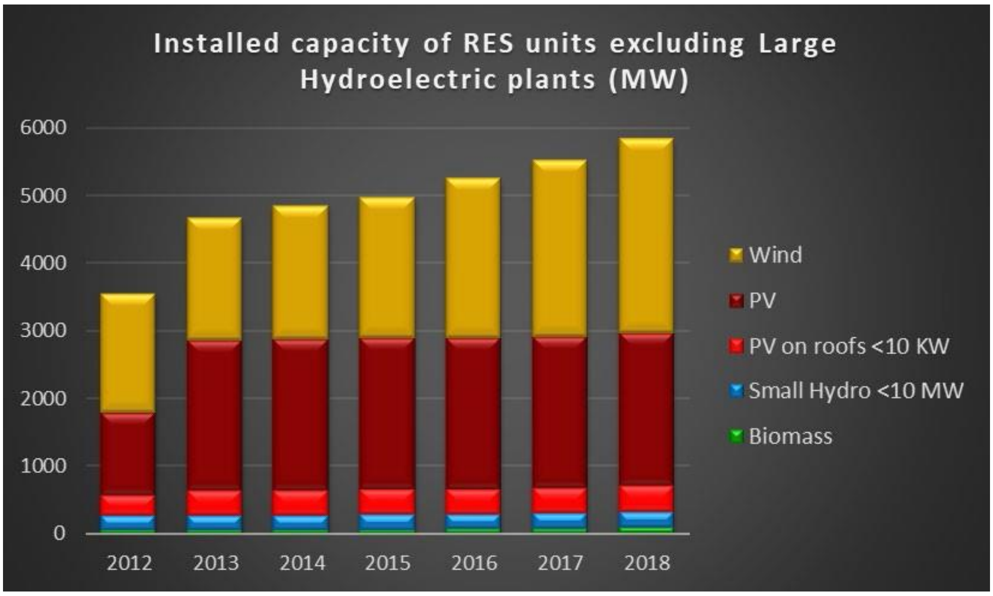


Figure 4. Installed capacity of RES units (MW) excluding large hydroelectric plants between 2012 and 2018 (RAE, 2018; DAPEEP, 2013; 2014; 2015; 2019).

Regarding the RES mix, as expressed by the installed capacity (MW) per technology, the PV stations have lost the leading position they had gained since 2013, and up to 2016. At the end of 2018, wind stations covered the greatest part of the total installed capacity of RES units, representing 49% of the total capacity, while PV stations (including PV on roofs) were ranked second, representing 45% of the total installed capacity. The smallest percentages are preserved by biomass stations and small hydroelectric stations, representing 1.4% and 4% of the total installed capacity of RES in 2018, respectively. The total electricity generation from RES units (excluding large hydroelectric plants) is also steadily increasing since 2012, mainly due to the installation of new biomass units and the installation of new wind power plants, with a total increase of 73% within 7 years (2012 - 2018). Especially for 2018, the increase of RES installed capacity by 5.5% compared to 2017 was accompanied by an increase in electricity generation by 7%. Only in 2014, total RES generation decreased (by 4% compared to 2013), mainly due to lower generation levels of wind power plants. Moreover, generation of small hydroelectric stations in 2017 decreased by 19% compared to 2016, due to significantly lower annual precipitation levels.

Current situation of energy consumption in Greece

In terms of the structure of the gross energy consumption per fuel, the most important change having taken place in Greece was the introduction of natural gas in the energy system in 1996, initially for electricity generation and then in final consumption sectors. As a result, oil products' share in the gross energy consumption decreased. Nevertheless, oil products still remain the main energy form in the Greek energy balance, mainly due to the dominance of oil in transportation and heating sectors (Mirasgedis et al., 2017). Similarly, the solid fuels' share (mainly lignite for electricity generation) presents a decreasing trend the last decade. The RES share consisted largely of biomass and hydropower until 2005, while the introduction initially of wind and then of photovoltaic energy in the energy mix started to become significant, exceeding 10% of the total gross and final energy consumption, in 2017.

Final energy consumption

Figure 5 shows the evolution of the final energy consumption in Greece by type of fuel (solid fossil fuels, oil and petroleum products, natural gas, electricity, renewable energy, etc.) during the last decade. The term 'final' refers to end-users, i.e. industry, transport, households, services and agriculture. The overall energy consumption presents a constant decreasing trend until 2013, reflecting the effect of the economic crisis of the country. The largest decrease within the 8-year period examined (2006 – 2013) was noted in fossil fuels and oil-petroleum products (decrease by 47% and 42%, respectively), while, conversely, consumption of natural gas and renewable sources, although with some variations, generally increased during the same period (increase by 32% and 21%, respectively). However, the decreasing trend of energy consumption has been reversed since 2014, and up to 2017. This period (2013 - 2017) was mainly characterized by an increase in consumption of natural gas and renewable sources (by 30% and 25%, respectively). In general, liquid fuels and electricity are the main forms of energy consumed in Greece (52% and 29%, respectively for 2017), while also the RES share is constantly increasing.

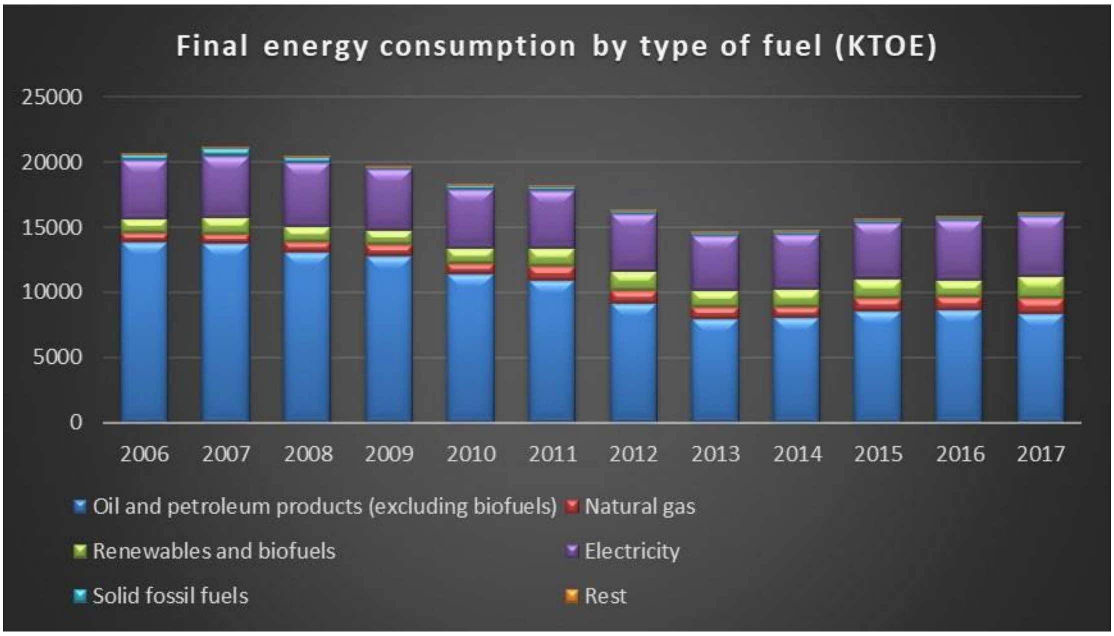


Figure 5. Evolution of final energy consumption by type of fuel in kTOE (Eurostat, 2019).

Share of renewable energy in energy consumption

Figure 6 depicts the evolution of the share of renewable energy in gross final energy consumption the last 14 years, an indicator that measures how extensive the use of renewable energy in the country is. It is calculated on the basis of data collected in the framework of Regulation (EC) No 1099/2008 on energy statistics and complemented by specific supplementary data transmitted by national administrations to Eurostat (Eurostat, 2019). As shown, the use of renewable energy has dynamically entered energy markets in Greece. The share of renewable energy presents a constant increase since 2004, reaching 17% in 2017 versus 6.9% in 2004 (increase by 147% between 2004 and 2017), approaching -to some degree- the European 20-20-20 target of increasing the share of renewable energy in gross final energy consumption to 20% by 2020, according to Directive 2009/28/EU (18% set for the case of Greece). As a result, the policy line of substituting fossil fuels by renewable fuels and contributing to the decarbonization of the EU economy has developed to a large extent in Greece, especially during the last decade.

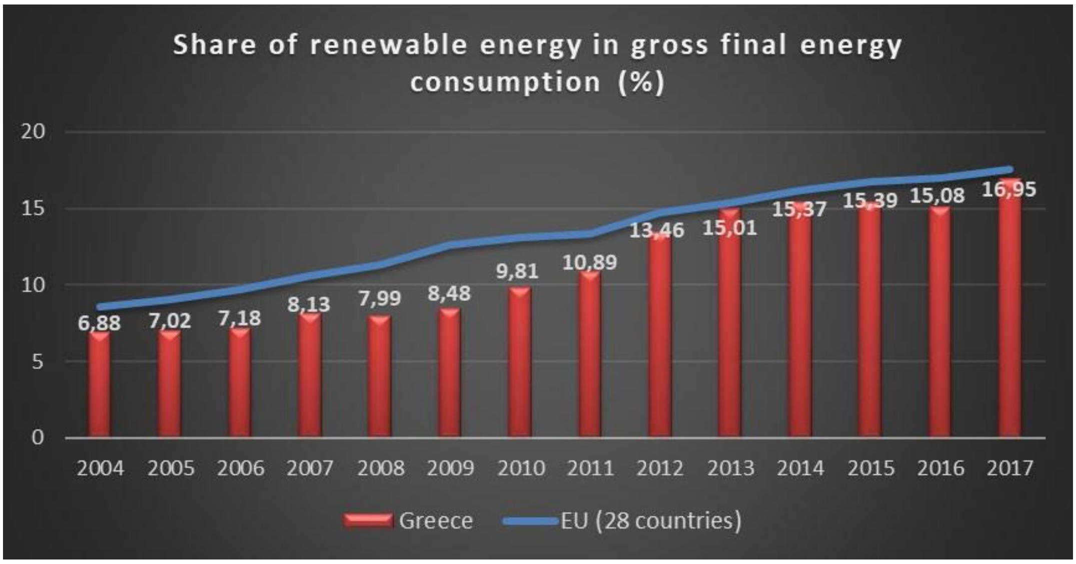


Figure 6. Evolution of share of renewable energy in gross final energy consumption (Eurostat, 2019).

Electricity consumption

The evolution of electricity consumption over the last 6 years (2013-2018) in Greece is presented in Table 4, per voltage category (low-medium-high voltage) and per customer category of the Interconnected System of the country. As shown, a continuous decreasing trend is marked during the period 2013-2016, a fact that is indisputably linked with the serious economic crisis of the country, with the drop of consumption being more intense in Low Voltage category (LV), i.e. households and professional customers up to 250 KVA. This trend was reversed in 2017, as energy consumption increased in almost all customer categories but, only temporarily, as it dropped again in 2018. Especially for 2018, electricity consumption reached 45898 GWh, marking a slight decrease (by 2%) compared to 2017 levels, according to data of the Hellenic Electricity Distribution System Operator (DEDDIE S.A.) for the middle voltage category (MV) and LV, and the Monthly Energy Balance Report (December 2018) about the Transmission System Operator (ADMIE S.A.) for HV (RAE, 2019). As a "rule of thumb", we can bear in mind that the total electricity consumption in Greece, of both the Interconnected System and the Non- Interconnected islands, is about 50 TWh.

Table 4. Evolution of electricity consumption per customer category in the Interconnected System of Greece, 2013-2018 (RAE, 2019).

	Year	Large industrial customers (GWh/year)	Household customers (GWh/ year)	Small Industrial & Commercial Customers (GWh/ year)	Other (e.g. agriculture, public, traction) (GWh/ year)	Total (GWh/ year)
LV	2013	-	15,973	9,560	3,640	**29,173**
	2014	-	15,569	9,523	3,735	**28,827**
	2015	-	15,817	9,245	3,277	**28,339**
	2016	-	15,048	9,192	3,385	**27,625**
	2017	-	15,651	9,344	3,285	**28,280**
	2018	-	14,767	9,324	2,983	**27,074**
MV	2013	-	-	8,904	1,487	**10,391**
	2014	-	-	8,179	1,477	**9,656**
	2015	-	-	8,351	1,473	**9,824**
	2016	-	-	8,643	1,478	**10,121**
	2017	-	-	8,764	1,536	**10,300**
	2018	-	-	9,049	1,486	**10,535**
HV	2013	6,599	-	-	1,168	**7,767**
	2014	6,702	-	-	1,314	**8,016**
	2015	6,805	-	-	1,150	**7,955**
	2016	7,062	-	-	1,115	**8,177**
	2017	7,268	-	-	1,028	**8,296**
	2018	7,351	-	-	937	**8,288**
TOTAL	**2013**	**6,599**	**15,973**	**18,464**	**6,295**	**47,331**
	2014	**6,702**	**15,569**	**17,702**	**6,526**	**46,499**
	2015	**6,805**	**15,817**	**17,596**	**5,900**	**46,118**
	2016	**7,062**	**15,048**	**17,835**	**5,978**	**45,923**
	2017	**7,268**	**15,651**	**18,108**	**5,849**	**46,876**
	2018	**7,351**	**14,767**	**18,374**	**5,407**	**45,898**

Main aspects of the energy policy in Greece

Greece, as a member of the EU, has built its energy strategy and policy upon the main pillars of the EU energy policy.

The 20-20-20 targets and the European Strategy for 2030 and 2050 (Energy Roadmap 2050)

In 2007, EU leaders endorsed an integrated approach to climate and energy policy that aimed to combat climate change and increase energy security, while also strengthening its competitiveness. As a result, the Directive 2009/28/EC of 23 April 2009 particularly promotes the use of energy from renewable sources, amends and subsequently repeals Directives 2001/77/EC and 2003/30/EC (LSE, 2019). In 2008, the European Commission proposed binding a legislation to implement the well-known 20-20-20 targets. This "climate and energy package" became law in 2009. The 20-20-20 targets include:

- Reduction of EU GHG emissions by at least 20% below 1990 levels by 2020
- 20% of EU energy consumption to come from renewable resources by 2020
- 20% reduction in primary energy use compared with projected levels, by improving energy efficiency

The EU committed to reduce its emissions to 30% by 2020, on condition that other major emitting countries commit to do their fair share under a global climate agreement. Member States agreed to limit GHG emissions between 2013 and 2020, according to a linear trajectory with binding annual targets. This would ensure a gradual move towards the 2020 targets, in sectors where changes take time to implement, such as buildings, infrastructure and transportation. To increase the cost-effectiveness of policies and measures, Member States were allowed to deviate from the linear trajectory to a certain degree (LSE, 2019).

The Renewable Energy Directive sets the following targets:

- At least 10% share of renewables in the final energy consumption in the transportation sector by 2020
- The biofuels and bio-liquids should contribute to a reduction of at least 35% of GHG emissions in order to be recognized. From 2017, their share in emissions savings should be increased to 50%.

The European Commission, after adopting the Energy and Climate Package for 2020 and the relevant Directives and Decisions, proceeded, on the 24th October 2014, to adopt a new set of important decisions aiming at a further decrease in greenhouse gas emissions and at the reform of the energy sector until 2030. Specifically, the following main targets were set (Mirasgedis *et al.,* 2017):

- A binding target to decrease greenhouse gas emissions at EU level by at least 40% in 2030 compared to the 1990 levels. This target will be collectively achieved by the Member States (the decision does not include national targets), with further interventions both in the Emissions Trading System sectors (which are expected to reduce emissions by 43% in 2030 compared to 2005), as well as in the sectors not included in the Emissions Trading System (by aiming at a 30% decrease in emissions compared to 2005).
- A binding target for RES share in the energy mix at EU level by at least 27% in the gross final energy consumption in 2030. For the time being, there is no target per Member State, although there are relevant consultations in progress, and this is expected to take place in the near future.
- An indicative target for the improvement of the energy efficiency at EU level by at least 27% in 2030, compared to a reference scenario. This target can be increased to 30% during the ongoing Efficiency Directive reform process.

A set of decisions and directive amendments are planned in order to achieve the targets, so as to define in greater detail the changes that will have to be made in the various sectors of the energy system economy towards this direction. Specifically, as regards the Emissions Trading System, the proposal to amend the Directive includes the following (Mirasgedis *et al.,* 2017):

- A 2.2% decrease in the maximum number of emission allowances that can be issued on an annual basis as of 2021 and 1.74% afterwards, in accordance with the 3rd period of the EU Emissions Trading System, until 2020.
- A reform of the rules for addressing the problem of carbon leakage. Specifically, the following measures are prescribed: focusing on the free distribution of emission allowances in the sectors with the highest risk of relocating their production outside the EU, granting a significant number of free allowances to new and developing facilities, improving the correlation between the freely distributed emission allowances and the production levels, as well as updating the benchmarks in order to take into account the technological innovations of the past decade.
- The adoption of supporting mechanisms so that the industry and electricity generation sectors can proceed to the necessary innovations and investments for the transition to a low carbon emission economy. Within this framework, two new funding mechanisms are proposed: (a) the innovation fund, with approximately 400 million for allowances, in order to demonstrate innovative technologies in the industry (this includes RES and carbon capture and storage) and (b) the modernization fund, with approximately 310 million allowances, in order to facilitate the modernization of the electricity

generation sector and, in general, energy systems, as well as the promotion of energy efficiency in the 10 poorest EU Member States (for the time being, these do not include Greece).

As regards the greenhouse gas emissions in the sectors outside the EU ETS (buildings, transportation, waste, agriculture, etc.), the European Commission proposed specific targets per Member State, as part of formulating the relevant Regulation[2]. For Greece, there is a requirement for a mere 16% decrease in 2030 compared to the 2005 levels. As far as the RES targets are concerned, Directive 2009/28/EC is under revision. The achievement of the 27% RES penetration in the gross final energy consumption of the EU in 2030 is expected to lead to a 50% RES penetration in electricity generation. No targets have been set per Member State. However, the Staff Working Document[3] of the European Commission contains indicative targets per Member State and for various scenarios/criteria for the necessary effort sharing. According to these, the RES penetration in the gross final energy consumption for Greece in 2030 ranges between 26% and 34%, amounting to 30% in the reference scenario (Mirasgedis *et al.*, 2017).

Particular emphasis is attributed to the promotion of RES in the heating/cooling sectors, to the promotion of next generation biofuels, electricity, hydrogen and renewable synthetic fuel in transportation, the limitation of the role played by traditional biofuels that compete in terms of food availability, as well as to the promotion of self-generation. Moreover, there is an intention to fully integrate the internal energy market by facilitating the construction of interconnection projects, particularly in energy isolated areas, such as Greece, Cyprus and Malta. The target for 2030 is a 15% electrical interconnection between Member States. Finally, as far as energy efficiency is concerned, in November 2016, the European Commission proposed the adoption of a binding target for improving the energy efficiency at EU level by 30% by 2030. This new target is part of a proposal by the European Commission to amend the Directive on energy efficiency. Specifically, the proposed policies to achieve the target include the following (Mirasgedis *et al.*, 2017):

- An annual decrease in energy sales at a national level by 1.5%
- Energy renovations carried out by the Member States in at least 3% of the buildings owned and used by the central government
- Compulsory use of an energy efficiency certificate during building selling and renting
- Development of National Energy Efficiency Plans every 3 years
- Installation of 200 million smart electricity meters and 45 million smart gas meters
- Energy inspection of large enterprises every 4 years
- Protection of consumers rights for easy and free access to current and past energy consumption data

All the aforementioned targets for 2030 are integrated in the Roadmap adopted by the EU for the development of a low carbon emission economy by 2050. In particular, the EU Roadmap aims at decreasing the greenhouse gas emissions in 2050 by 80% compared to the 1990 levels, through the exclusive implementation of national actions and without the utilization of international coal markets. For this reason, it will be necessary to apply suitable policies and measures in all Member States and in all sectors.

Specifically, according to Mirasgedis *et al.* (2017):

[2] Regulation of the European Parliament and of the Council on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 for a resilient Energy Union and amending Regulation No 525/2013 of the European Parliament and the Council on a mechanism for monitoring and reporting greenhouse gas emissions and other information relevant to climate change http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52016PC0482&from=EN

[3] Staff Working Document (2016) 418 Final.

- The emissions from the electricity generation sector may be eliminated by 2050, despite the requirement to cover additional energy loads in transportation and heating.
- In the transportation sector, emissions will have to be decreased by over 60% in 2050 compared to 1990. The main interventions are penetration of energy-efficient vehicles and biofuels, as well as the partial electrification of the sector.
- In the building sector, the decrease in emissions will have to reach a 90% level through the construction of passive house standard buildings, the renovation of the existing building stock and the integration of RES technologies into them.
- Decreases in emissions in the order of 80% will also be required by energy intensive industries through the application of more efficient and cleaner technologies.

The case of Greece within the frame of EU energy policy

The overall targets of the European Union for 2020 have been specialized and broken down among the Member States, through relevant decisions adopted. Particularly for Greece, the targets prescribed as part of the climate-energy set of measures for 2020 are as follows (Mirasgedis *et al.,* 2017):

- In accordance with Decision No 406/2009/EC (on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020), by 2020, Greece will have to reduce the non-ETS emissions by 4% compared to the 2005 emissions.
- Directive 2009/28/EC (on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC) prescribes that the RES share in the final gross energy consumption in 2020 will have to amount to 18% for Greece. The same Directive prescribes that "Each Member State shall ensure that the share of energy from renewable sources in all forms of transport in 2020 is at least 10% of the final consumption of energy in transport in that Member State".
- In accordance with Directive 2012/27/EU (on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC), Greece set the target for energy consumption not to exceed 24.7 Mtoe in 2020 (primary energy consumption) or 18.4 Mtoe (final energy consumption).

Law 3851/2010, with which Greece integrates Directive 2009/28/EC into the national legislation, sets the following national targets for RES penetration (Article 1, paragraph 3):

- 20% share of energy generated by RES in the gross final energy consumption. This is a more ambitious target compared to the provisions of Directive 2009/28/EC (18% RES share).
- At least 40% share of electricity generated by RES in the gross energy consumption.
- At least 20% share of energy generated by RES in the final energy consumption used for heating and cooling.
- At least 10% share of energy generated by RES in the final energy consumption in the transportation sector (adopting the relevant target of Directive 2009/28/EC).

Table 5 shows the achievement rates of the aforementioned national targets.

Table 5. Progress towards meeting national targets for 2020 (2005-2017) regarding RES penetration and limitation of GHG emissions (Eurostat, 2019)

Year	RES share: Gross final consump�on (%)	RES share: Transporta�on (%)	RES share: Hea�ng & Cooling (%)	RES share: Electricity genera�on (%)	Primary energy consump�on (Mtoe)	GHG emissions outside the ETS (Mt CO_2 eq)
2005	7.02	0.05	12.76	8.21	30.11	62.08
2006	7.18	0.73	12.42	8.92	30.08	59.57
2007	8.13	1.26	14.37	9.33	30.15	59.45
2008	7.99	1.06	14.22	0.65	30.31	59.12
2009	8.48	1.10	16.52	11.02	29.26	58.11
2010	9.81	1.91	17.92	12.31	27.05	55.79
2011	10.89	0.59	19.45	13.81	26.49	53.84
2012	13.46	0.90	23.44	16.36	26.33	48.16
2013	15.01	0.97	26.54	21.24	23.22	44.18
2014	15.37	1.31	26.99	21.92	23.08	44.41
2015	15.39	1.08	25.76	22.09	23.17	45.45
2016	15.08	1.61	24.57	22.66	22.84	44.90
2017	16.95	4.00	26.57	24.48	23.12	44.25
Target (2020)	**18.00 (20% from Law 3851/2010)**	**10.00**	**20.00**	**40.00**	**24.70**	**61.24**

At this stage, no long-term energy planning for Greece has been officially adopted. The last attempt to elaborate a long-term plan dates back to 2012, when there was a public consultation on the Roadmap 2050 by the then Ministry of Environment, Energy and Climate Change (YPEKA, 2012). Although this plan was never officially adopted by the Greek state, it still includes a set of scenarios for the evolution of the Greek energy system during the period until 2050. This specific plan will be discussed in the next chapter, with particular emphasis on the role of hydropower.

The Roadmap 2050 integrates the National Action Plans for Renewable Energy Sources and Energy Efficiency, which for the period aimed at a 20% RES penetration in the gross final energy consumption until 2020 and a 4% decrease in the non-ETS greenhouse gas emissions compared to 2005. Besides the future evolution of the energy system, the Roadmap 2050 also presents the evolution of the greenhouse gas emissions until 2050. Three (3) main groups of scenarios for the evolution of the energy system have been developed (Mirasgedis *et al.*, 2017):

- The *"Existing Policies"* Scenario (EP Scenario) assumes a conservative policy implementation for energy and the environment. It foresees a medium limitation of greenhouse gas emissions by at least 40% until 2050, compared to 2005. It also foresees a medium level of RES technology penetration and energy savings as a result of its conservative implementation policies.
- The "*RES Maximization Measures*" Scenario (RESMM Scenario) assumes RES maximum penetration at a 100% level in electricity generation and at a much larger scale overall, aiming at reducing the greenhouse gas emissions by 60%-70%, with high energy savings in buildings and transportation. The same scenario is examined in combination with electricity imports that will result in a cost decrease in the electricity sector due to the lower investments and purchase of electricity at lower prices (RESMM-a Scenario).

- The "*Minimum Cost Environmental Measures*" Scenario (MCEM Scenario), where the energy technologies' mix is selected based on the minimum cost policy for a 60-70% decrease in the greenhouse gas emissions, combined with high energy savings in buildings and transportation. The RES penetration level is quite high but does not exceed 85% in electricity generation due to a limitation in the required storage units. Based on the assumptions formed for the MCEM Scenario, an alternative scenario is also examined (MCEM-a Scenario), which assumes that, during the period 2035-2040, the carbon capture and storage technology (CCS) is integrated in two of the existing (and newest) steam-electric power stations using lignite (1.1GW power). This alternative scenario actually examines the possibility of extending the presence of domestic solid fuels in the electricity generation system.

Considering the abovementioned, it seems that further use of RES and great decrease in greenhouse gas emissions are priorities of Greek energy policy. The official long-term energy planning of the country, which will be issued within 2020 unexpectedly, will provide more certain targets and data. Nevertheless, RES will be at the forefront of Greek energy policy.

Electricity production in Greece has been based mostly on lignite until the beginning of the 21st century. After 2006, when RES started to develop rapidly, the electricity mix of the country has changed significantly. Nowadays, about one fourth of the country's electricity is produced by RES and 8% of the electricity comes from big hydropower plants (with capacity more than 15%), which are not operating like the other RES technologies. About one fourth of heating energy demand is also covered by RES. The economic crisis resulted in decrease in energy consumption. Following the EU energy targets, mostly oriented to greenhouse gas emissions decrease, Greece will further develop RES for the next 30 years. It seems that big hydropower projects will not be part of this effort for increasing the share of RES in energy consumption.

HYDROPOWER IN GREECE

In this Chapter the main aspects related to hydroelectrical energy in Greece are presented. More specifically, the development and present status of big and small hydroelectric plants is discussed. Some major impacts of hydroelectric power plants are analyzed, as well as social reactions against dam constructions. Finally, the role of hydropower in the country's energy strategy is presented.

Hydroelectric Energy Development in Greece and basic facts

Between 1927 and 1931 the first energy units, based on hydraulic energy, started operating in Greece; Glafkos (Peloponnese), Vermio (Western Macedonia), Ayia Chanion (Crete), and Agios Ioannis Serron (Central Macedonia). The total installed capacity of those units was 6 MW. After the foundation of the Public Power Corporation of Greece (DEI) in 1950, the electricity production in the country was based on two strategic pillars; thermal power station fired by lignite and big hydroelectric plants. Besides, lignite and water are the main "domestic fuels" of Greece and their exploitation was a central political strategy, supported not only by the conservative governments of the '50s and '60s, but also from progressive intellectuals (Batsis, 1977). Hence, until 1970, more than 1,000 MW of hydroelectric capacity were installed and until 1990 the total installed hydroelectric capacity of Greece exceeded 2,200 MW. After the decade of 1990, the growth rate of hydropower in Greece slowed down. The last, big hydroelectric unit was completed in 2012 (the one of Ilarionas, in river Aliakmonas, in the Region of Western Macedonia) and the total installed capacity of big hydropower stations is now 3,172.7 MW (Mamassis & Koutsoyannis, 2019). This is an important share, almost 30%, of the total installed electricity production capacity of the country, regarding conventional energy sources[4]. Big hydro plants in Greece cover, in average, 9% of the total electricity consumption.

The European and national energy policy targets have led to the rapid development of RES in Greece, especially after 2006. The RES targets include small hydroelectric power stations and not big hydroelectric stations. According to the standards applied in Greece, a small hydropower station must have installed capacity less than 15 MW (Mamassis et al., 2018). However, the RES technologies that were mainly developed in Greece, so far, are photovoltaics and wind generators. The small hydroelectric units represented 4% of the total RES capacity (Figure 9), in August 2019, and they produced 7% of the total RES energy (Figure 10), between January and August 2019 (DAPEEP, 2019). The energy production of small hydro plants covers about 1.5% of the total electricity consumption of the country. The growth rate of small hydroelectric plants in Greece is also considered rather low, especially when compared to other forms of RES. More analytically, the installed capacity of small hydro increased by 33% between 2009 and 2019, while the capacity of wind generators increased by 218% and the capacity of photovoltaics by 3,054%.

As shown in Table 6, although the installed capacity of big hydro plants is rather high in Greece, the capacity factor is low (17%), almost half compared to the European average[5]. It is noted that the capacity factor is defined as the ratio of an actual electrical energy output over a given period to the maximum possible electrical energy output over that period. The low capacity factor of big hydropower plants in Greece is, generally, related to the fact that they have been designed for covering the peak loads of electrical energy demand. The capacity factor of small hydro plants is significantly higher. For the period 2016-2018, it was, in average, 34% (DAPEEP, 2016; 2017; 2018). It even exceeded 70% during some months characterized

[4] As conventional energy sources for electricity production are considered thermal power stations (fired by lignite or natural gas) and big hydroelectric plants.
[5] https://setis.ec.europa.eu/system/files/Technology_Information_Sheet_Hydropower.pdf

by plentiful water potential, but it was less than 15% during some dry months (Figure 11). Compared to other forms of RES, small hydro plants have higher capacity factor than wind farms (26%) and photovoltaics (17%) and lower than biomass units (52%). The standard deviation of small hydro plants' capacity factor, as well as the difference between its the maximum and minimum values are the higher among the other RES technologies.

Table 6. The big hydroelectric power stations of Greece in operation (Dimolikas, 2018).

No.	Power Station Name	Location (Region/ Regional Unit)	Installed capacity (MW)	Average annual production (GWh)	Operating since	Capacity Factor
1	Agras	Central Macedonia/ Pella	50	35	1954	8%
2	Ladonas	Peloponnese/ Arkadia	70	260	1955	42%
3	Plastiras	Thessaly/ Karditsa	130	198	1962	17%
4	Kremasta	W. Greece/ Aitoloakarnania	437	848	1966	22%
5	Kastraki	W. Greece/ Aitoloakarnania	320	598	1969	21%
6	Edesseos	Central Macedonia/ Pella	19	25	1970	15%
7	Polifito	W. Macedonia/ Kozani	375	420	1974	13%
8	Pournari I	Epirus/ Arta	300	235	1981	9%
9	Sfikia	Central Macedonia/ Imathia	315	380	1985	14%
10	Asomata	Central Macedonia/ Imathia	108	130	1985	14%
11	Thisavros	E. Macedonia/ Drama	384	440	1988	13%
12	Stratos I	W. Greece/ Aitoloakarnania	150	225	1989	17%
13	Platanovrissi	E. Macedonia/ Drama	116	240	1989	24%
14	Piges Aoou	Epirus/ Ioannina	210	165	1990	9%
15	Pournari II	Epirus/ Arta	33	45	1998	16%
16	Ilarionas	W. Macedonia/ Kozani	165	330	2012	23%
TOTAL			**3,182**	**4,574**	**AVERAGE**	**17%**

Figure 7. View of Glafkos small hydroelectric unit, one of the oldest hydropower plants of Greece, which is still in operation. (Georgitsis & Sinnis, 2010)

Figure 8. View of Ilarionas dam and reservoir; the last big hydropower station founded in Greece[6]

[6] http://greekriverfriends.blogspot.com/2013/03/blog-post.html

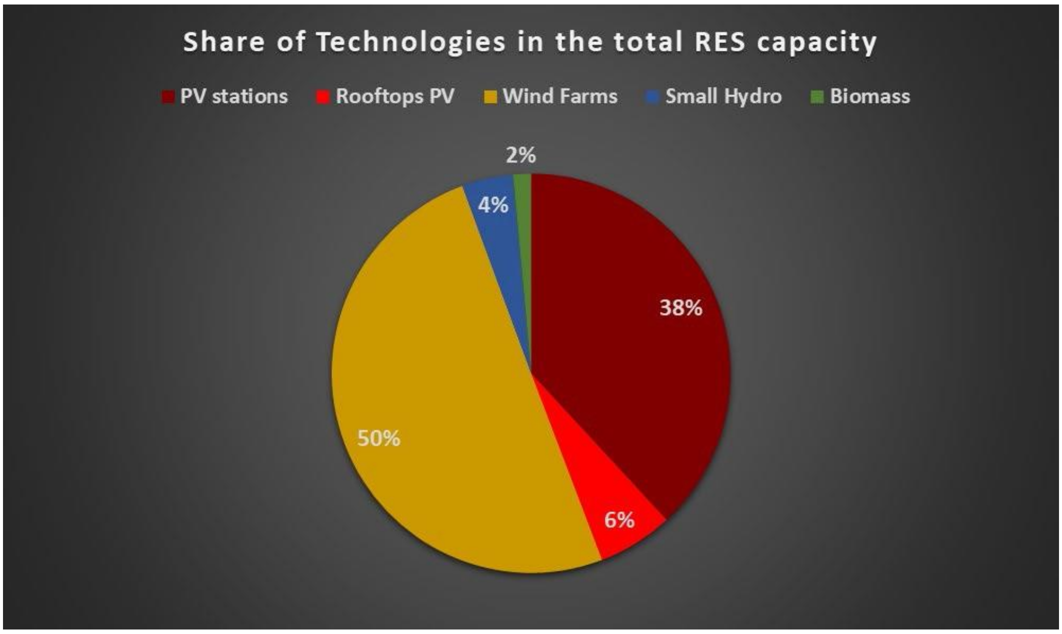


Figure 9. Percentile share of renewable technologies capacity in Greece (DAPEEP, 2019)

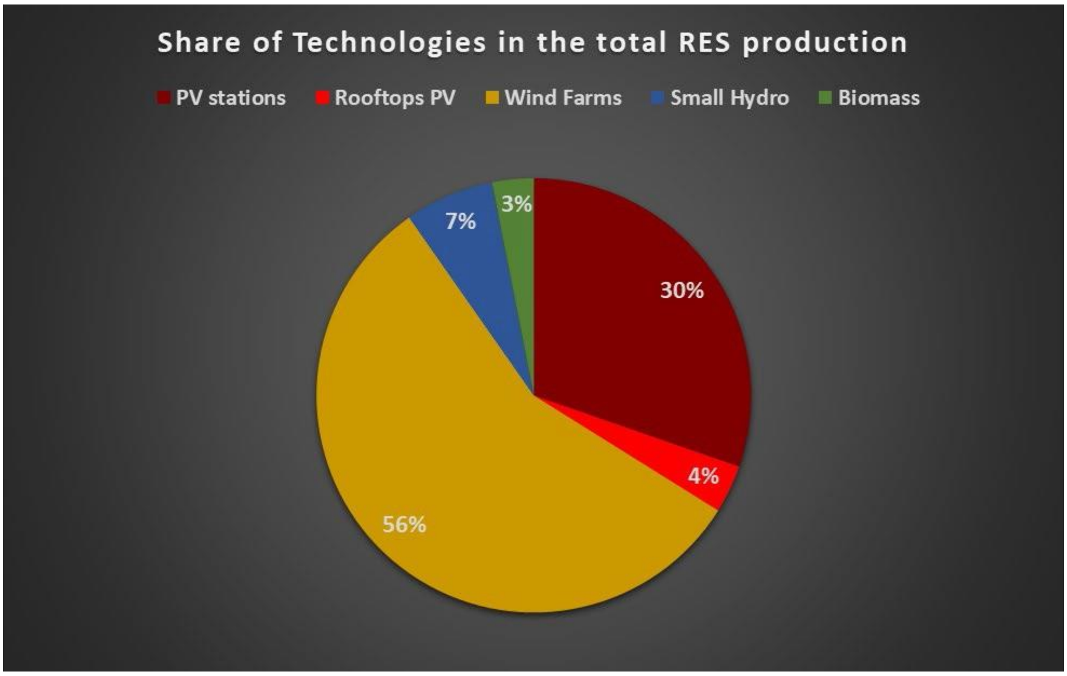


Figure 10. Percentile share of renewable technologies energy production in Greece (DAPEEP, 2019).

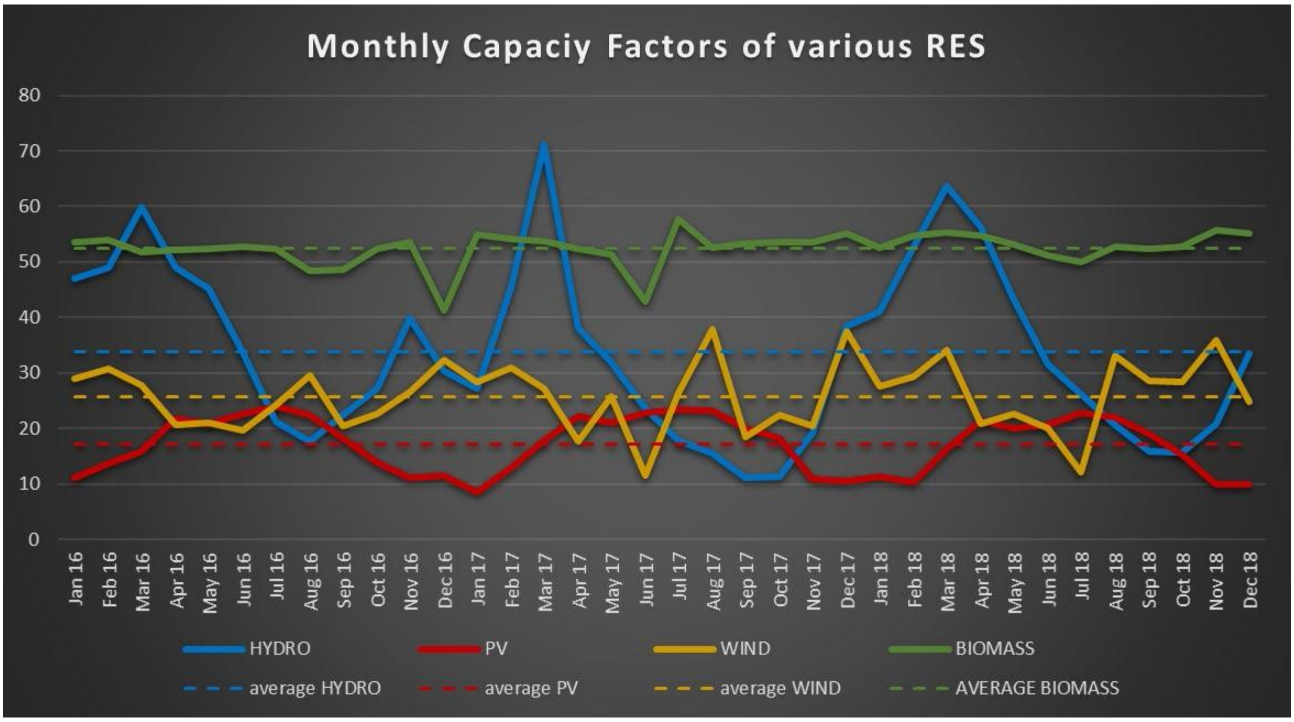


Figure 11. Monthly capacity factors of small hydro, photovoltaic, wing and biomass energy units in Greece for the years 2016, 2017 and 2018 (DAPEEP, 2016; 2017; 2018).

Impacts and social reactions caused by hydroelectric dams in Greece; some major case studies

Kremasta lake and dam

The lake of Kremasta was created after the construction of the Homonymous dam in 1966 in the Acheloos river, as water reservoir for the hydroelectric station. The dam is the biggest in Greece (height 153m) and the lake is the biggest artificial lake in the country (4.7 billion m^3). The power station is the one with the highest installed hydroelectric capacity in the country (437 MW). The landscape in the area of the lake is particularly beautiful and the lake is popular among inhabitants and visitors of the Aitoloakarnania and Evrytania regional units. However, such a major construction could not be free from great impacts. The river basin of Acheloos changed dramatically in a location, where three tributaries (Agrafiotis, Tavropos, Trikeriotis) join the main river. The creation of the Kremasta lake changed, totally, the life in a broad area. Some basic issues are summarized below (Ismailidou, 2011; Kotsias, 2013):

- 20 villages were flooded, and their inhabitants were forced to migrate. It is estimated that more than 2,000 people abandoned their homes.
- The land use of 90 km^2 of land was changed, in total, due to the creation of the lake. Among them many pieces of arable land, mainly used for olive trees and citrus trees cultivation.
- Some important monuments were flooded: the byzantine monastery of Episkopi (8th century AD); the stone bridge of Manolis (1659) that connected the two banks of Agrafiotis river[7]; the stone bridge of Tatarna (17th century AD) that connected Evrtytania and Aitoloakarnania and was characterized by special stone technique[8].

[7] https://www.info-karpenisi.gr/karpenisi-portal/tourism/sights/preview.jsp?id=20
[8] https://www.agrinionews.gr/agnosto-ean-diasozete-palea-gefyra-tatarnas/

- A major spring (Mardacha) was covered by the lake. This was a plentiful spring of potable water that also contributed to the river flow, especially during the summer.

Another important fact is the earthquake that happened in 1966 (magnitude 6.2R) and caused the death of 1 person, the wounding of 60 and the demolition of 750 houses. This earthquake, not a usual phenomenon in this area, was related to the filling of the Kremasta lake, after the completion of the dam (Papazachos, 1997).

Figure 12. View of Kremasta dam[9]

[9] https://eyrytixn.blogspot.com/2013/05/50.html

Figure 13. Photo of the Byzantine Monastery of Episkopi, covered now by the Kremasta lake[10]

Figure 14. View of the Manolis bridge, which is partly revealed when the level of Kremasta lake drops during the summer[11]

Plastiras lake and dam

This lake is the water reservoir for the Plastiras hydroelectric unit and provides water for the town and the plain of Karditsa. The dam has been built near the springs of Tavropos river. The lake is surrounded by impressive mountain masses. The beautiful landscape has made the Plastiras lake synonymous with mountain tourism in Greece. However, the creation of this beautiful lake and its use have caused significant impacts and changes in the broader area. More specifically:

- A small plain, the plain of Nevropoli with a total area of 24 km^2 was flooded by the lake. This was the main arable area utilized by the local societies. The creation of the lake changed the economy of the area and made many people from the surrounding villages to abandon them for many years[12].
- The communication between the two banks of the lake was difficult for many years, because the construction of the ring road that now exists in the area was delayed for many years. So, for some years, villagers were obliged to use boats for transport. This was a major problem, since local societies were not familiar with this kind of transport. In 1959, a sudden storm caused the death of 20 people which were travelling on a boat from the village of Neochori to the opposite bank of the lake (Filippou, 2015).
- The operation of the hydroelectric plant of Plastiras and the supply of water to the town of Karditsa are, essentially, a major diversion. Water from the Acheloos river basin (Tavropos belongs to Acheloos river basin) is transferred to the plain of Karditsa. Annually, more than 150,000,000 m3

https://eyrytixn.blogspot.com/2013/05/50.html
www.evrytanika.gr/index.php?option=com_content&id=1201329%3A-312-&Itemid=170
[11] https://www.info-karpenisi.gr/karpenisi-portal/tourism/sights/preview.jsp?id=20
[12] https://www.plastiras-lake.gr/index.php/istoria-limnis-plastira.html

of water are diverted from Acheloos river basin to Karditsa, through the operation of Plastiras dam (Mamassis & Koutsoyannis, 2019).

Figure 15. View of the Plastiras dam and lake[13]

The diversion of Acheloos: the dams of Mesochora and Sykia

The diversion of Acheloos is a major project aiming at transferring water from the Acheloos river to the plain of Thessaly. The precipitation in the plain of Thessaly is low (about 400 – 450 mm/year), while in the river basin of Acheloos exceeds 1,000 mm. The discussion for transferring water from Acheloos to the plain has started in 1925. Such a project is highly composite and difficult and could not be implemented, although it was part of the political debates for many decades. 60 years after the first discussions, in 1986, the preliminary studies and construction works for the Acheloos diversion started. A series of changes in the planning and design, litigation, social opposition, inefficient and fragmentary political decisions, and interventions by several bodies (ecological organizations, the EU etc.) caused great delays in the project and, finally, in 2011 the construction stopped, after a decision by “Symvoulio tis Epikrateias”, the Greek supreme constitutional court (Filippou, 2015; Aggelopoulos, 2017).

The Acheloos diversion project was based on the construction of dams, which would transfer, through tunnels, water to Thessaly. Since dams and reservoirs were planned, hydroelectric power stations were also part of the project. The main technical features of the Acheloos diversion project, especially regarding the interventions in Acheloos river flow, are summarized below (Filippou, 2015):

- Transfer of water from Acheloos river to the plain of Thessaly: This was designed to be realized through an underground tunnel, with a length of 17.5 km and diameter of 6.3 m. The initial planning described that the quantity of water transferred to Thessaly would be 1,100,000,000 m^3/year. The final plan reduced the quantity to 250.000.000 m^3/year. The water tunnel has been constructed, but is not in use, due to the interruption of the project.
- Hydroelectric power plant of Mesochora: The main parts of this plant were completed in 2001, but it is not operating, due to the interruption of the project. The power plant includes: (a) A dam with

[13] https://cyclinghellas.gr/el/tour/diimeri-ekdromi-multisport-family-adventure-meteora-limni-plastira/limni-plastira1/view-map?tmpl=component

150 m total height, (b) a water reservoir with total area 7.8 km^2 and maximum volume $358x10^6$ m^3, (c) a diversion tunnel with 645 m total length for the ecological water flow which was estimated to be 1.3 m^3/sec, (d) a small hydro-turbine with installed capacity 1.6 MW that will operate constantly based on the ecological water flow through the diversion tunnel, (e) a supply tunnel for the main power station, with 7.4 km total length, and (f) two hydro-turbines (Francis) with a total capacity of 165 MW. It should be noted that the dam of Mesochora does not divert water from the river to Thessaly, although it was built as a part of the Acheloos diversion project.

- Hydroelectric power plant of Sykia: This power plant is related to the diversion of the river and is partly completed. The planning included: (a) A dam with 150 m total height, (b) a water reservoir with total area 12.8 km^2 and maximum volume $502x10^6$ m^3, (c) two diversion tunnels, one for keeping the ecological water flow and one for transferring water to the water tunnel meant to diverse the water from the river to the plain (d) a supply tunnel for the main power station, with 1 km total length, and (e) two hydro-turbines (Francis) with total capacity 87 MW.

It is true that the transfer of water to Thessaly, considering the needs of a productive plain without enough water resources, may sound reasonable; especially, if the support of the agricultural sector is set as a development priority. However, it also undeniable that such a big infrastructure project has major environmental consequences. Even if we accept that a major argument against the project, the one related to the negative impacts of the diversion on Acheloos water flow, is not alarming (MINENV, 1995; Tyralis et al., 2017), we cannot pass by: the great changes in the ecosystem of the river, major landscape changes and the significant reduction of debris flow downstream of the diversion constructions. The landscape changes are, to some extent, depicted in Figures 16 and 17[14]. The reduction of debris flow downstream is particularly reasonable, especially if we consider that three dams are already operating in Acheloos (Kremasta, Kastraki, Stratos).

As it may be expected, the diversion of Acheloos has caused serious social reactions. It can be said that the reactions to the project are the longest running, organized ecological movement in Greece. For 35 years, since 1984, the inhabitants of Mesochora are collectively struggling against the project[15]. They managed to get many people and collectivities all over the country on their side. In cooperation with ecological organizations, such as WWF, people fighting against the Acheloos diversion have organized massive protests, not only in the area of the construction works, but also in Athens and Thessaloniki. The relevant appeals to the courts, finally, managed to interrupt the project. However, the Mesochora dam is again back in the news, since the newly elected Government in Greece (July 2019) wants to restart the discussion and procedures for the operation of the power plant (Chaini, 2019). Although, it seems reasonable repair a hydroelectric power plant that is already constructed and does not transfer water to Thessaly, it is also up for discussion if turning a river into a huge electricity factory is really a sustainable, green/ blue energy solution. We must consider that if the Mesochora and Sykia hydro plants operate, one single river will host 1.16 GW of hydro power (or 1.29 GW if we add the Plastiras plant, which belongs to the same river basin)!

[14] It is often argued that, at least, the hydroelectric plant of Mesochora, since it is not related to the diversion of the river should be finished and set to operate. The supporters of this opinion propose that in the current situation the deterioration of the landscape is even worse than in the state of the power plant operation. If the plant operates, the reservoir will be filled, while now the only view is a huge dam and earthworks.

[15] http://mesochora-acheloos-sos.blogspot.com/

Figure 16. General view of the Mesochora dam and the earthworks. It is clear that the intervention in the wild, mountainous landscape is major[16].

Figure 17. General view of the Sykia partially constructed dam and the earthworks. Again, the landscape has been heavily affected[17].

The Aoos – Arachthos system

The Piges Aoou hydropower unit is the main energy unit in the main area under study. The three hydropower plants, Piges Aoou, Pournari I, Pournari II, although belonging to different water basins can be considered as a unified system. The water from Aoos enters the diversion tunnel in order to be directed to the power

[16] https://www.ypethe.gr/archive/perissoteres-plirofories-fragma-mesohoras
[17] https://www.ypethe.gr/news/o-k-spirtzis-episkefthike-ton-aheloo

station. The power station is in the Arachtos river basin and not downstream of the Aoos dams. Some main technical features of Aoos – Arachtos system are the following (Katsoulis, 2011; Argyrakis n.d.):

<u>Piges Aoou</u>

- Seven dams have been constructed in the plain of Politses, near the town of Metsovo for collecting the water of the Aoos river springs and create the water reservoir
- The water reservoir covers $9km^2$ and its volume is $145x10^6m^3$
- The installed power capacity is 210 MW (Pelton turbines)
- The annual quantity of water diverted to Arachtos is, in average, $125x10^6m^3$

<u>Pournari I</u>

- A dam with a total height of 87m has been built near the city of Arta
- The water reservoir covers $18.2km^2$ and its volume is $303x10^6m^3$
- The installed power capacity is 300 MW (Francis turbines)

<u>Pournari II</u>

- This is a regulatory dam, with aheight of 15m, for ensuring the constant water flow of Arachtos downstream of Pournari I
- The volume of the water reservoir is 4x106m3
- The installed power capacity is 33.6 MW (Bulb and S-type turbines)

The Aoos-Arachtos system is important for electricity production. The plentiful precipitation in the region of Epirus ensure adequate quantities of water for the operation of the hydroelectric energy stations. However, the construction and operation of these units has caused major impacts. The most important is the diversion of more than 100 million m^3 water every year from Aoos to Arachtos. This is a major interference in the hydrological equilibrium of the Aoos water basin. It should be kept in mind that the diversion of Acheloos, which has caused intense social reactions, has been interrupted, was planned to transfer 250 million m^3. The diversion in the Plastiras dam amounts 150 million m^3. So, a significant quantity of water is removed from Aoos flow. The inhabitants of Northern Pindos and, especially, those in the area of Eastern Zagori argue that the construction of Aoos dams has changed the situation downstream a lot. The concerns of the local societies have been intensified recently, after the publication of a rather complicated and strange plan that included the following main points (Leontaritis, 2014):

- Abstraction of $70x10^6m^3$ of water from the area where Arkoudorema is meeting Aoos (downstream of the Piges Aoou dams)
- The water will be pumped back to Piges Aoou reservoir
- A quantity of $50x10^6m^3$ will be directed to Pamvotis Lake through small hydroelectric plants (in order to provide clean water to the lake) and the rest $20x10^6m^3$ will be utilized for electricity production from the Piges Aoou power station.

This project, if applied will increase the total diversion from Aoos river basin to 195 million m^3. The social opposition has resulted in the interruption of these plans.

The creation of the Pournari I lake had also some important impacts on the area. The lake covered the village of Kato Kalentini, which, as a result, was abandoned. Many years after the completion of the hydroelectric unit, there is neither a ring road nor a bridge, in order to facilitate transport in the area surrounding the lake. This is a problem both for the villages near the lake and the Municipality of Kentrika Tzoumerka, which is one of the most isolated areas in Greece. The construction of the dam has changed the hydrological situation in the plain of Arta (Kousoulas, 2015). Even though the dam, in general, acts as a protective mechanism against floods, its proximity to the town of Arta raises safety concerns, especially in the case of a major fail. In February 2015, the plain of Arta flooded, after many hours of storms. The dam overflow system was, obligatorily, put into operation. This increased the water flow downstream even more and caused great damages, especially for the agricultural production[18].

Hydropower in Future Energy Planning

The long-term energy planning of Greece was under consultation until the last parliamentary elections. The discussion was based on an extensive document issued by the Ministry of Environment and Energy. At the basis of this plan that was published for consultation, some conclusions regarding the future of hydropower can be extracted. Moreover, some of the latest announcements, like the one related to the withdrawal of lignite units are discussed in this Section. In general, Greece's energy system is in front of great changes and challenges.

According to the document issued for consultation by the Ministry of Environment and Energy in 2018, the main targets of Greek energy policy until 2030, are the following (YPEN, 2018):

- For the sectors not subject to the emissions trading system (non-ETS), the greenhouse gas emissions must be reduced by 16%, compared to 2005.
- For the ETS sectors, the greenhouse gas emissions must be reduced by 43%, compared to 2005.
- The RES share in gross, final energy consumption must be at least 30%
- The reduction of the final energy consumption must be at least 30%, taking as reference the forecast for energy consumption of 2030 that was made in 2007. This means that final energy consumption in 2030 must not exceed 18.7 Mtoe.

There are many other energy policy targets, related to various aspects of the energy sector, like the interconnection of energy autonomous islands to the electricity grid of the mainland. However, the four targets mentioned are the ones that define the country's strategy in the energy sector.

A closer look at the targets and forecasts of the energy planning for 2030 that was under consultation reveals some interesting details, which are summarized below:

- The protagonists in RES development will be wind and photovoltaic energy units, whose energy production will almost triple compared to their production in 2016.
- In order to be able to utilize the energy production of wind and photovoltaic units, which presents variations, the installed capacity of biomass units will increase fivefold and the energy produced by them will be six times higher, compared to the corresponding production in 2016.
- The development of hydraulic energy unit, both big and small hydropower plants, will not follow the fast pace of wind, photovoltaic and biomass energy. More specifically, the installed capacity of hydropower will be 4 GW, while now it is almost 3.4 GW. The estimated increase in hydroelectric production is 12% between 2030 and 2016. However, it should be noted that even though the total capacity of hydropower is not increasing significantly, the increase of small hydroelectric plants' capacity will be almost 100%. This means that the increase in hydraulic energy exploitation will depend almost absolutely to small hydroelectric plants. Moreover, despite the increase in electricity production from hydroelectric units, the share of hydroelectric energy will slightly decrease; it will be 11%, while in 2016 it was 12%.
- A great decrease in solid fuel will take place. Lignite, oil, natural gas will cover 37% of the electricity production. In 2016 they covered 69%. This is an important change, necessary for reducing

[18] http://www.watcharachthos.eu/index.php/newsflash/101-ta-nea-mas/139-istorikes-plimmyres-stin-arta

greenhouse gas emissions, which is the strategic target of the overall energy planning. However, the energy planning that was under consultation does not match the announced withdrawal of all lignite units of Greece by 2028.

In Figure 18, the shares of energy technologies for electricity production for the years 2016 and 2030 (the latest according to the energy planning that was under consultation) is depicted.

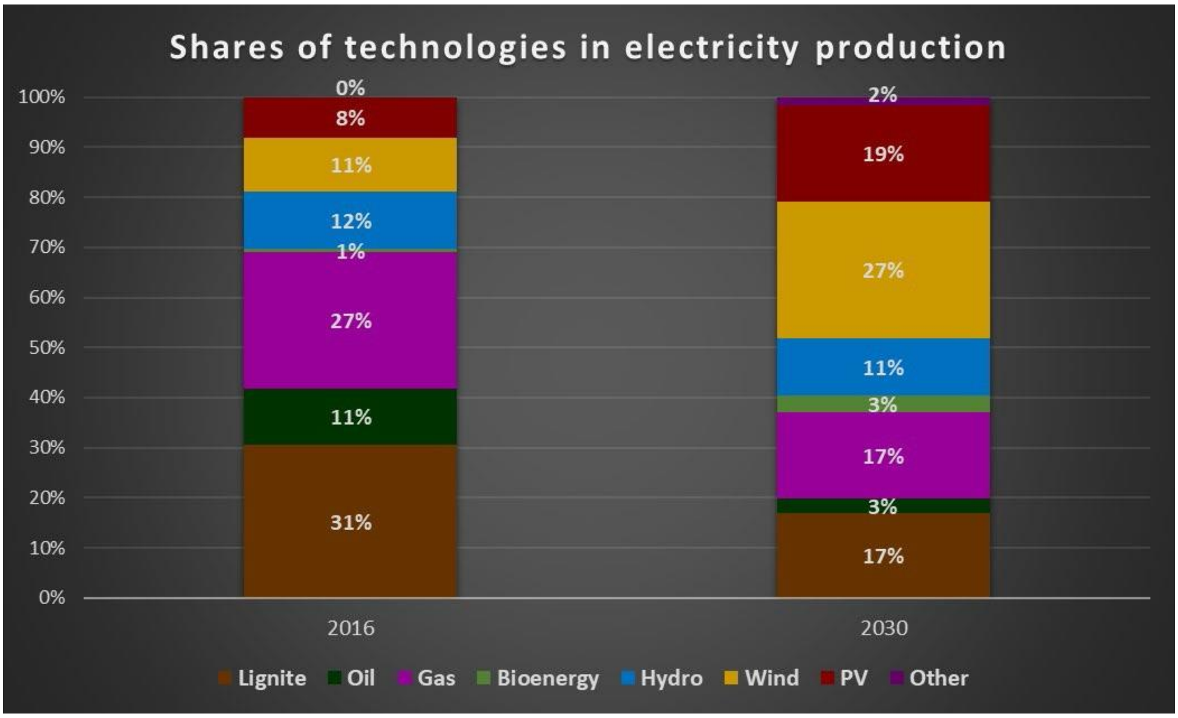


Figure 18. Shares of various technologies in electricity production in Greece for the year 2016 and the corresponding estimation for 2030 (YPEN, 2018).

The energy planning discussed in 2018, as shown clearly in Figure 18, by 2030 will result in a major change of the electricity production system. To a great extent, the conventional energy sources (based on solid fuels) will give their place to renewables, which will become the main pillar of electricity production. It should be noted that this great increase in renewable energy production – according to YPEKA (2012), wind power will increase by 300% and photovoltaic power will increase by 310% - will not be neutral, in terms of environmental consequences. It will lead to major decrease in greenhouse gas emissions, but the sitting of, especially, wind farms will be a major issue, since the places with high wind velocities for wind power development are, mostly, mountainous areas (Katsoulakos, 2013). So, even if big hydropower stations seem not to be further developed, other forms of RES are expected to cause debates, not without cause, since especially mountainous areas include sensitive ecosystems and protected areas.

The discussion about the lignite units' withdrawal

As already mentioned, the long-term energy planning of Greece has not been completed yet. After the parliamentary elections of July 2019, the plan of YPEKA (2018) is no longer under consultation. The new Government is preparing its plan for the country's long-term energy planning. It is estimated that the strategic plan for great reduction in greenhouse emissions and increase in RES share will not change. However, some individual points seem to be different from the previous Government's plans. The most important among them is the plan for withdrawing all lignite units of the Public Power Corporation until 2028 (Liakos, 2019). This procedure is described in Greece as "de-lignification". The Ministry for Energy proposed de-lignification not only for reducing greenhouse emissions, but also because of the particularly high costs of CO_2 emission rights, which were about 200 million euros in 2018. The latest development in this issue is that the Prime Minister, in the UN summit, announced that delignification will take place until 2023, five years earlier than the first plan (Liaggou, 2019). The first units – the oldest and less effective - are going to stop operating in 2020.

The target of de-lignification includes composite and difficult procedures, which will cause many implications. The announcement about withdrawing the lignite units in just five years seems to be not well justified and designed. Within the next months, we estimate that a proposal by the Government will be issued, which will allow the start of an official discussion. Some main concerns that arise from de-lignification of the country are the following:

- A major reduction in PPC's personnel will happen. So far, voluntary schemes for early retirement have been introduced in the discussions that are taking place in the parliament.
- The security and sufficiency of energy supply are important technological challenges that need to be addressed. Therefore, after the announcements of the Government, it is discussed that at least one or two units should remain in operation. Especially, the Ptolemaida V unit is a brand new facility, with high efficiency and if it stops operating just four of five years after its introduction to the energy systems, the economic loss for PPC will be unduly high.
- The socioeconomic consequences of de-lignification in Western Macedonia and Megalopoli – the main centers of lignite and energy production – will be severe. Hence, the Government is going to issue an integrated development plan for these areas, in order to ensure their future perspectives in the after-lignite era. Part of the necessary new investments will be covered by the European Fair Transition Fund.

The great reduction in the share of lignite in electricity production (or even the complete withdrawal of lignite units) will cause major changes in the energy mix. Figure 18 illustrates the changes, even though it is based on an energy planning scenario that keeps lignite electricity over 15% in the energy mix. The stability of the electricity system, in case of de-lignification will demand the operation of energy production technologies with low variability, since wind and solar energy will increase further. There are two main solutions to this issue, considering the characteristics of the Greek energy system: (a) increase in hydroelectric energy, particularly from big hydropower stations, and (b) increase in electricity production by fossil fuel units, with less emissions compared to lignite.

According to the discussion made so far about de-lignification, the previous energy planning under consultation, and the country's commitments within EU policy, hydropower cannot substitute lignite electricity. Moreover, big hydropower as seen already are designed to cover peak electricity loads and so, they cannot cover great parts of the "base" load. Hence, natural gas is most likely to increase, in order to ensure the stability of the electricity grid. Besides, important private, industrial companies are planning to proceed to the construction of new natural gas units (Liaggou, 2019). Such a choice raises also important issues, such as how can the energy dependency of the country be reduced, in this way, since natural gas is an imported fuel.

De-lignification is an issue of great importance for a country that was based on lignite for more than 50 years. It is an utter necessity to have a new plan for long-term energy strategy and policy under consultation as soon as possible. The whole discussion, so far, is made through media, not even in the parliament. This is why a systematic, well organized and scientifically supported dialogue should start, in order to create the country's future energy strategy. In any case, the role of big hydropower projects, which are of particular importance for our area of study, will not be upgraded. Both the capacity and the energy produced by big hydroelectric stations will remain at the current levels.

It cannot be denied that hydropower has contributed to the economic development of Greece after World War II. It plays an important role in the current structure of Greece's electrical energy system; it covers one tenth of the electricity consumption and represents one third of the total installed capacity of conventional energy sources. However, both the design of big hydro plants for peak loads and the impact of water flow variations on small hydro plants keep the capacity factors at relatively low levels. Regarding RES, biomass units present the highest capacity factors with very small variations and so they can enhance the stability of the electricity network. Further development of biomass is an issue that should be considered in the future energy planning of the country. Finally, the contribution of hydropower to the country's development was a procedure with major environmental and social impacts. Major planning related to hydropower and water transfer through diversions have been interrupted, at the basis of opposing social movements, as well as environmental concerns. Future energy planning, which includes the scenario of de-lignification does not include important increase in hydroelectricity production, especially from big hydropower stations. However, the change in electricity system that will take place in the next 30 years will cause major changes and raises important issues and concerns.

COST OF ENERGY PRODUCTION AND BENEFITS FROM ENERGY INVESTMENTS

The cost of energy production is, eventually, one of the most important factors affecting the energy sector. Liberalized energy markets and, in general, the domination of capitalism make studying and understanding the financial dimension of energy production crucial, for extracting integrated conclusions about energy policy. In this Chapter data related to renewable energy production costs are presented, aiming at extracting some useful conclusions regarding, especially, evolutions in hydropower cost. The general finding is that wind and solar power have become far more attractive investments. In some cases, they can be more competitive than hydropower, especially small hydroelectric units. So, even from a financial point of view, it has become feasible to invest in various RES technologies. In addition, a short reference is made to the economic benefits for the society (direct, indirect and induced) of investments in various RES and energy efficiency technologies. The data regarding benefits are presented for the case of Greece and the findings provide interesting insights to the positive social effects of the various technologies.

Levelized Cost of Energy for several renewable technologies

Cost can be measured in several ways, and each way of accounting the cost of power generation, brings its own insights. The costs that can be examined include equipment costs (e.g. wind and hydropower turbines, PV modules, solar reflectors), replacement costs, financing costs, total installed cost, fixed and variable operating and maintenance costs (O&M), fuel costs and the levelized cost of energy (LCOE). The LCOE of renewable energy technologies varies by technology, country and project based on the renewable energy resource, capital and operating costs, and the efficiency/performance of the technology. Although different cost measures are useful in different situations, the LCOE of renewable energy technologies is a widely used measure by which renewable energy technologies can be evaluated for modeling or policy development. The formula used in the International Renewable Energy Agency organization (IRENA, 2019) for calculating the LCOE of renewable energy technologies is:

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

- LCOE: the average lifetime levelized cost of electricity generation
- I_t = investment expenditures in the year t
- M_t = operations and maintenance expenditures in the year t
- F_t = fuel expenditures in the year t
- E_t = electricity generation in the year t
- r = discount rate
- n = economic life of the system

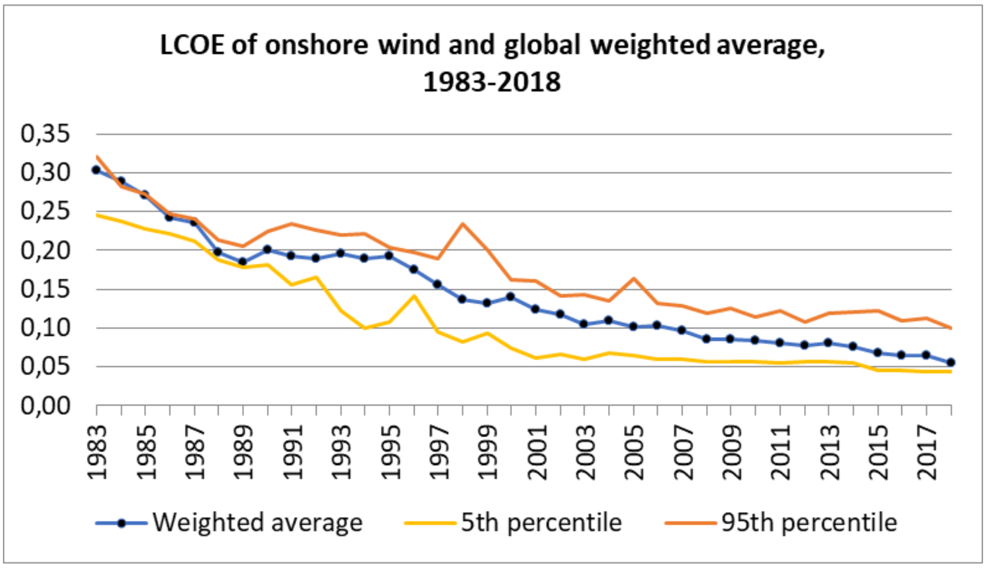
Based on the abovementioned, the LCOE expresses mathematically the price of electricity required for a project where revenues would equal costs, including making a return on the capital invested equal to the discount rate. An electricity price above this, would yield a greater return on capital, while a price below it, would yield a lower return on capital, or even a loss. The LCOE of a given technology is the ratio of lifetime costs to lifetime electricity generation, both of which are discounted back to a common year using a discount rate that reflects the average cost of capital.

In IRENA (2019), all LCOE results are in real 2018 USD (that is to say, taking into account inflation) excluding any financial support and using a fixed assumption of a real cost of a capital of 7.5% in OECD countries and China, and 10% in the rest of the world, unless explicitly mentioned. All LCOE calculations exclude the impact of any financial support. Planning, development and construction can take 2–3 years for solar PV and onshore wind, but can take 5 years or more for CSP, fossil fuels, hydropower and offshore wind.

In the following sections, the evolution of LCOE levels per technology is presented, as analyzed by IRENA (2019), based on data from the IRENA Renewable Cost Database[19].

Onshore Wind Power

The evolution of LCOE levels of global onshore wind power for the last 30 years is illustrated in Figure 19. The global weighted-average LCOE of onshore wind projects presents a large decreasing trend over the period examined, with the value of 2018 reaching USD 0.056/kWh, 13% lower compared to 2017 and 35% lower compared to 2010 (when USD was 0.085/kWh). Onshore wind represents a competitive source of electricity in most parts of the world, as these costs of electricity are now at the lower end of the fossil fuel cost range. The lower cost of electricity for onshore wind in 2018 was driven by continued reductions in total installed costs, as well as by improvements in the average capacity factor. The factors driving this trend, include continued improvements in turbine design and manufacturing, more competitive global supply chains and an increasing range of turbines designed to minimize LCOE in a range of operating conditions. Indicatively, the weighted-average LCOE of onshore wind farms commissioned in 2018 in China and the United States were identical, at USD 0.048/kWh. Although China has lower capacity factors than the United States, this is offset by lower installed costs. In 2018, the weighted average LCOE of onshore wind farms commissioned in Brazil was at USD 0.061/kWh, in France at USD 0.076/kWh, in Germany at USD 0.075/kWh, in India at USD 0.062/kWh and in the United Kingdom at USD 0.063/kWh. Since 2014, there has been an increasing number of projects commissioned with a LCOE of between USD 0.03 and USD 0.04/kWh. These projects, combining competitive installed costs in areas with excellent wind resources are, in some markets, becoming a growing proportion of new deployment. They are significantly cheaper than even the cheapest fossil fuel-fired options for new electricity generation and will be undercutting the variable operating costs of some existing fossil fuel-fired generators.



[19] The IRENA Renewable Cost Database contains cost and performance data for around 17,000 renewable power generation projects with a total capacity of around 1,700 GW. It includes data on around half of all renewable power generation projects commissioned by the end of 2018.

Figure 19. Evolution of LCOE of onshore wind projects, 1983-2018 (IRENA, 2019).

Offshore Wind Power

The global weighted average LCOE of offshore wind projects in 2018 was USD 0.127/kWh, 1% lower than in 2017 and 20% lower than in 2010 (from USD 0.159/kWh to USD 0.127/kW), as shown in Figure 20. The major drivers of this reduction were innovations in wind turbine technology, installation and logistics, economies of scale in O&M (from larger turbine and offshore wind farm clustering), improved capacity factors from higher hub heights, better wind resources (despite increasing cost in deeper waters offshore) and larger rotor diameters. The market for offshore wind is still relatively thin and there is wide variation in country-specific declines in LCOE since 2010. In Europe, which has the largest deployment of offshore wind, between projects commissioned in 2010 and 2018, there was a 14% drop in LCOE, from USD 0.156/kWh to USD 0.134/kWh. The largest drop occurred in Belgium, by 28% between 2010 and 2018, with the LCOE dropping from USD 0.195/kWh to USD 0.141/kWh. In Germany and the UK, which were the biggest markets for commissioned projects in Europe, in 2018, there were 24% and 14% drops between 2010 and 2018, with the LCOEs in Germany and the UK falling to USD 0.125/kWh and USD 0.139/ kWh for projects commissioned in 2018, respectively. In Asia, the LCOE reduction between 2010 and 2018 stands at 40% (from USD 0.178/kWh to US 0.106/kWh). This was driven by China, which has over 95% of offshore wind installations in Asia. The LCOE in Japan is high in comparison to China, at an estimated USD 0.20/kWh, given that projects to date are small in scale and are perhaps better categorized as demonstration projects.

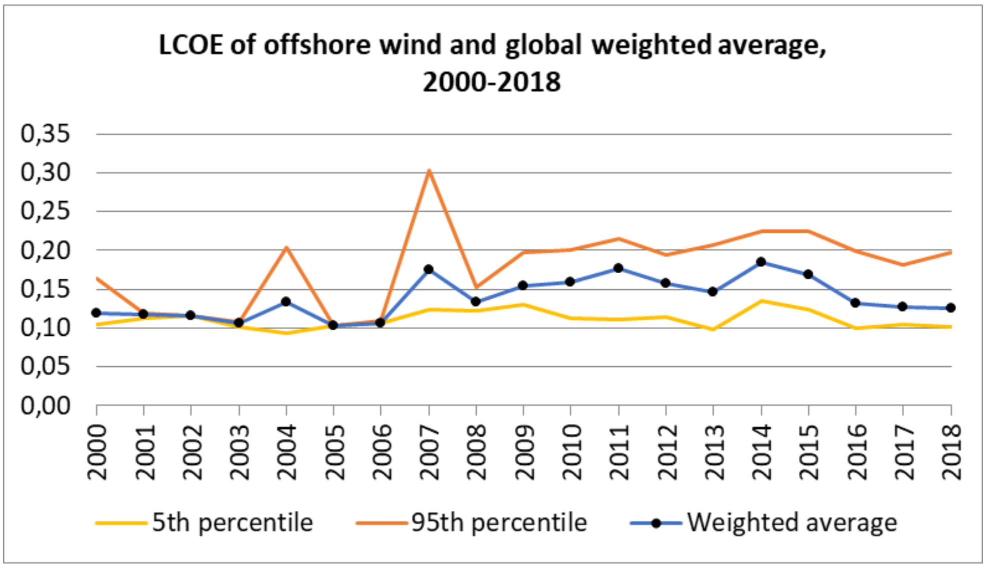


Figure 20. Evolution of LCOE of offshore wind projects, 2000-2018 (IRENA, 2019).

Solar photovoltaics

The sustained, considerable decline in the cost of electricity from utility-scale solar PV continued in 2018, with a drop in the global weighted-average LCOE of solar PV to USD 0.085/kWh, 13% lower compared to 2017 and 77% compared to 2010 (Figure 20). Globally, although the range has narrowed, the 5th and 95th percentile for projects in 2018 ranged from USD 0.058 to USD 0.219/kWh. Indicatively, in China, the weighted-average LCOE of new utility scale solar PV plants commissioned in 2018 declined, year-on-year, by 20%, to USD 0.067/kWh. The decline in India was 21% (USD 0.063/kWh in 2018), in the United States 18% (USD 0.082/kWh in 2018) and in Japan 1% (USD 0.153/kWh in 2018). The average LCOE of new utility-scale solar PV projects in Germany increased by an estimated 2% year-on-year in 2018, driven by a slight increase in total installed costs.

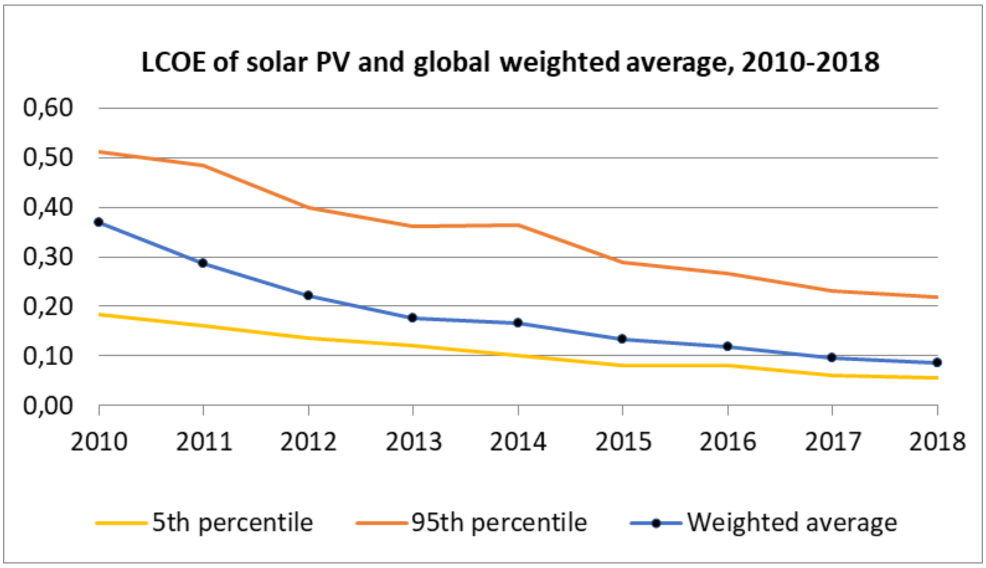


Figure 21. Evolution of LCOE of utility-scale solar PV projects, 2010-2018 (IRENA, 2019).

Hydropower

Hydropower is, as a rule, an attractive renewable technology from the financial point of view, due to the low-cost of the electricity it produces and the flexibility it can provide to the grid. In 2018, the global weighted-average LCOE of hydropower was USD 0.048/kWh, 13% lower compared to 2017, but 17% higher compared to 2010 (Figure 21). Between 2010 and 2013, the global weighted-average LCOE of hydropower was relatively stable, before starting to rise from 2014 onwards to a new, slightly higher level. The reason for this increase was the increased total installed cost in 'Other Asia' (Asia, excluding China, India and Japan). Given that hydropower is a highly site-specific technology, with each project designed for a certain location within a given river basin, the exact reasons for this cost increase are difficult to identify. While further analysis is necessary, the rise in costs in 'Other Asia' was likely due to the increased number of projects with more expensive development conditions compared to earlier projects when the best sites were developed. Current sites may be in more remote locations, further from existing grid infrastructure, necessitating higher grid connection, access and logistical costs. They may also be in areas with more challenging geological conditions, increasing the cost of construction. A combination of these factors could be driving the recent cost trends. Moreover, there is often variation in the weighted-average LCOE of big and small hydropower projects. The country or regional weighted-average LCOE of newly commissioned big hydropower projects varied between USD 0.04/kWh and 0.09/kWh in most instances, although being higher in Europe and Oceania. Average LCOE's were broadly flat or slightly down in major markets (Africa, Brazil, China, India, North America, Other Asia and Other South America) between 2010-2013 and 2014-2018. The country or regional weighted-average LCOE of newly commissioned small hydropower projects varied between USD 0.04–0.09/kWh in the 2014-2018 period but were higher in Eurasia (USD 0.11/kWh) and Europe (USD 0.19/kWh). The LCOE of hydropower plants is particularly competitive, despite the variations. Nevertheless, the gap between it and the two other main RES technologies, namely onshore wind farms and solar PV, has been significantly reduced. Moreover, small hydroelectric units, which are part of RES development in Greece, have similar or even higher LCOE compared to solar PV and wind generators.

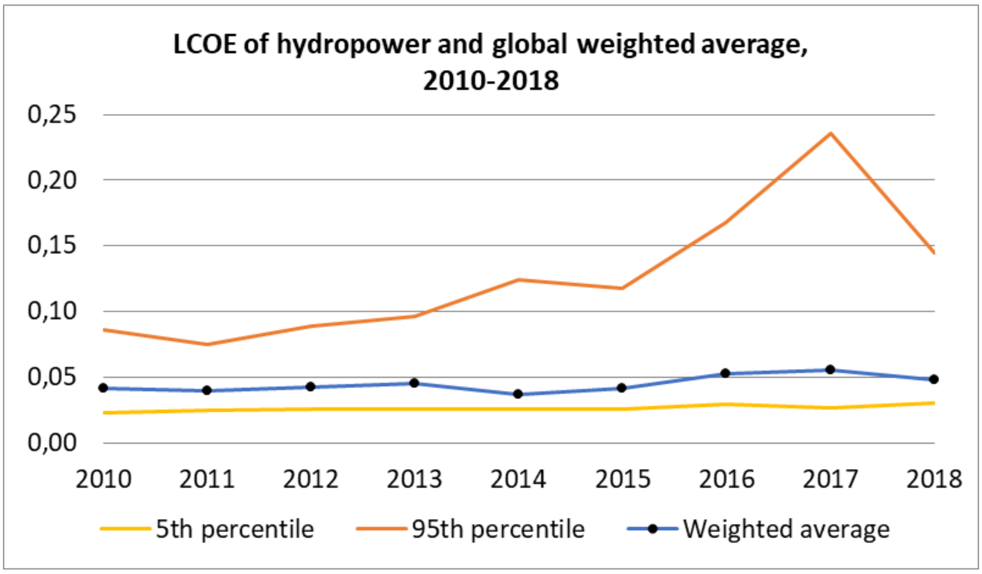


Figure 22. Evolution of LCOE of hydropower, 2010-2018 (IRENA, 2019).

Bioenergy

In 2018, when around 5.7 GW of new bioenergy electricity generation capacity was added worldwide, the global weighted-average LCOE of new bioenergy power plants commissioned was USD 0.062/kWh, 14% lower compared to 2017. This is also an interesting finding. However, for the time being, in the Greek case the cost of biomass investments remains high. This must be further investigated, since biomass is important, especially for mountainous areas, which have high thermal loads, since it can be utilized for co-generation of heat and electricity.

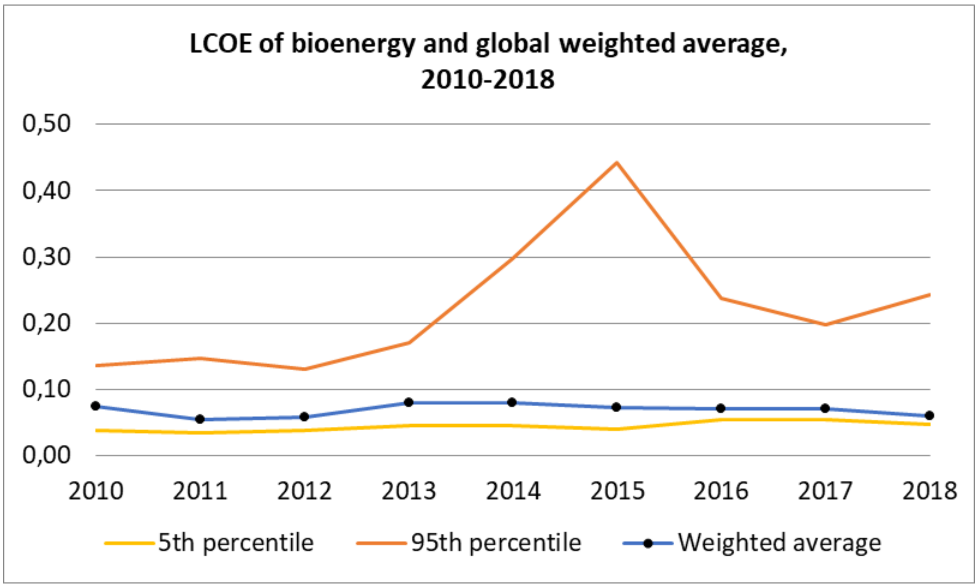


Figure 23. Evolution of LCOE of bioenergy, 2010-2018 (IRENA, 2019).

In total, the highest levels - as absolute values - of the global weighted average LCOE were recorded at the newer solar and wind power technologies (concentrating solar power - CSP), while the lowest levels at hydropower plants, as shown in Figure 24. Data show that since 2010, the global weighted-average levelized cost of electricity (LCOE) from bioenergy, geothermal, hydropower, onshore and offshore wind projects have all been at low levels, within the range of fossil fuel-fired power generation costs (between

USD 0.049 and USD 0.174/kWh)[20]. Since 2014, the global-weighted average LCOE of solar photovoltaics (PV) has also fallen into the fossil fuel cost range. More specifically, in 2018, the global weighted-average LCOE of hydropower, onshore wind, bioenergy and geothermal projects were all at the lower-end of the fossil-fuel cost range, so these technologies competed head-to-head with fossil fuels, even in the absence of financial support. With continued cost reductions, solar PV power has also started to compete directly with fossil fuels. Offshore wind and concentrating solar power (CSP) are less widely deployed, and their global weighted average electricity costs are in the top half of the fossil fuel cost range.

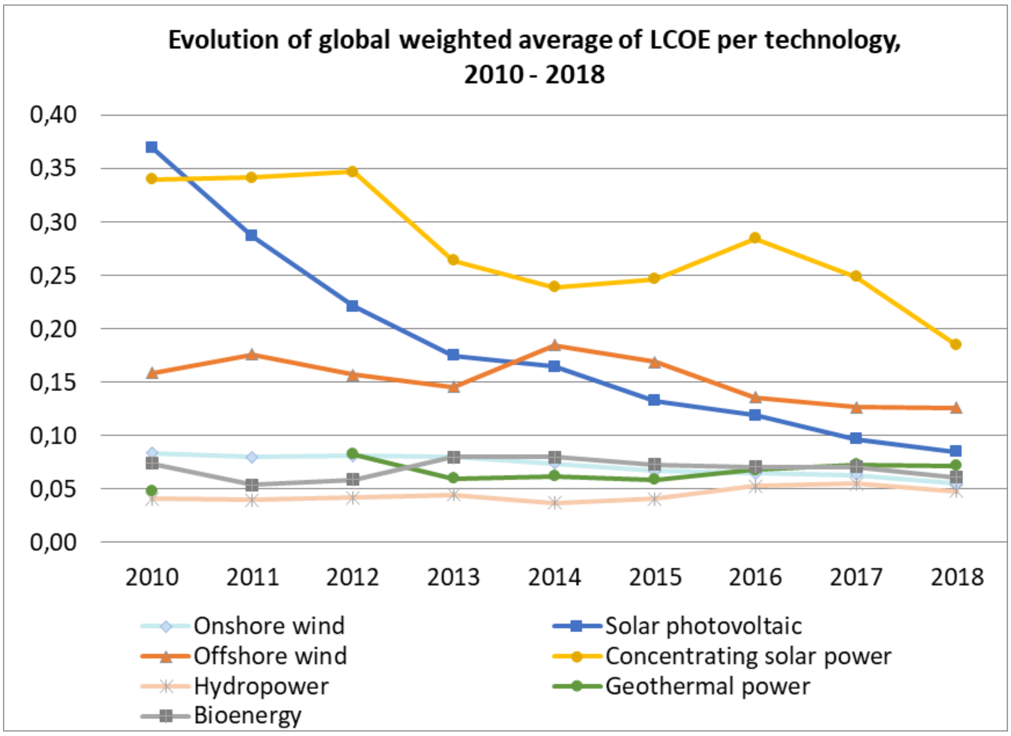


Figure 24. Evolution of LCOE for several RES technologies, 2010-2018 (IRENA, 2019).

However, what should be noted is the considerable cost variations marked since 2010. The largest variation was recorded in the case of solar photovoltaics, as the LCOE value of solar PV installations presented a dramatic decrease (by 77%) since 2010 (Table 7). The second larger variation was recorded at concentrating solar power (CSP), marking a decrease of 45% between 2010 and 2018. Onshore and offshore wind plants were the next technologies of a considerable decrease since 2010 (by 34.5% and 20.8%, respectively), followed by bioenergy plants, with a decrease of 17.6% since 2010. Cost reductions for solar and wind power technologies are foreseen to continue up to 2020 and beyond. On the contrary, geothermal power plants, as well as hydropower plants were the two technologies that marked an increase in the LCOE value (by 50% and 17.1%, respectively) between 2010 and 2018, not following a competitive line in the market during the last years. As it is apparent, rapidly falling costs of electricity for solar PV, as well as considerable cost reductions for CSP and wind to 2020 and beyond mean that these renewable sources are becoming the competitive backbone of the global energy sector transformation. Hydropower, although preserving steadily low LCOE levels (at the lower level of the fossil-fuel cost range), does not seem to be able to keep pace with the rapid cost reduction of other RES sources.

[20] The fossil fuel-fired power generation cost range by country and fuel is estimated to be between USD 0.049 and USD 0.174/kWh. All cost data is expressed in real 2018 United States dollars (USD), taking into account inflation.

Current auction and Power Purchase Agreement (PPA) data suggest that by 2020, onshore wind and solar PV will consistently offer less expensive electricity than the least-cost fossil fuel alternative, while by then, offshore wind and CSP - with progressively falling costs - are also expected to be highly competitive, leaving hydropower behind, within an increasingly competitive RES market.

Table 7. Percentage variation of the global weighted-average LCOE (%) between 2010 and 2018, by RES technology

	LCOE difference between 2010 and 2018 (%)
Onshore wind	-34.5%
Offshore wind	-20.8%
Solar photovoltaic	-77.0%
Concentra�ng solar power	-45.6%
Hydropower	**+17.1%**
Geothermal power	+50.0%
Bioenergy	-17.6%

Socioeconomic benefits of energy investments

Investments in a sector of the economy produce, as a rule, positive and negative impacts to other sectors of the economy, known as externalities. In the case of energy investments, since we have already explored their LCOE, it is useful to have an overview of their benefits, especially to employment. Two research works for the case of Greece, the ones of Mirasgedis et al. (2014) and of Markaki et al. (2013), provide useful data, which are going to be presented in this Section. These studies emphasize on the following macroeconomic implications of clean energy investments:

- Direct effects: i.e. jobs created and lost as a result of developing certain energy investments
- Indirect effects: benefits to the sectors of the economy that provide materials and services to the industries associated with clean energy investments
- Induced effects: benefits that result from the changes in the income that will be available to households for spending because of the economic benefits of energy investments

Following the study of Markaki et al. (2013), for the period 2010-2020, it is estimated that the greatest benefits (expressed in monetary terms) per MW of green investments are produced by biomass energy units, followed by offshore wind farms and photovoltaics. Figure 25 shows the total output (the sum of direct, indirect and induced effects) of various green energy technologies for the ten-year period 2010-2020 in the Greek economy. It is noted that the estimations are related to investments in the electricity generation sector. Onshore wind farms and small hydro present the lowest values of external economic benefits.

The study of Mirasgedis et al. (2014) is particularly interesting, because it explores the benefits associated with energy efficiency interventions. This is important because it estimates the benefits to the economy and the society of interventions that can be applied at decentralized, household level and which are very useful for mountainous areas like the ones under study, which have great thermal loads because of the cold winters. The study examines the three most popular (and effective) interventions promoting energy saving in Greece: (a) insulation of walls and roofs, (b) installation of energy efficient windows, and (c) replacement of old diesel oil boilers. The benefits of investments in energy efficiency prove to be important. The highest benefits are produced be boiler replacement, followed by walls/ roofs insulation and then window replacement. The approach of the study includes the estimation, in monetary terms, of the external benefits for every million euros of investments in energy efficiency, taking as basis the year 2010. More specifically:

- For every million of Euros invested in wall and roof insulation in 2010, the estimated benefits were 160,000 €.
- For every million of Euros invested in window replacement in 2010, the estimated benefits were 110,000 €.
- For every million of Euros invested in old diesel boilers replacement in 2010, the estimated benefits were 230,000 €.

Considering the data regarding benefits of green energy investments, it seems that in the electricity sector, biomass is the technology that creates the highest positive impacts. Small hydro together with onshore wind present far less socioeconomic benefits. Moreover, investments in energy saving – which is a prerequisite for sustainable energy policy but not as much highlighted as power production – also create important socioeconomic benefits. These issues have to be included in an integrated energy planning strategy both at national and local level. In our area under study, both biomass and energy savings are crucial for local societies; energy saving reduces thermal energy loads and biomass can primarily produce heat based on local sources.

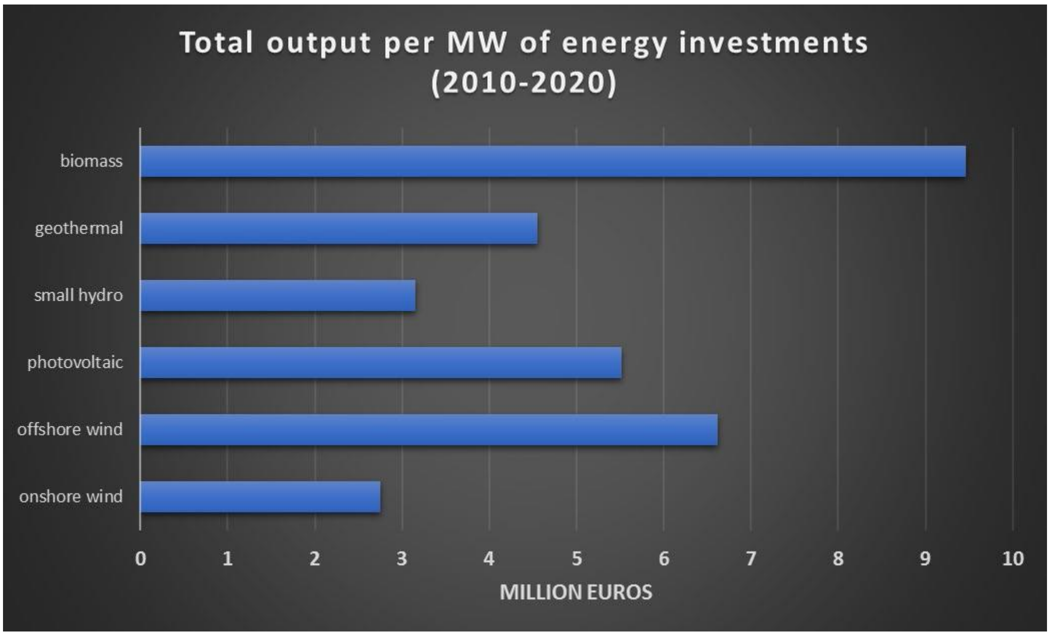


Figure 25. Total output of green energy investments in the electricity generation sector for the period 2010-2020.

The investigation of the LCOE data regarding renewable energy technologies show that hydropower remains a particularly competitive form of energy compared to fossil fuels. However, during the last decade a rapid fall in the LCOE of photovoltaics and wind generators has taken place. This trend will probably continue, while at the same time the LCOE of hydropower, although low, presents increase. Hence, the global effort to replace fossil fuel can now be based, in a financially viable way, to several renewable energy technologies. This is a finding particularly important for our study area, in which hydroelectric projects are operating and there is investment interest for small hydroelectric plants. From a financial point of view, the global trends make wind and solar energy even more competitive, compared particularly to small hydroelectric plants. Regarding green energy investments' socioeconomic benefits (particularly increase in employment), small hydro electric units present low benefits, while biomass creates the highest positive impacts. The benefits of energy saving interventions are also important.

SYNOPSIS OF THE CURRENT SITUATION REGARDING ENERGY IN THE UPPER BASIN OF AOOS

After having analyzed the characteristics of the energy sector in Greece, some particular aspects related to hydropower and the trends in RES technologies LCOE, a specialized overview of the energy sector in the upper basin of Aoos - which is our main are under study – can lead to useful findings. Firstly, we have to clarify that, in order to be able to analyze energy related data, the study area is considered to include the Municipalities of Metsovo, Zagori and Konitsa.

The Piges Aoou Hydropower Station

The energy analysis in the upper basin of Aoos cannot start in a different way, than with the presentation of the big hydropower plant in the area of Aoos river springs near the town of Metsovo. This is the most important operating energy unit in the area and, as already described, has produced significant changes in the river flow. In the broader area of the power station the average annual rainfall exceeds 1,400 mm and reaches even 1,800 mm in higher altitudes; this is a major favorable factor that led to the construction of this power plant (Koutsoyannis & Mamassis, 1998; Nikolaou, 2011). The annual water diversion from Aoos to Arachtos amounts to $125x10^6$ m^3. In order to gain a view about the magnitude of this quantity of water, it is noted that Athens needs about 10^6 m3 water daily.

The energy unit was constructed between 1981 and 1990 and started operating in the end of the year 1990. It belongs to the Public Power Corporation of Greece (PPC). It includes one main dam, five neck dams and one auxiliary dam. These dams are trapping the water in the "Politses" plateau, where the sources of Aoos river are located. The area belongs administratively to the Municipality of Metsovo. So, a water reservoir is created, with an area of 9 km^2 and maximum capacity of 180 million m^3 of water. The water from the reservoir is transferred through a diversion tunnel to the area of Xrysovitsa, where the hydroelectric power station is located. Then, the water is being drained to Metsovitikos river, which belongs to the Arachtos river basin. The hydraulic drop height is 675 m and the operational flow rate equals to 20 m^3/sec. This makes Piges Aoou hydropower station the one with the greatest hydraulic drop height in Greece (Katsoulis, 2011).

The installed capacity regarding electricity production is, in total, 210 MW. Two turbines (the type in use is Pelton, because of the high hydraulic drop height) are utilized. According to the data of the Operator of the Electricity Market of Greece (LAGIE), during the last four years, the total electricity production of Piges Aoou Hydropower station was **449,601 MWh**. So, the capacity factor of the station, during this period has been **7.9%**. This is a rather low capacity factor that shows that the Piges Aooou power station is designed for covering only the great peaks of electricity demand. In Figure 26, the energy production during the last four years is presented. There are important differentiations in energy production between "wet" and "dry" months. The average energy production in the period from October to March is about 60% higher than the energy production in the period from April to September. In Figure 27, the capacity factor of the hydropower station is presented, during the last three year, at a monthly basis. Based on the last four years, the energy production of this hydroelectric unit covers about 0.25% of the total electricity production of the country and 3.25% of the total hydroelectric energy production of the country. Therefore, it can be claimed that the Piges Aooou hydropower station is not one of the main electricity producing stations in Greece and its share in hydroelectricity production is rather small.

The great differentiations in energy production are depicted in the value of the standard deviation. More specifically, the standard deviation in electricity production during the last four years is 9,364 MWh, while the monthly average energy production is 9,176 MWh. The situation is similar regarding the capacity factor.

The average value is 6.0% and the standard deviation is 6.1%. Practically, this means that when speaking about energy production from the Aoos power station we cannot make general assumptions, since the energy production presents +/- 100% fluctuations from its average value!

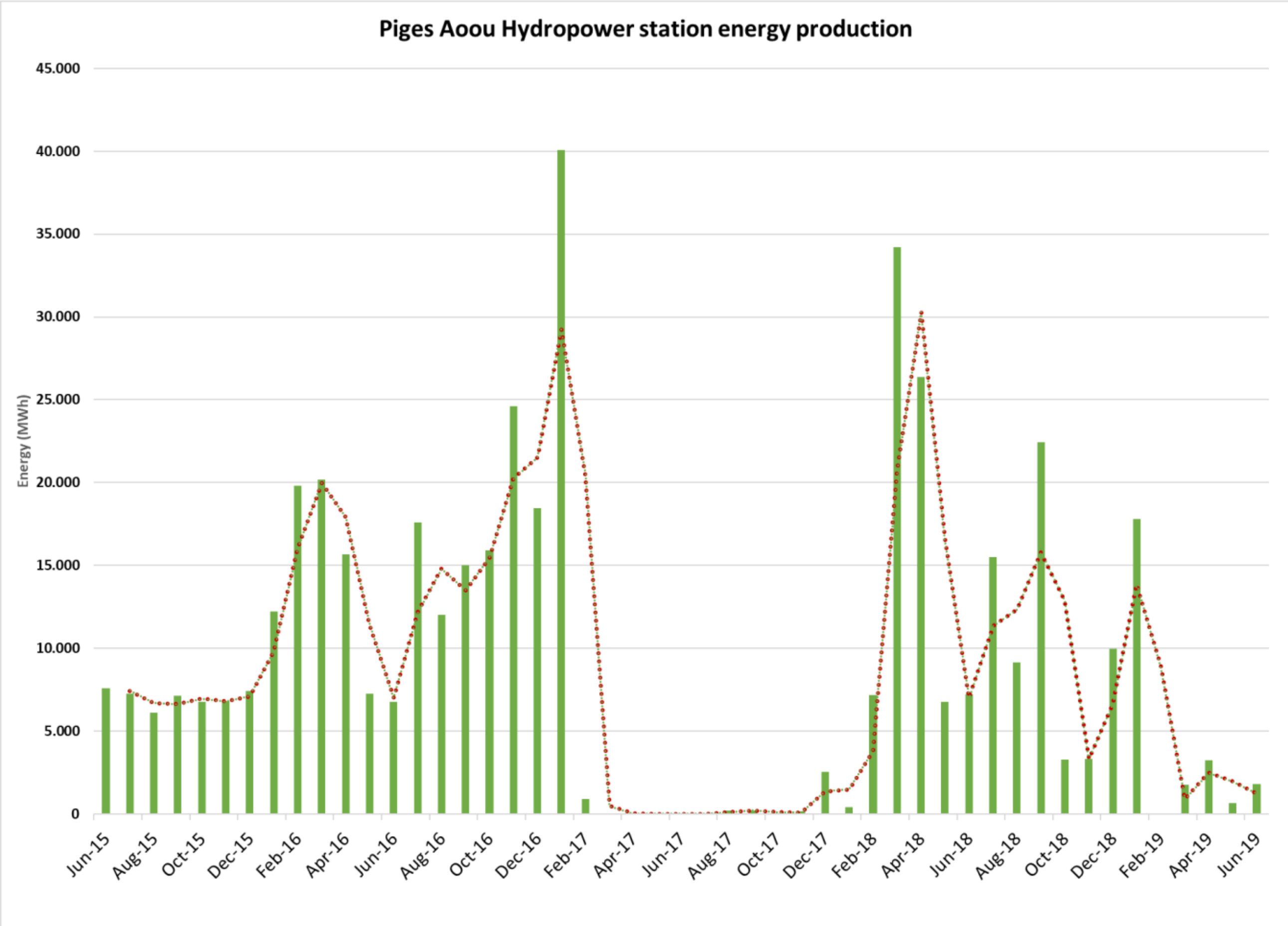


Figure 26. Electrical energy production from the Piges Aoou Hydropower station, between June 2015 and June 2019.[21]

Regarding the cost of energy produced in the Piges Aoou Power Station, the differentiations are significantly lower. The average cost is 54.40 €/MWh and the standard deviation is 24.31 €/MWh. It should be noted that such prices of electricity production cost are relatively low. Specifically, the average energy cost of the power station is 11% lower than the annual marginal price of the electricity system in Greece. Regarding the total revenues provided to the PPC for the energy produced by Piges Aoou Hydropower Station, during the last four years sum up to 26.72 million Euros. This corresponds to 6.68 million Euros per year. In Figure 28, the cost per MWh of produced energy is illustrated. The revenues from the power station are being received by the Public Power Corporation of Greece, which owns the power station. The Municipalities of Metsovo and Zagori, in whose territory the power plant operates, do not receive any compensation from the PPC.

[21] Operator of the Electricity Market of Greece (LAGIE). *Monthly Bulletins of Day Ahead Scheduling*. http://www.lagie.gr/agora/analysi-agoras/miniaia-deltia-iep/ and Energy Exchange Group. *Monthly Bulletins of Day Ahead Scheduling* http://www.enexgroup.gr/agores/analysi-agoras/deltia-iep/

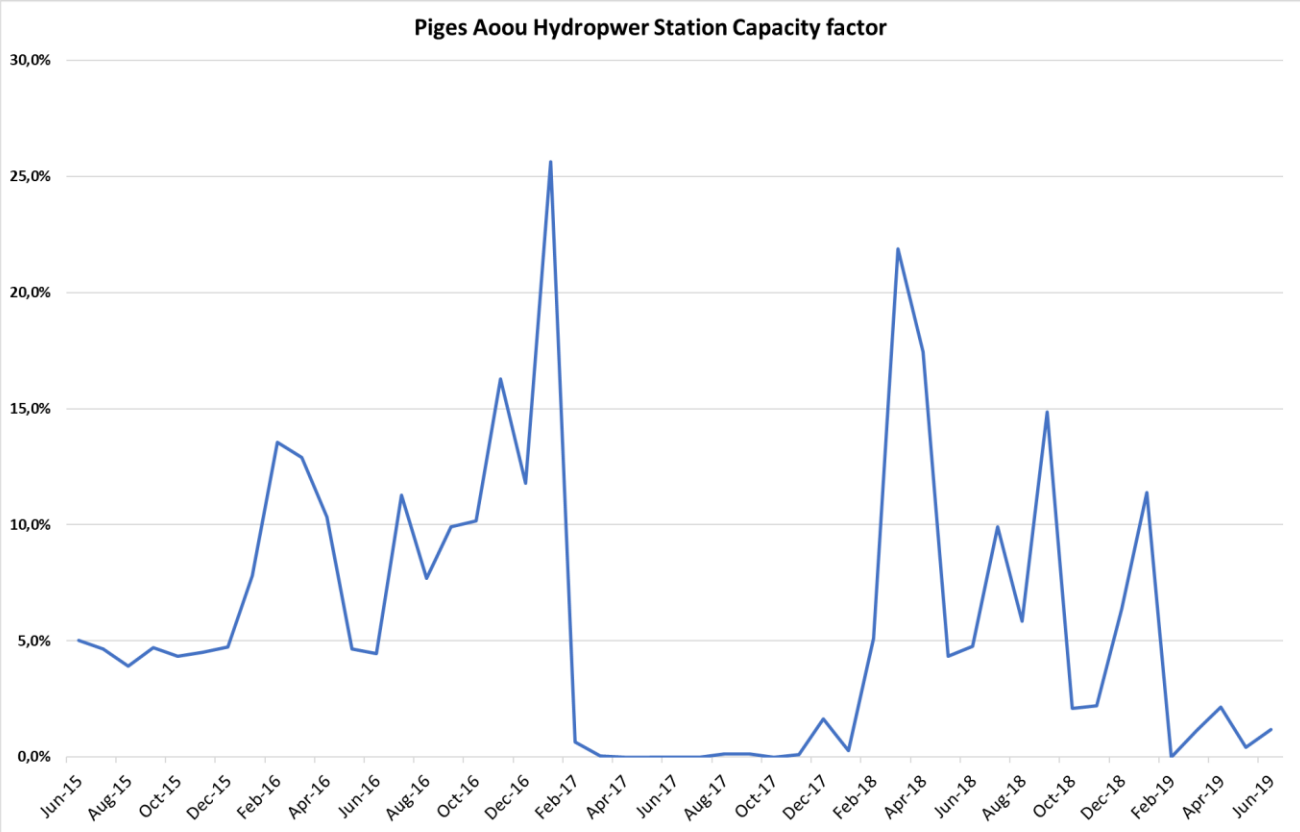


Figure 27. Capacity factor of the Piges Aoou Hydropower Station, between June 2015 and June 2019.

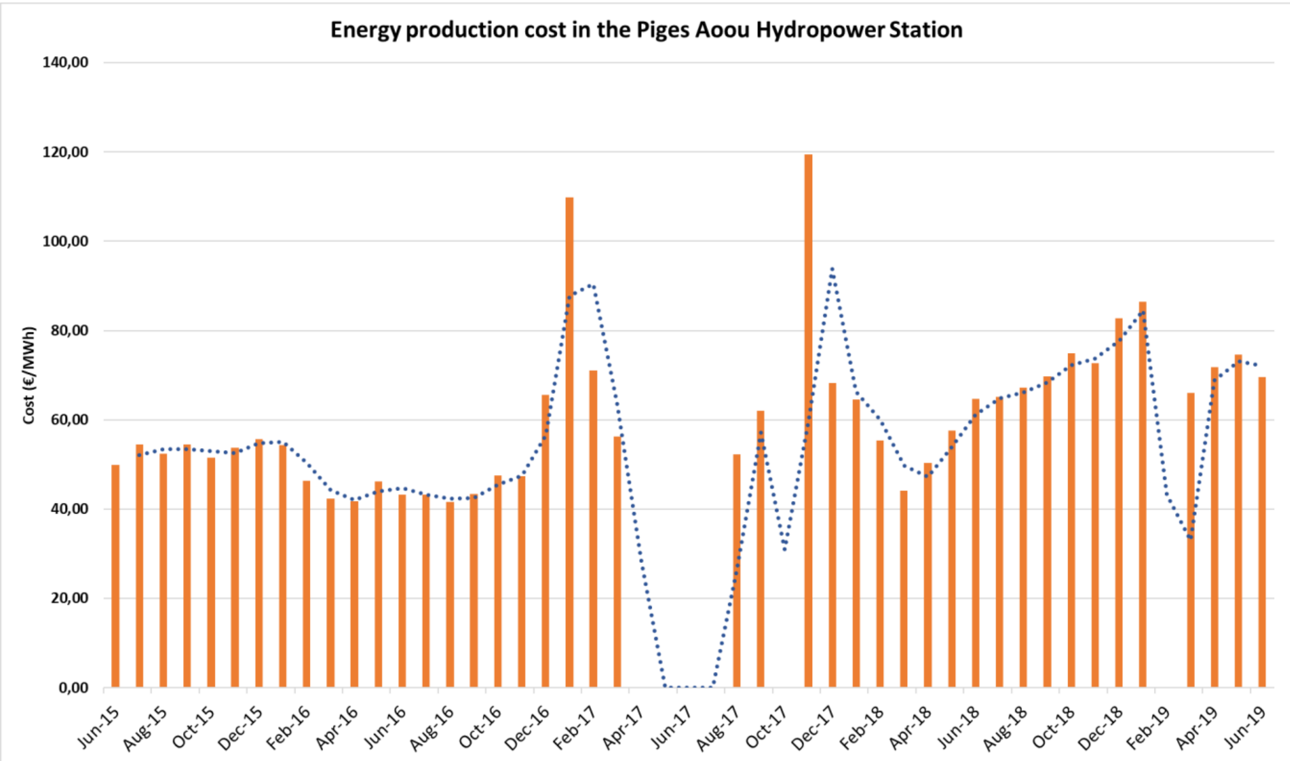


Figure 28: Energy production cost of the Piges Aoou Hydropower plant, between June 2015 and June 2019.

- **The intervention to the Aoos river system, because of the hydropower station, is major; $125x10^6$ m^3 of water from Aoos are diverted annually to Arachtos, because of the dam and power station operation.**
- **Despite the great intervention in the river, the energy production is rather low; the capacity factor of the power station is only 6.0%. The fluctuations in the energy production are also particularly high.**
- **The Piges Aoou hydropower station, despite the great intervention in the river Aoos hydrological system produces only 3.25% of Greece's hydroelectric energy**
- **Local societies do not receive any financial benefits from the power station operation, whose annual revenues exceed 6.5 million euros, apart from some quantities of water that are utilized for cultivations in the Chrysovitsa plain.**

In the next page, Figure 29 and the short explanation show how the hydrosystem in the Piges Aoou power plant works.

Study on Renewable Energy Sources in the Aoos basin – beyond hydropower exploitation

Figure 29: General diagram of the Piges Aooou hydro-system.

Aoos river and the streams of its springs are trapped by the main dam (and the other auxiliary dams). The diversion tunnel transfers water to the power station (located near the village of Chrysovitsa) and then to Metsovitikos river, one of the main branches of Araxhtos.

Renewable energy potential and relevant investments

In this Section data related to the renewable energy potential of the area under study will be summarized. Moreover, according to the available information energy investments planned in the area will be presented. Furthermore, illustrative examples of alternative, decentralized and mild renewable energy exploitation options, compatible with the characteristics of the area will be mentioned. This will practically help forming a view of a truly sustainable energy future for an area, whose main features are extensive protected areas and untouched natural landscapes.

Solar energy potential

The solar radiation data, as well as the electricity production potential of polycrystalline photovoltaics (the most common and cost-effective type of photovoltaic panels) in the study area are summarized in Table 8. The data refer to Vovousa, Konitsa and Metsovo and as it can be seen the situation is similar in all areas. It should be noted that although the upper basin of Aoos is situated in a highly mountainous terrain, in an area with plentiful precipitation, the solar radiation remains at satisfying levels for energy production. The quantity of electricity that can be produced by 1 kW of photovoltaic panels (installed peak power) amounts to 1,600 kWh/year, which is a rather good performance. It is noted that the annual average electricity consumption of a Greek household is 3,750 kWh (ELSTAT, 2013), in order to have a comparative perspective with the photovoltaics energy yield.

Table 8. Solar radiation and photovoltaic production in the areas of Vovoussa, Konitsa and Metsovo[22]

	VOVOUSSA				KONITSA				METSOVO			
Month	**E_d**	**E_m**	**H_d**	**H_m**	**E_d**	**E_m**	**H_d**	**H_m**	**E_d**	**E_m**	**H_d**	**H_m**
Jan	1.91	59.2	2.35	72.7	1.95	60.4	2.43	75.3	1.91	59.1	2.31	71.6
Feb	2.20	61.6	2.72	76.2	2.28	63.9	2.88	80.6	2.13	59.6	2.61	73.1
Mar	3.45	107	4.36	135	3.24	100	4.18	130	3.27	101	4.12	128
Apr	3.72	112	4.80	144	3.74	112	4.90	147	3.64	109	4.68	141
May	4.01	124	5.31	165	4.20	130	5.61	174	4.12	128	5.42	168
Jun	4.46	134	6.03	181	4.63	139	6.32	190	4.64	139	6.23	187
Jul	4.73	147	6.46	200	4.91	152	6.77	210	4.86	151	6.62	205
Aug	4.61	143	6.33	196	4.80	149	6.67	207	4.76	148	6.50	202
Sep	3.80	114	5.08	152	3.99	120	5.39	162	4.02	121	5.34	160
Oct	3.22	99.8	4.16	129	3.31	103	4.36	135	3.42	106	4.40	137
Nov	2.23	66.9	2.83	84.9	2.44	73.1	3.13	93.9	2.48	74.3	3.10	93.0
Dec	1.69	52.4	2.09	64.8	1.79	55.5	2.24	69.3	1.78	55.0	2.16	67.1
Yearly average	**3.34**	**102**	**4.39**	**133**	**3.45**	**105**	**4.58**	**139**	**3.43**	**104**	**4.47**	**136**
TOTAL, ANNUAL	**1,220**		**1,600**		**1,260**		**1,670**		**1,250**		**1,630**	

***E_d**: Average daily electricity production from 1 KW of polycrystalline photovoltaic panel (kWh)*

***E_m**: Average monthly electricity production from 1 KW of polycrystalline photovoltaic panel (kWh)*

***H_d**: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)*

***H_m**: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)*

[22] https://ec.europa.eu/jrc/en/pvgis

Additionally, such rates of solar radiation can effectively support the operation of thermal solar panels, whose use is crucial, particularly in areas with cold climatic conditions, in order to reduce the use of expensive, fossil fuels. Solar thermal panels can produce heat by directly utilizing incidental solar radiation. According to the relevant technical legislation/ regulation, the coefficient of solar utilization is 0.34 in the area under study[23]. This means that 34% of the incidental solar radiation can be transformed to thermal energy by a solar collector (selective surface).

In general, the investment interest for solar energy in the study area is not intense. According to the Regulatory Authority for Energy (RAE, 2019):

- In the Municipality of Konitsa 334.40 kW of photovoltaic plants are in operation
- In the Municipality of Metsovo 99.75 kW of photovoltaic plants are in operation
- In the Municipality of Zagori 99.75 kW of photovoltaic plants are under evaluation

In the Municipality of Metsovo a big photovoltaic unit with total capacity near 10 MW is under consideration. This is a rather big investment, considering the characteristics of the area, since the necessary space amounts to 160,000 m^2 at the slopes of mount Lakmos.

It should be noted that photovoltaics is an energy technology that can be used by "energy communities" or "energy collectives". These are forms of social economy structures and have been introduced recently to Greece, according to the Law 4513/2018. The national energy planning of Greece, which is currently under discussion, sets up specific goals regarding energy production by energy communities. Energy communities will be presented more analytically in a separate Section, since they are important for an alternative, sustainable energy future.

Photovoltaics are ideal for being used by energy communities because they are flexible, not expensive for applications with low power. In the study area, households can install small systems, at home level and form an energy community. This collective energy initiative will create benefits for households (through energy net metering) and additionally increase the share of renewable energy in the area. Furthermore, a utilization of photovoltaics through collective projects is a mild form of exploitation, in contrast to investments such as this under consideration that needs 160,000 m^2 for implementation.

Solar PV are a popular technology, because of the simplicity in installing and operating, for setting up energy communities. The following example, adopted at the basis of the work of Doulos (2019), illustrates how an alternative model for RES development could be applied in the area under study. One or more municipalities in the river basin of Aoos could take the initiative for creating an energy community, in which citizens of the area are also going to participate. The energy community will be an example of decentralized energy production, aiming not only to cover energy loads, but also address energy poverty, an important social problem among mountainous areas (Katsoulakos, 2011). This example is a truly sustainable alternative and highlights our proposal for a different approach to energy production in the area of Aoos. In the following box the main aspects of an energy community based on solar energy in the area under study are described. The operation of a solar energy-based energy community proves to be a viable practice, while the impact on the environment is negligible.

[23] According to Greek Regulation for Buildings' Energy Performance (initials KENAK).

"Aoos Solar Cooperative (ASC)"
An energy community that will have the following characteristics:

- A photovoltaic unit with capacity 250 kW/ this requires 2.5 acres of land
- The total cost is estimated to be 240,000 euros
- The energy production is considered to be 1,450 kWh/kW, smaller than the area's potential, in order to have a safe estimation

(basic assumptions cost of maintenance 2.5% of the initial cost/ tax rate 26%/ depreciation rate 5%/ borrowing rate 5%)

Scenario A: The energy community is formed by the Municipalities (40%) and citizens that are interested (60%) and will be a for-profit corporation. The produced energy will be sold to the power grid; part of it will cover the expenses of the participants and the greatest part will subsidize the energy cost of vulnerable customers.
In this case the funds can be covered as follows: 50% from public funds that are aimed to boost energy communities, 30% from bank loans, 20% from participants' funds. The citizens that will be members of the ASC (at least 278) will pay 100€ each, as initial dividend and the Municipalities will cover the rest necessary part of the own funds. Considering that such an energy unit could be refunded with 84 €/MWh of produced energy, the annual revenues will be 30,450 €.

The annual cash flow will be about 15,500 €. This cash flow will be used as follows:

- 10% for creating an obligatory, regular reserve
- 20% as dividend for the citizens that are members of the community
- 70% for subsidizing the energy expenses of vulnerable households

This means that, annually, 10,850 euros, will be available for energy vulnerable households; about 32 households can have 50% discount in their electricity expenses. At the same time, the participants in the community will have profits and will repay their initial investments in less than 8 years.

Scenario B: The energy community is formed by the Municipalities (80%) and a private non-profit body that operates in the area of (20%) and will be a corporation – either non-profit or will offer some funds within its social responsibility actions. The energy produced will be through net-metering lower the energy costs of vulnerable customers.
In this case the funds can be covered as follows: 50% from public funds that are aimed to boost energy communities, 40% from the Region of Epirus, 10% from participants' funds. The Municipalities will need to offer 19,200 € and the corporation 4,800 €.

The produced energy will be counterbalanced through net metering. About 100 ulnerable households will benefit from this and they could save up to 57% in their electricity costs. The whole procedure is calculated to have positive Social Net Present Value and Social Internal Return Rate greater than the discount rate, which was taken equal to 5%. So, it is a viable practice, positive for the local society.

Wind energy potential

As far as wind energy potential is concerned, the area under study is not characterized by particularly high wind velocities. In Figure 30, the wind velocities in the Regional Unit of Ioannina are depicted. As it can be seen the areas with high average wind velocities (over 6 m/sec), suitable for major wind energy investments, are restricted. They consist mainly of high-altitude areas in ridgelines. Many of them are not suitable for wind energy projects, either because it is difficult to approach them or because they are included in protected territories, such as National Parks.

There is investment interest for wind energy projects in the study area. More specifically, according to RAE (2019):

- In the Municipality of Metsovo 3 MW of wind power are in operation
- In the Municipality of Metsovo, eight wind energy units are under evaluation, with total proposed installed capacity 174.25 MW
- In the Municipality of Konitsa, one wind energy unit is under evaluation, with proposed installed capacity 36 MW

It should be noticed that, practically, the investment interest in wind energy is concentrated on the area of Metsovo. Wind energy projects are also under evaluation in the neighboring to Metsovo Municipalities, in the Region of Thessaly. This may lead to a particularly dense network of wind generators, if the investment plans are approved, with major environmental impacts.

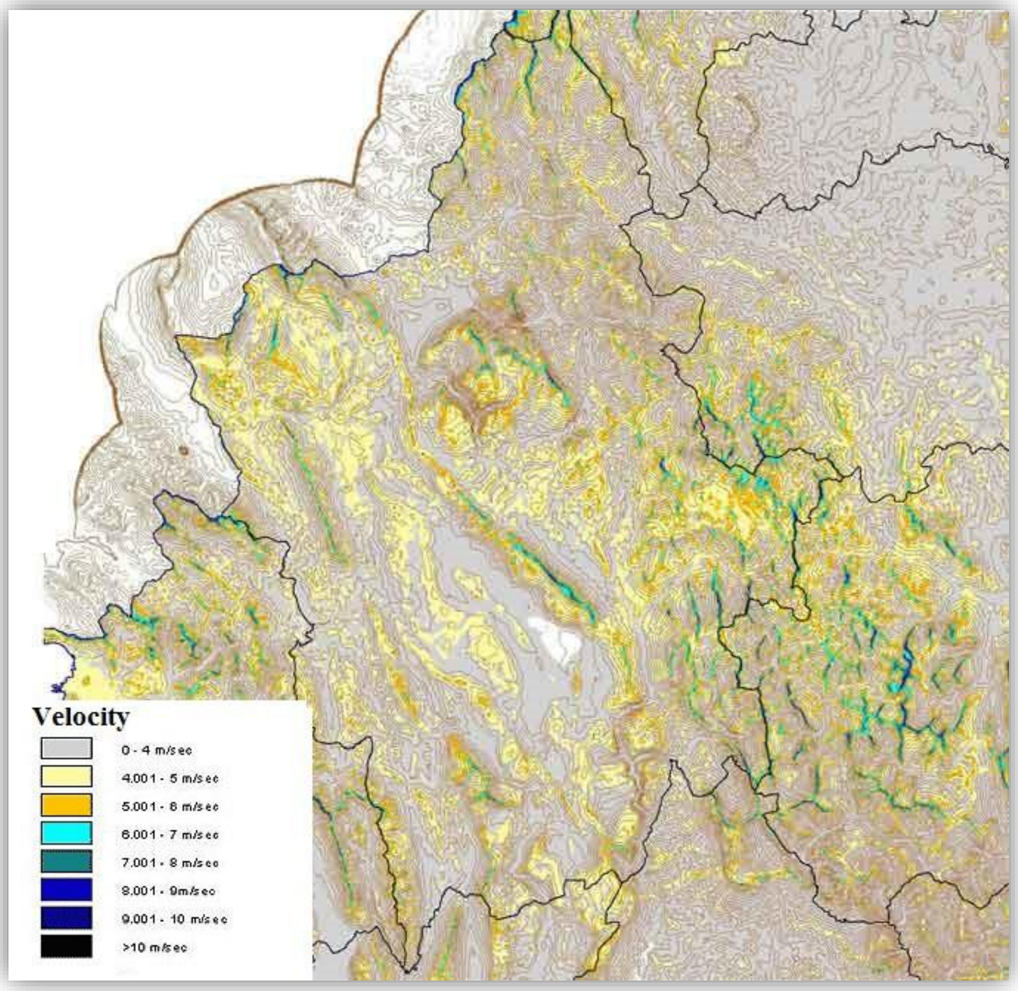


Figure 30. Wind velocities in the regional unit of Ioannina [24]

[24] http://www.cres.gr/kape/datainfo/maps.htm

Again, contrary to the energy projects with high installed capacity that include big wind generators, there are important opportunities for development of wind energy, in an alternative way, friendlier to the environment and local societies. More specifically, at local level, the installation of small wind turbines can be promoted (capacity less than 60 kW). Such units need lower wind velocities for operating, create less impacts to the environment and their cost allows collective, local initiatives to use them, like in the case of photovoltaics. A short, illustrative example is given in the Box below:

Example regarding the use of small wind turbines in Vovousa

- In the mountainous area surrounding the village of Vovousa, according to the National Information System for Energy, there is an area of 10 Km^2, with average, annual wind velocities ranging in 7 km/h.
- With such wind velocities, a small wind turbine with a nominal capacity of 3 kW, can operate at a capacity of 2 kW, in average.
- Considering a capacity factor of 35%, this kind of wind turbine can provide about 6 MWh of electricity, at an annual basis.
- The investment cost of such a wind generator is about 3,500 €.
- Considering that this system can be used for net-metering, with an average electricity cost of 0.15 €/kWh, the annual economic benefit will be 900 €.
- A good practice could be the following: people from the Vovoussa village could form an energy community (like in the case of PV shown before), install such small wind generators and reduce their energy costs, through viable investments, with low initial cost.

Biomass energy potential

The role of biomass is crucial, especially for mountainous areas, since it is a renewable source of energy that can primarily produce heat, something important for these cold areas (Katsoulakos & Kaliampakos, 2014). The Region of Epirus is rich in forest biomass (as seen in Figure 31), since extensive forests cover great part of its area. In the Regional Unit of Ioannina, 58% of the territory is covered by forests, while the corresponding percentage in Greece, in total, is about 20% (Katsoulakos, 2013). The area under study is the most important one, regarding forest production in the Region of Epirus. In Table 9 the thermal content of the main productive forest in the Region of Epirus are presented, categorized into Municipalities (CRES & EUROTEC, 2011). Following the data of Table 9, 63% of the forest biomass potential of Epirus is found in the Municipalities of Zagori, Metsovo and Konitsa. It must be noted that the content of Table 9 is based on an analytical study, coordinated by the Center for Renewable Energy Sources (CRES) of Greece, and refers to the biomass potential that can be utilized, following the principles of sustainable forestry. The thermal content of biomass in the area under study is equal to the thermal energy demand of about 4,000 households, considering the characteristics of the buildings and the climatic conditions in the area (Katsoulakos, 2013). So, forest biomass is a very important source of energy. For the town of Metsovo, the National Technical University of Athens has conducted a research study for providing heat to the town (70% of the total thermal energy needs) via a district heating system, based on a central woody biomass (forest and residues) combustion unit.

The key issue that should be considered in the case of biomass exploitation is the necessity of applying sustainable forest production methods, which are already mentioned. The annual forest production should follow specialized studies of the forest authorities. Otherwise, the exploitation is not sustainable and, consequently, the energy produced cannot be characterized as green or renewable. Problems related to energy poverty in the area under study (Papada & Kaliampakos, 2017) have led to illegal logging, as reported by local forest authorities. This is something that should be alleviated, because it sets risks to local forests and environment, in general. The organized exploitation of biomass is a good practice that can act against illegal logging and, simultaneously, help local communities to lower their energy costs.

Regarding household energy use, in many households, especially in the smaller settlements biomass fired systems are systematically used. However, most of them are of low efficiency (open fireplaces or old stoves). The use of more effective systems, like firewood heated boilers, can provide better conditions to the households, while retaining lower firewood consumption. Indicatively, a house that uses central heating based on firewood burner-boiler system consumes 65% less firewood than a house that uses an old wood stove. In the following box examples regarding the cost of using various heating systems are presented, in order to highlight the cost-effectiveness of modern biomass systems. Finally, households should keep firewood to dry for at least six months before they use it, in order not to use firewood with high humidity content. This is a common problem in Greece and in the area under study; people buy freshly cut firewood, with high humidity and low heating capacity .

Comparing the costs of heating systems

In Greece the most popular heating system is diesel boilers. In the area under study, biomass is also used by many households. Taking into account that the average household's thermal energy demand is 20,000 kWh in the Aoos river basin (Katsoulakos, 2013), the various costs for covering this demand are calculated:

- **Diesel oil boiler** (efficiency ratio 90%, cost of fuel 1.1 €/lit, fuel heating capacity 9.77 kWh/lit): The necessary diesel oil consumption in this case is 2,274 lit and the corresponding annual cost amounts to **2,500 €**.
- **Old wood stove** (efficiency ratio 55%, cost of fuel 120 €/tn, fuel heating capacity 3.2 kWh/kg, with 20% humidity): The necessary firewood consumption in this case is 11.36 tn and the corresponding annual cost amounts to **1,360 €**.
- **Firewood boiler** (efficiency ratio 80%, cost of fuel 120 €/tn, fuel heating capacity 3.2 kWh/kg, with 20% humidity): The necessary firewood consumption in this case is 7.81 tn and the corresponding annual cost amounts to **935 €**.
- **Pellet boiler** (efficiency ratio 85%, cost of fuel 220 €/tn, fuel heating capacity 5 kWh/kg): The necessary pellet consumption in this case is 7.81 tn and the corresponding annual cost amounts to **1,035 €**.

From the data shown in the Box, it is clear that biomass is a far cheaper fuel than diesel. So, in cold areas like the study area, it can be seen as good choice for households. However, we should keep in mind that an old stove, despite the lower cost compared to diesel, because of its low efficiency and the rather low combustion temperature, has high PM (ash) emissions. A certified firewood boiler is a better choice and has the lowest cost. The pellet boiler is a more expensive choice (still with low operating costs), but has the least PM emissions and moreover, it includes an automatic fuel feeding system, whereas stoves and firewood boilers need to be filled with fuel regularlyby hand. In any case, the use of biomass could be a good choice, especially with modern combustion systems, and is is an important way to alleviate energy poverty in mountainous areas (Katsoulakos, 2011).

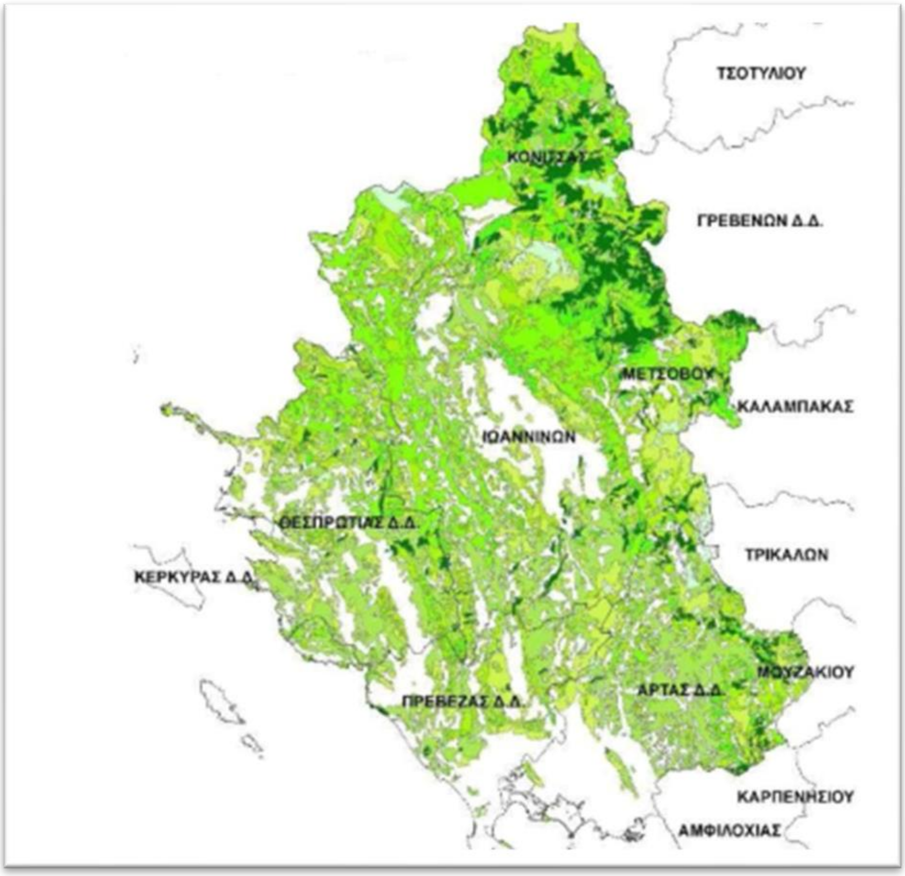


Figure 31. Forest coverage in the Region of Epirus; practically all green areas are forest covered areas (CRES & EUROTEC, 2011)

Table 9. Thermal content of the forest biomass, which can be utilized for energy production in the Region of Epirus

Municipality	Biomass Potenial – Thermal content (GJ)
Zagori	267,129
Pogoni	108,768
Zitsa	21,818
Dodoni	6,596
Metsovo	66,798
Konitsa	27,857
Arteon	14,711
Kentrika Tzoumerka	9,443
Georgios Karaiskakis	31,962
Filiates	17,392
Souli	1,506
TOTAL	**573,980**

As far as organic residues are concerned – another important bioenergy source - the potential is not such plentiful as in the case of forest biomass, because of the, generally, restricted production activities. Data from the Municipality of Metsovo, which still has important activities in livestock breeding and food production, show that there is potential that can be utilized and contribute to the local energy mix.

More specifically, in the Municipality of Metsovo, from organic waste - agricultural residues, livestock residues, wine production residues and cheese production residues (Katsoulakos et al., 2017):

- 1,210,000 m3 of biogas can be produced, at an annual basis
- The thermal content of the biogas is 8,228 MWh, at an annual basis

Hence, biogas produced in the area of Metsovo equals to the thermal energy demand of 330 households. So, organic waste should not be neglected as an alternative energy source, which additionally presents the advantage of reducing organic pollution of water and soil.

There is no investment interest regarding biomass in the area under study. Despite the competitive LCOE of biomass, in Greece it remains an expensive technology and investors are not keen on designing and implementing relevant investments.

Hydroelectric energy potential

The numerous water streams and the plentiful precipitation create favorable conditions for hydroelectric energy units' development, as already mentioned. This facilitated the Piges Aoou hydropower plant construction in the area. The development of big hydropower plants in the Region of Epirus is not a priority anymore - at least if we consider the course of the energy market since 2006 and the content of the national energy planning that is still under discussion. Relevant energy studies, like the one of CRES and EUROTEC (2011), which was the last major study for quantifying the energy potential of the region, do not include estimations related to the exploitation of hydraulic energy through the use of power plants with capacity greater than 15 MW. Hence, when speaking about renewable energy, the exploitation of hydroelectric potential is restricted to small hydropower plants, with a capacity less than 15 MW. There is only one exception. The PPC is constructing a 29 MW hydropower plant in the Metsovitikos river. This power plant will utilize the water transferred from Aoos to Arachthos for the operation of the Piges Aoou power plant.

The Aoos watershed is characterized by an average annual discharge of 2.2 billion m^3 (YPAN, 2003). This is the greatest annual discharge among all watersheds (Aoos, Arachthos, Kalamas, Louros, Aheron) in the Region of Epirus. However, this great value of annual discharge does not automatically mean that the exploiting hydraulic energy is efficient or easy within a watershed. Hydroelectric energy units are composite structures, whose efficient operation – especially the operation of small units – depends on various factors, such as: available hydraulic drop, geological factors, seasonal differentiation in discharge, accessibility to the energy unit spot etc. During the first six years of renewable energy development in Greece (2006-2012), in the Aoos watershed, there was no investment interest for developing hydroelectric projects.

This situation has changed and nowadays, it seems that there is quite a lot of interest for constructing small hydropower plants in the area under study. As it is shown in Figure 32, in the watershed of Aoos, that there is interest for an overall amount of 26 MW generated by small hydroelectric plants. 5.68 MW are already in operation in the Municipality of Konitsa. In the Araxhtos watershed, within the Municipality of Metsovo, 6.2 MW of hydropower is planned to be installed. The total number of small hydropower installations sums to 19. Considering that there is already a big hydropower plant operating in the area and one more is going to operate soon, the existence of 19 more hydroelectric installation will drive to quite an increased density of hydropower units. Although new investments are projects of low capacity, categorized as small hydroelectric plants, if local hydroelectric potential is exhaustively utilized, the impacts on water streams and their hydrological balance will not be negligible. It is, once more, highlighted that the greatest part of the area under study includes protected areas. Water streams are spots of high biodiversity and great importance, in general. This is why an one-dimensional exploitation of water streams for energy production will potentially create negative impacts to other ecosystem services provided by these water bodies.

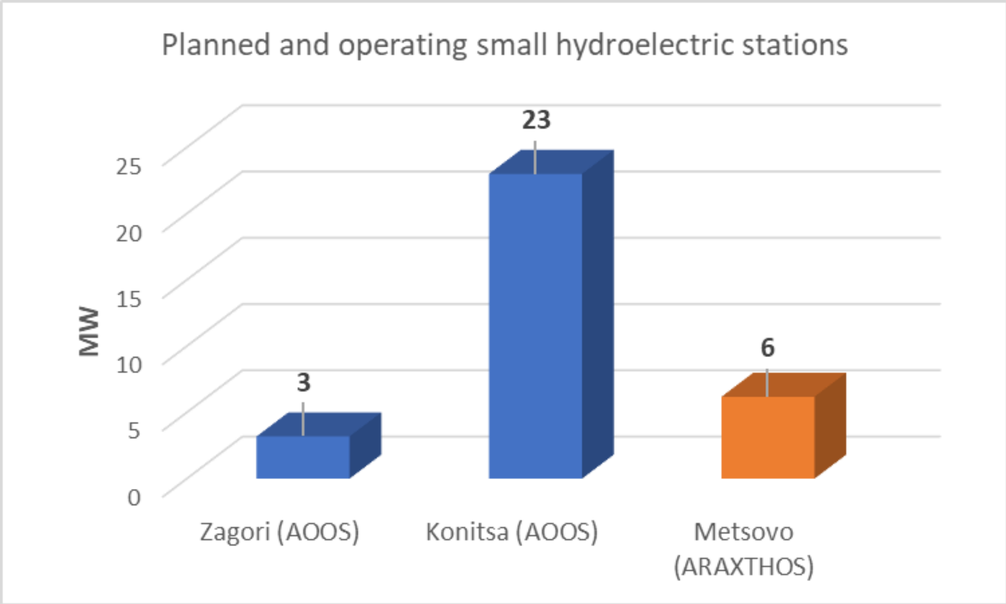


Figure 32. Planned and operating small hydroelectric stations in the area under study (RAE, 2019)

Energy saving potential

Energy saving and energy efficiency, although included in the EU energy policy targets are not included in the studies that examine energy potential. In many cases they are also not included in energy optimization models, as part of optimal energy mixes. We have already made reference to the significance of lowering energy demand and consumption in mountainous areas, like the one under study. This is why in this section, some more particular facts related to energy saving are mentioned.

It must be highlighted that lowering the energy demand is a prerequisite for a more sustainable future and more effective use of renewable energy sources, which are not characterized by great capacity factors, like fossil fuel and nuclear-based power stations. Moreover, energy saving lowers household's energy expenses and, as a result, decreases vulnerability to energy poverty. The main energy efficiency measures that can be applied to an household, especially an household in our area of study are:

- Thermal insulation to walls and roofs
- Replacement of old windows with new, energy efficient ones
- Replacement of diesel boilers with biomass ones or heat pumps
- Installation of solar heating systems
- Soft measures, like installation of digital thermostats, thermostatic valves in radiators, increase in windows air tightness etc.

In the area under study, two rather innovative studies (Theodorou, 2012; Katsoulakos, 2013) have been realized in the past years regarding the energy saving potential of the two main settlements of the territory, Metsovo and Konitsa. The main findings of these studies have been included in the following box. Because of the, in general, old building stock in the settlements, there is great potential for lowering energy demand, over 50% at town level. Considering this, the energy saving potential is, from another perspective, an abundant energy source in the area under study. Systematic investigation of the energy saving potential in the main settlements should be realized and future energy policy should include energy efficiency as a core part.

Energy saving potential in Konitsa and Metsovo

Konitsa

Almost half of the houses in Konitsa have been built before 1960. This results in particularly low energy efficiency. A model of the settlement was created, according to statistical data and some fieldwork (Theodorou, 2012), in order to calculate the technoeconomic efficiency of energy saving interventions. The main findings are the following:

- The application of thermal insulation can save up to 36% of thermal energy demand of the town (buildings without insulation), leading to a total reduction of 445,000 € annually.
- The replacement of old windows can save up to 17% of thermal energy demand of the town (buildings with old windows), leading to a total reduction of 250,000 € annually.

Metsovo

A similar methodology was applied in Metsovo, but the study was more detailed (Katsoulakos, 2013). Again, more than half of the town's houses have been built before 1960 and so the settlement is characterized by low energy efficiency; the average, annual thermal energy demand exceeds 25,000 kWh/ household. The main findings in this case are the following:

- The application of thermal insulation can save up to 37% of thermal energy demand of the town (buildings without insulation).
- The replacement of old windows can save up to 20% of thermal energy demand of the town (buildings with old windows).
- By combining thermal insulation, replacement of windows and solar heaters the energy savings can reach 55% of the total thermal energy demand of the town.

- **The solar energy potential in the area under study is at good levels. Not only photovoltaics, but also thermal solar systems should be utilized for energy production.**
- **The wind energy potential is not very high, but there is interest in wind energy investments in the broader area.**
- **The biomass potential is plentiful, and its sustainable utilization is crucial for local societies since biomass can produce heat, which is important, considering the harsh winter conditions in the area**
- **Hydropower causes significant interventions in river/ water stream flow. The investment interest is important for new small hydropower plants, but the number of installations planned is quite great, considering that big and small hydropower stations are already in operation.**
- **It is proposed to utilize solar, wind and biomass energy further, but at another basis. Instead of major projects, we need to create small units, preferably community-based ones, that will be utilized for local needs.**

TOWARDS A SUSTAINABLE ENERGY FUTURE

The question regarding how we can reach a sustainable energy future is not easy to be answered. A lot of aspects must be considered, there are contradicting viewpoints and additional information to be analyzed, the whole discussion cannot be exhausted in the present report. However, some basic thoughts that can mobilize a further dialogue, especially for the area of interest will be included in this Chapter, following data and arguments that have been presented.

Firstly, it should be highlighted that the dominant, current structure of the energy system is a centralized one. This means that power stations are operating in certain spots and provide electricity to the transmission and distribution networks. The whole system is tree-like. Such a structure of energy system was convenient, especially in the era of fossil fuel domination; power stations were built where fuel was available and then electricity "travelled" throughout countries and even continents. Even nowadays, when RES have become a priority, the same logic was followed. Extensive wind farms are built in areas with great wind velocities; photovoltaic parks with high capacities are created in sunny places with favorable orientation; biomass combustion units are created near productive forests or big cattle farms; dams are constructed where the flow of rivers can be controlled and so on. This kind of energy system structure inherently produces imbalances. The main cause of imbalance is that we need to create energy production units where the "fuel" is found, either renewable or non-renewable. In conclusion, we tend to create energy plants of big installed capacity (this is also attributed to the better financial performance of bigger energy units) and then transmit and distribute energy. In this way, some areas are obliged to incur all the impacts caused by energy production units, in order to provide energy to a whole region or country.

An important change that will lead, potentially, to an energy future with better perspectives includes decentralized energy production. This means that smaller energy units can operate practically everywhere, even on rooftops. The energy will be provided by "smart" grids to the consumer, who can potentially be, simultaneously, the producer. Of course, such a change demands major investments in grid infrastructure, storage systems and metering/ monitoring equipment that will help to optimizing the energy production – energy consumption coupling. The great advantage of such a change is that energy production units will not necessarily have high installed capacity and exhaust local resources. Moreover, decentralized energy production can also lead to democratized energy production and consumption. The above mentioned systems are illustrated in Figure 31, which shows the past/ present and the future of energy.

The Aoos basin is a representative example of the inherent imbalance of the current structure of energy system. More specifically, for the time being in the area under study the Piges Aoou hydropower station is operating (210 MW), as well as three small hydroelectric stations (5.86 MW) and a small wind farm (3 MW). The 29 MW hydropower station of Metsovitikos will operate within the next years, while 210.25 MW of wind energy units are being planned, as well as 26.52 MW of small hydropower plants. These figures imply that the density of energy production units in the area is particularly high. From the energy projects in operation, 217.93 MW are currently operating in the Aoos watershed. Regarding the energy units planned, 57,25 MW will operate within the Aoos watershed. In Figure 34, the installed capacity per capita for the Aoos watershed and Greece are shown. In our area of study, the installed energy production capacity is 7.5 times higher than the country's average, while the population of the three Municipalities (Metsovo, Konitsa, Zagori) amounts to only 0.1% of Greece's population. This is an indicator of great imbalance that the current energy system structure produces.

Considering the extensive protected areas and the valuable natural and cultural resources of the area, the further development of energy projects is not the best choice. The main priority should be the utilization of RES in a way of the "Energy Future" shown in Figure 33.

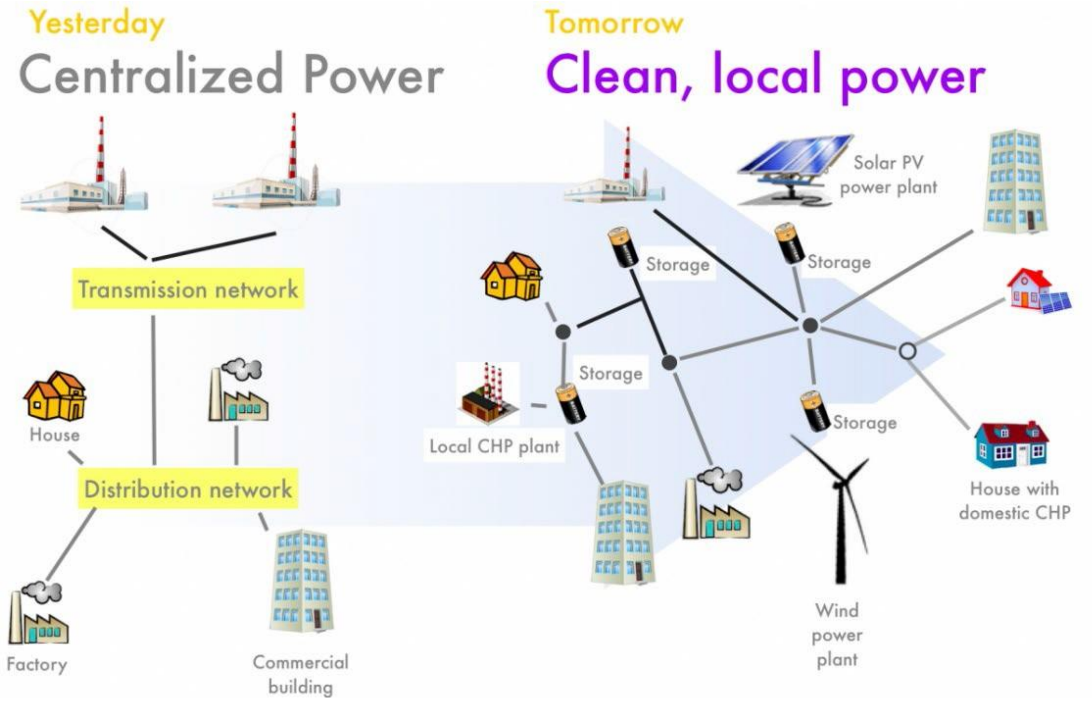


Figure 33. The past and the future of energy (Farrell, 2011).

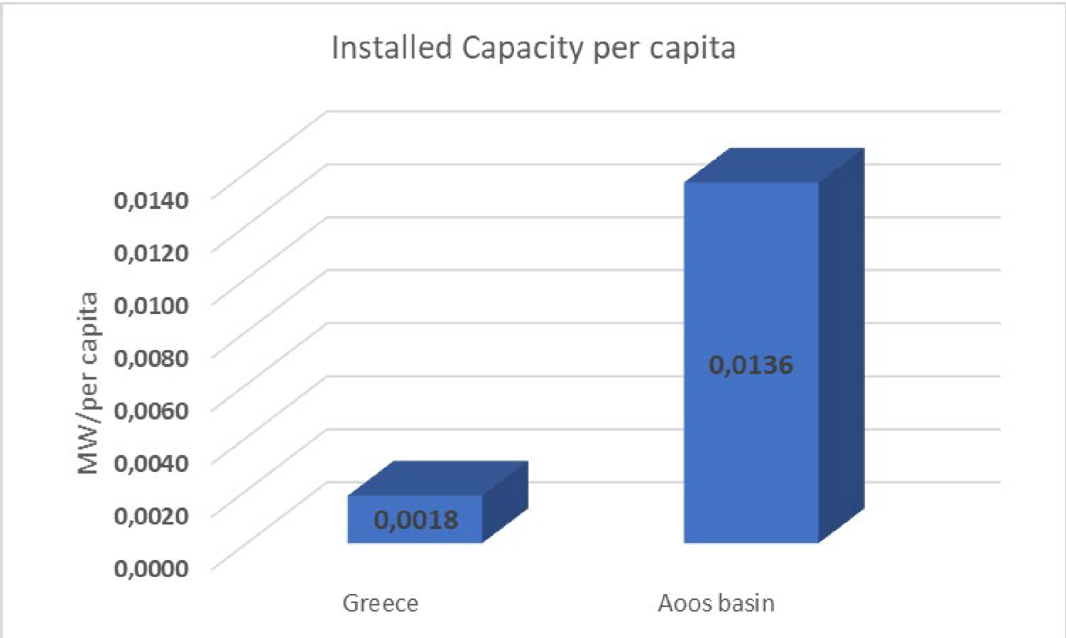


Figure 34. Electricity production installed capacity per capita in Greece and in the Aoos basin.

The mobilization of a social economy and its role for creating a sustainable energy future

As already mentioned, community-based energy projects are an alternative to the development of RES through large scale projects. In order to gain a better perspective about energy communities, in this section a series of issues and examples related to them and to social economy in general, are presented. Before ending up with policy proposals, we think that a presentation of community energy – some aspire to see it as the first step to energy democracy – would provide useful evidence, which proves that cooperative energy projects are a realistic choice.

The European Union (EU) faces serious challenges that are directly related to the increasing energy demand, the significant fluctuation of energy product prices as well as the disturbances in the security of energy supply. However, the environmental impact of energy consumption in all areas of economic activity remains high. In order to ensure that European citizens and businesses have safe, affordable and environmentally friendly energy, the European Union has set three key objectives: security of supply, competitiveness and sustainability in the energy strategy, which was designed and implemented in order to meet these challenges.

In order to ensure the EUs capacity to address the challenges of both climate change and energy production, the Energy Union Framework Strategy was drawn up in February 2015. In November 2016, the EU presented a package of measures, also known as the Clean Energy Package for all Europeans, aiming to boost the transition of the EU economy to clean energy through the creation of new jobs, business models and financial sectors.

Greece, in accordance with the obligations arising from the Governance of the Energy Union, must compile the National Energy and Climate Action Plan as well as the Long-term Energy Planning. The National Energy and Climate Action Plan proposes objectives, measures and policies at national level that will contribute to European energy and climate pursuits. Social economy is playing a significant role towards this aims. Law 4513, that was approved by the parliament in 2008, was a major step for organizing and supporting cooperative schemes in the energy sector. In social economy enterprises, the social goals outweigh the speculative goals, and the open democratic system of member participation differs both from the shareholding system of public limited companies and from the administrative control of the state of public enterprises and organizations.

Examples of cooperative energy schemes in Europe

Co-operative enterprises in energy have a very important momentum in Europe. The list of successful examples is great. Just a few of them are mentioned below (HBS, 2019):

The Energy Community of Som Energia in Spain

The Community was founded on 2010 in Catalonia, Spain and until now has more than 35.000 members. The energy which is produced is distributed to households, enterprises and municipalities. The staff of the cooperative is 40 persons, and many volunteers are also involved, while the fee that member have to pay in order to participate in the cooperative is 100 €.

The REScoop Plus initiative

The REScoop Plus initiative, funded by the European Commission under the framework of the program Horizon 2020, focuses on developing energy cooperatives with focus on analyzing and improving the energy behavior of their members (e.g. reduction of energy consumption, investment in energy production by renewable energy sources, etc.). At the same time, the initiative highlights best practices and promotes appropriate energy efficiency measures, creating added value for existing and future renewable energy cooperatives. In particular, the initiative aimed at upgrading the processes of production and supply of "green" energy to energy cooperatives in Europe and promoting good energy-saving practices for their members as a new pillar in their organization. The project involves research centers, energy cooperatives and organizations from eight European countries (Portugal, Greece, France, Spain, Italy, Belgium, Denmark, Netherlands).

The case of Deltawind

Deltawind Energy Community was founded in August 1989 on the island of Goeree-Overflakkee, in the southwestern parts of the Netherlands. Deltawind was founded with the vision to contribute to renewable energy production and the responsible consumption in the region and beyond. Deltawind focuses on wind energy as, according to its members, "this is the most cost-effective way of producing renewable energy". In addition to wind farms, the energy community has built a solar park, and they have organizeda collective purchase of photovoltaic roofs for the citizens of the island. Nowadays, Deltawind has more than 2.080 members and employs 8 people. Individuals or legal entities (companies, churches, or other organizations) affiliated with the island, residing, originating or owning, or, in the case of organizations, have a legal basis in the Goeree-Overflakkee, may become members of the energy community with a contribution which starts from 50 €.

In Greece the new institutional framework seeks to link Social and Solidarity Economy (SSE) and the energy sector and introduces a new type of urban partnership, the Energy Community. Energy communities are an important tool for achieving a fair energy transition in the country, since renewable energy sources and energy saving offer and require, for their proper exploitation, the geographical spread of investments and the participation of many in it.

The Law on Energy Communities (Law 4513/2018) enables citizens, local authorities and small and medium-sized enterprises to set up urban cooperatives exclusively active in energy-related fields, locally and regionally. The law therefore recognizes the role of “many” as subject to energy transition and promotes social and solidarity economy in the field of energy, tackling energy poverty, promoting energy sustainability, production, storage, self-consumption, distribution and energy supply, enhancing energy self-sufficiency and safety in island municipalities, and improving energy efficiency locally and regionally.

Briefly, the key elements of the law are the following:

- «Locality», which is a necessary condition for the creation of synergies and partnerships for the implementation of energy projects responding to local needs, utilizing local renewable energy resources, with the aim of disseminating benefits to Energy Communities members and generating added value to local communities.
- The role of islands, which introduces special arrangements and privileges for the case of very small islands, in order to address issues such as the high cost per kWhel produced, as well as the environmental, economic and social issues raised by the use of conventional forms of fuel for energy production.
- The activation and enhancement of technological tools such as energy offsetting and virtual energy offsetting for their implementation, especially in Energy Communities, to shield vulnerable consumers living below the poverty line and tackle energy poverty.
- The providence of financial incentives and support measures for Energy Communities, which mainly concern the development of RES power plants, in order to exploit domestic potential with the participation of local communities, as defined in national energy targets.

According to the legislative framework (Law 4513/2018) energy communities are defined as follows:

The energy community is a city cooperative with the sole purpose of promoting social and solidarity economics and innovation in the energy sector, tackling energy poverty and promoting energy sustainability, production, storage and self-consumption, enhancing energy self-sufficiency and safety in island municipalities, and improving end-use energy efficiency at local and regional level. The above objectives are achieved through the activation of energy communities in the fields of renewable energy , the combined heat power energy production, the rational use of energy, the energy efficiency, the sustainable forms of transport and managing the demand, production, distribution and supply of energy.

Having in mind that the country’s energy sector is being restructured, energy communities can play an important role in the future. Their main objectives may be the following:

- Utilizing the available renewable resources and protecting the environment
- Promoting decentralized energy production and management
- Protecting and strengthening the role of the consumer and combating energy poverty
- Highlighting existing opportunities for social innovation, particularly at local level
- Enhancing competitiveness in the energy market

Examples of cooperative energy schemes in Greece

In Greece, social economy schemes have just recently started to develop, compared to other European countries. The legislative framework is particularly favorable for energy communities and it seems that they will play an important role in the country. Some successful examples are given below.

The case of Sifnos Island – The Energy & Development Sifnos Island Cooperative Ltd.[25]

The Energy & Development Sifnos Island Cooperative Ltd. with distinctive title Sifnos Island Cooperative (SIC) was established in 16/11/2013 by 53 founding members (partners) and has since then steadily expanded with over 100 members in two years. The vision of the residents of Sifnos was to make Sifnos an energy autonomous island by utilizing its rich RES potential. The electricity will be generated from RES installations jointly owned by the inhabitants and the friends of the island who will be prosumers (producers and consumers at the same time).

Sifnos Island Cooperative (SIC) is advancing towards the realization of the energy autonomy plan for Sifnos, by submitting an application for a production permit to the Regulatory Energy Authority (RAE) in September 2016. SIC's project refers to a Hybrid Power Station consisting of a wind park and a pumped storage plant. It is foreseen to have the capacity to generate all the energy required in Sifnos through Renewable Energy Sources only. All new facilities to be installed, will consider key objectives like the protection of the environment and tourism on the island, which is expected to increase in the future.

According to the conducted study, the investment will be profitable from the first year of operation of the Hybrid Station (since electricity production now is based on diesel oil and is particularly expensive) and will continue to be profitable throughout the lifetime of the investment, as the energy demand is secured. The Hybrid Station will be owned by Sifnos Island Cooperative, in which all major decisions are made by the General Assembly, equal members of which are all partners with one vote each.

In order to start the project, an open consultation was held on submitting comprehensive proposals for the energy autonomy of Sifnos. The General Assembly of the SIC selected the creation of a RES hybrid station incorporating a sea water pumped storage plant as the best proposal.

The hybrid station will consist of:

- a small (5 turbines) wind park
- one sealed sea water reservoir of 1,000,000 m^3, dug in the rocky area near the sea, at an altitude of 330 meters
- a hydroelectric power station with 4 hydroturbines
- a pumping station with 12 pumps

The electricity which will be generated by the wind turbines will supply both the grid and the pumps that will elevate seawater, filling the water reservoir. The hydroelectric generators will be constantly operating, providing stability to the grid. Even if there is no wind for several days, the hydroelectric plant will be able

[25] https://www.sifnosislandcoop.gr/energyautonomy/index.html

to meet the electric power demand of the island. Concerning the financial dimension of the project the investment cost is estimated to be 37,000,000€.

The case of the self-managed hydroelectric power station of Velvendo town[26]

The Velvendo area is a rural area of western Macedonia. The agricultural products of Velvendo, through the cooperative business operating in the region, have managed to establish themselves in the markets of Europe and Russia. The self-managed hydroelectric power station was built by the Local Organization of Land Reclamation. The budget for the construction of the hydroelectric power station was estimated at 3,000,000 €, including a 4.5km long water pipeline and the constructions of surveillance tanks. The hydroelectric power plant has a rated capacity of 1,9 MW and exploits the water from the mountainous area called "Skepasmeno", which is used for electricity generation in winter and for irrigating the fields in summer. About 200,000 - 280,000 euros are spent annually on the operation of pumping stations to irrigate crops. The hydroelectric power station, generates electricity, which is sold to the power grid and thereby, the annual costs the irrigation are covered, to a great extent. It has been estimated that even in a year without plentiful precipitation, the operation of the hydroelectric power station could offer up to 150,000 euros.

The case of Karditsa Energy Cooperative Company[27]

The Karditsa Energy Cooperative Company has the legal form of an urban cooperative (Law 1667/1986), ensuring the participation of all residents of the Karditsa regional unit or those who come from the region of Thessalyand. Their vision is the development of an energy autonomous prefecture. The Constituent Assembly was held on July 15, 2010, 476 founding members were registered, and a provisional Board of Directors (BoD) was appointed.

The primary objective was to build a small power plant on the base of biomass producing a 500 kW capacity. Initially the BoD concentrated information on the available biomass of various forms (quantity, seasonality, cost, organization of the biomass concentration network, etc.) and investigated the institutional and legislative framework (environmental requirements, technical specifications, licensing, incentives, restrictions etc.). They proceeded to design the investment plan and search for appropriate technology, the optimum unit size, and looked for the appropriate location within the Karditsa region.

The year 2015 marks the first active step for the Karditsa Energy Cooperative Company investment plan with the completion of the construction of the solid fuel production plant. The Perfecture of Karditsa produces about 200,000 tonnes of biomass annually, in the form of residues from agriculture or forestry, which either are burned unnecessarily and unjustifiably diffuse into the atmosphere large amounts of pollutants, or they are discarded uncontrollably. Through the project they created a reception area, a manufacturing facility unit for processing and standardizing local biomass and converting it into a commercial form, such as pellets.

The second stage of the Karditsa Energy Cooperative Company investment plan concerns the production of electricity energy from biomass. The new project has been divided into its own parcel. The new project has already been located in the adjacent privately-owned parcel of Karditsa Energy Cooperative Company and the environmental licensing is expected. The power plant will also generate thermal energy, which can be exploited either in the existing facilities of the current factory, or in new ones.

[26] https://energypress.gr/news/o-protos-aytodiaheirizomenos-ydroilektrikos-stathmos-stin-ellada-einai-gegonos
[27] https://www.anka.gr/portal/index.php?option=com_content&view=article&id=461&Itemid=62&lang=el

Recommendations for a sustainable energy policy in the Aoos river basin

After the analysis made in the previous chapters and sections and considering the examples mentioned, we can close this report by presenting a concise set of energy policy proposals for the Aoos river basin. We suggest naming this energy strategy plan "**S**ustainable **E**ne**R**gy policy **V**ision for **AOOS** river basin".

The basic principles/ axes of SERVE-AOOS can be described by the following points:

- The area of Aoos includes unique ecosystems and the utter priority regarding the future perspective of the area is the protection of these ecosystems, with special emphasis on water streams and rivers.
- Hence, further development of hydropower should stop, even in the form of small hydroelectric projects. Besides, the big hydropower plant of Piges Aoou has already caused a major intervention in Aoos river.
- In general, we should avoid the construction of high capacity energy units of any kind in the area of Aoos basin, in order to minimize the intervention to the natural environment.
- However, we cannot deny that global action against climate change includes the further development of RES and energy efficiency projects, which should be widely supported.
- To this direction, we propose the utilization of wind, solar and biomass energy through small-scale projects, as well as the promotion of energy saving interventions.
- Small-scale projects can be realized through cooperative schemes, which seem to be more compatible with the effort to protect the natural environment of the Aoos basin, compared to the big energy investments.
- We, after all, propose that Aoos river basin should become the pilot area for a transition to the future of energy. A future whose core will be decentralized energy production, based on small-scale projects, prosumers and local grids.

Taking these principles into account, the energy policy in the Aoos river basin should:

- Aim at minimizing interventions to the environment due to the construction of energy units and infrastructure
- Alleviate energy poverty, which is an intensifying problem in the area and, in general, provide benefits to the local societies
- Utilize local resources, in a sustainable way and in favor of local societies
- Contribute to reducing the carbon footprint of the area

It should be highlighted that a new vision for the energy sector in the Aoos river basin is not easy to be realized. However, the proposed plan is not an utopia. Evolutions in energy are rapid and many things that were just part of research projects (or even dreams) are now becoming parts of global energy policy. Especially decentralized and cooperative energy projects, which are for the time being only exceptions to the dominant way of energy development, are being introduced to the EU energy policy. We believe that an ambitious vision like SERVE-AOOS should be discussed by local authorities and societies. If they agree on such a plan, with the help of proper scientific support and systematic efforts, the vision can become reality.

Once again, apart from energy production systems, energy savings should play an essential role in the energy future of the Aoos basin. Current evidence shows that an optimum energy mix for the town of Metsovo includes energy saving interventions as a major part (41%) of the thermal energy mix (Katsoulakos, 2013; Katsoulakos & Kaliampakos, 2016).

The implementation of SERVE-AOOS is illustrated in the chart contained in Figure 35.

SERVE-AOOS Declaration

- The protection of the ecosystems of the Aoos river basin should be declared as a priority by local societies and authorities
- After consultation SERVE-AOOS should be presented to the public and declared as local, sustainable strategy

Issue of a local energy action plan

- Based on SERVE-AOOS principles decentralized energy planning in the Aoos river basin should be realized, in the form of local energy optimization studies
- This has to include data on: renewable potential/ energy demand of settlements/ future energy demand/ energy schemes and technologies that will contribute to optimization of the local energy systems

Consultation on the formation of energy cooperatives

- According to the energy action plan, a systematic and exhaustive discourse should be made, in order to investigate the possibilities of creating cooperative schemes that will implement energy projects
- Municipalities, citizens, local business, NGOs, research centers should be part of this dialogue

Fund raising

- After the formation of cooperative schemes, funds should be raised
- The funds should be retrieved by the Cooperative Bank of Epirus, the Region of Epirus, the Projects that will promote energy communities, as well as by Research Funds and Charity Funds
- Apart from cooperative schemes, the residents of the area should be systematically informed by authorities and other bodies about the funding possibilities for energy interventions at residential level

Figure 35. Steps for implementing SERVE-AOOS.

Regarding some technical aspects of SERVE-AOOS, following the analysis of the previous chapters, the following issues are highlighted:

- Photovoltaic units are proposed to have an upper capacity limit of 250 kW, which corresponds to 2.5 acres of land and so, do not cause major environmental implications.
- Regarding thermal solar systems, it is recommended to install systems that do not include boilers in the rooftops (thermosiphonic systems), in order to protect the aesthetics of settlements.
- Wind farms should not include more than 3 wind generators of 1 MW nominal capacity, in order to minimize visual impacts. Of course, within protected areas wind generators must not be installed. In settlements located in protected areas, only small wind turbines should be allowed (capacity up to 50 kW).
- Biomass combustion units that can distribute heat through district heating systems can only be constructed in the towns of Metsovo and Konitsa. In smaller settlements it is better to use biomass in residential systems. The possibility of creating a pellet production unit, which will utilize local forest production could be investigated. Such a small industry does not create important environmental impacts and could provide benefits to the local economy.
- Firstly, in the towns of Metsovo and Konitsa and then in groups of settlements, smart meters should be installed. This is a part of EU and Greek energy policy. Local authorities, following the principles of SERVE-AOOS should claim the installation of smart meters in parts of the Aoos river basin and

try to find funding. This will help towards the energy transition in parts of the area and will facilitate the inclusion of energy cooperatives, energy corporations and prosumers to local, smart grids.

- Energy saving will continue to be part of Greek energy policy. A sustainable energy future in the Aoos river basin should include it as a core part. Again, consultation between local Municipalities and regional/ national authorities should be made, in order to claim higher subsidies and funds for the area under study, regarding energy saving interventions. This claim could be based on the intensity of energy poverty in the area and the importance of energy savings in optimized local energy mixes, as depicted by several studies (Katsoulakos, 2013; Papada & Kaliampakos, 2017).

We believe that SERVE-AOOS can contribute to improve the perspectives of Aoos river basin. It is a way to utilize RES, in a way compatible with environmental protection. It gives priority to solar, wind and biomass energy and does not include hydropower in future energy planning. Moreover, it gives emphasis on energy savings and sets the alleviation of energy poverty as a priority.

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