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Cost-optimal scenario analysis for the Cypriot energy system

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Preface

The Republic of Cyprus is confronted with significant decisions as to how energy infrastructure should develop in the coming decades. This is heavily dependent on the overall new energy system Cyprus aims to achieve by 2030 and 2050. As this island-country presently imports all of its required oil products for electricity generation, transport and much of its heating needs, attempts are underway to reduce this import dependency through the development of domestic energy resources. The continued reduction in the cost of renewable energy technologies, coupled with abundant renewable energy potential, provides the opportunity for reducing the island's dependency on fossil fuels while complying with energy and climate targets for 2020 and 2030. Further, it would bring it on track with the goals set by the COP21 agreement in Paris, which aims at peaking carbon dioxide emissions as soon as possible. Additional to these targets, Cyprus has to conform with directives on energy efficiency improvements and transport and in particular national emission limits, which will become stricter in 2020 due to the phase out of a derogation on EU directives[1].

The need for informed decision-making is evident and this study aims to fill this gap through a quantitative analysis of the entire Cypriot energy system, using OSeMOSYS (Open Source Energy Modelling System); a cost-optimization tool used for long-term energy planning. A set of three key scenarios were analysed, through which results assessed the impact a potential arrival of natural gas would have on the energy mix of the island, especially in the generation sector. In case arrival of this fuel is delayed indefinitely, then investments are necessary in renewable energy technologies, both as a measure of cost-reduction but also to achieve the binding European and international legislation affecting the energy sector of the island. This report presents the methodology followed in the study, the key findings of the study based on the analysed key scenarios and provides insights on which technologies are the most cost-competitive across the entire energy system.

[1] Article 10c of the Directive 2009/29/EC. The derogation adopted provides reduction in the quantity of free emission allowances to be received by the EAC from 70% in 2013 to 0% in 2020. Also two exceptions (derogations IED) based on Articles 34 and 33 of the IED Directive (Law 184(I)/2013).

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1. Introduction

As IRENA's recent Renewable Energy Roadmap for the Republic of Cyprus (IRENA, 2015) pointed out, the island is at a crossroads in regards to its long-term energy planning. Since its independence in 1960, Cyprus has relied on oil for all of its energy related needs; electricity generation, transport, and heating and cooling. In the absence of any domestic oil production, there has been high vulnerability to fluctuating oil prices. Despite the widespread use of solar water heaters for several decades throughout the island, it was only in recent years that additions of renewable energy technologies have been made for electricity generation. By the end of 2015 renewable energy corresponded to roughly 8.5% of total generation (Ministry of Energy, Commerce, Industry and Tourism based on information released by TSO-Cy, 2016).

The past system of electricity generation has dominated for the past 40 years and has been based on monopolised ownership of a few, large, centralised and inflexible generation plants. Even though it has served well for most of the past, recent years have increasingly exposed its vulnerability, be it from the risk of consequences of generation incidents, be it from the emergence of rather high swing load during the day and year due to the lack of base consumption and the high tertiary activity during the day in summer months, or be it simply to volatility to global oil price fluctuations.

In terms of political obligations, Cyprus has agreed to a number of targets pertaining to energy use. First of all, according to Directive 2009/28/EC, renewable energy sources should contribute to at least 13% of final energy consumption by 2020. According to the official National Renewable Energy Action Plan (Ministry of Commerce, Industry and Tourism, 2010), this breaks down into 16% in electricity generation, 4.9%[2] in transport sector, which translates to 10% for road transport according to the article 3(4) of directive 2009/28/EC, and 23.5% in heating and cooling. Additionally, based on Directive 2012/27/EU, Cyprus has to introduce a series of measures to improve energy efficiency across all sectors of the economy. Based on the latest version of the National Action Plan on Energy Efficiency (MECIT, 2014), the measures proposed by the authorities would lead to estimated energy savings of 14.5% as compared to primary energy consumption in the national reference scenario.

Furthermore, several stricter restrictions regarding emissions of greenhouse gases and air pollutants will effectively be introduced in 2020. These will affect electricity generation, transportation, and heating and cooling sectors. Frequently, energy planning decisions are made in a disaggregated manner. The electricity supply may be assessed individually and be seen as disconnected from demands for heating and cooling. At the same time, the transport sector is often treated as a separate entity. However, it is obvious to argue that in case of an increased electric vehicle fleet, for instance, this is no longer the case. Similarly, once domestic gas reserves become operational, demand for natural gas may not be confined to conventional power generation. Compressed natural gas may become a viable alternative in the transport sector. Also, even though outside the scope of this study, use of natural gas in industry, residential heating purposes or gasification of the transport sector are potential alternatives.

Such shifts in the national energy profile can bring about challenges, but can also provide opportunities and this study aims to address these. With the financial support of the European Commission and collaboration with authorities in Cyprus, a long-term least-cost tool (OSeMOSYS) is used to simulate the entire energy

[2] The transport target has to be compatible with the requirements of Article 3(4) of Directive 2009/28/EC for a 10 % share of renewable energy in transport. It should, however, be noted that the calculation of compliance with the target in Article 3(4) (has been amended through ILUC directive) differs from the calculation of transport's contribution to the country's overall national target for renewable energy. For the total amount of energy consumed only petrol, diesel and biofuels consumed in road and rail transport and electricity including electricity used for the production of renewable liquid and gaseous transport fuels of non-biological origin shall be taken into account. For the amount of RES all types of RES consumed in all forms of transport shall be taken into account. Moreover, biodiesel from non-crops sources are counted two times and electricity 5 times their energy content.

system of the island and different development pathways are explored with the aim of achieving the country's national targets, conforming to international policy, and ensuring access to reliable modern energy services at cost-optimum prices. As such, a goal of this study is to identify the areas within the entire energy system in which investments should be directed to, in order to achieve a low-emission and reliable system that accommodates for all energy-demanding services at minimum cost for the energy system as a whole. This translates to achieving a lower cost for the country. Reducing the cost of energy results in lower bills for households and industry. That in turn increases household welfare and economic competitiveness. A key output of the effort is an open source model of the Cypriot energy system, which in the long-run can be used to form consolidated energy planning decisions and offer insights to potential energy policy options before they are adopted. In the short-term, this study will support the efforts of the Ministry of Energy, Commerce, Industry and Tourism (MECIT) to revise its National Renewable Energy Action Plan.

In this report we discuss the approach taken to fulfil the project's set of objectives and present the main findings of the analysis. In Section 2 of the report, the methodology followed is presented and the three main modules of the developed model are analysed. In Section 3, the main scenarios are presented along with the rationale for developing these. Results for each sector in each of the scenarios are presented in Section 4. Finally, the report ends with concluding remarks, recognizing the limitations of the analysis and making suggestions for further studies, in Section 5.

2. Methodology

The MESSAGE model that was used in the development of IRENA's Renewable Energy Roadmap for the Republic of Cyprus (IRENA, 2015) was taken as a base and translated into an OSeMOSYS (Howells et al., 2011) model to improve representation of short-term system constraints; the reasoning for this is further elaborated in the following subsection. Whereas the existing version of the model focused on the electricity supply of the island, in this study the model was expanded to include the entire energy sector (Appendix A). In essence, the model developed had three distinct modules with interlinkages between them, taking into consideration CO_2 emissions of all sectors combined. These modules were:

- Electricity Supply
- Transport
- Heating and Cooling

The importance of the interlinkages between these sectors relates to the many plausible synergies that can exist between technologies in one sector and how it affects demand in another sector. For instance, in a theoretically more technologically advanced system in 2030 and 2050, the transmission system operator will be able to temporarily shed load from less important services, such as cooling of a shopping centre or desalination plants, so as to cope with potential rapid drops in generation[3]. Similarly, the batteries in electric vehicles can facilitate the use of higher shares of variable renewables. They might be charged when there is an increase in generation. This, enables the grid operator to use them as demand response and a means of electric storage from which it can draw (together with selective load shedding) in cases of generation shortage or to smoothen out fluctuations in electricity demand. Even though the present effort can be considered as ambitious, it was in no way a novelty in the field. Countries around the world base their energy planning to a considerable extent on insights offered by such quantitative analyses (Börjesson et al., 2014; Schulz et al., 2007; Taylor et al., 2014; U.S. Energy Information Administration, 2015).

It should be noted that wherever data were not available from local sources, assumptions were based on literature. At the same time, input was drawn from other parallel studies conducted for MECIT. It is also important to mention that the maximum level of SO_x emissions was examined through the model for the entire system by evaluating the least cost choice of technologies that would be needed to meet the emissions constraints. Due to the vast amount of data used in this study, the following subsections present the key input and assumptions used to develop the model, while all of the data were made available separately as supplementary material to this report.

2.1 Electricity Supply

Code extensions that allow the incorporation of short-term constraints into long-term energy system models were included (Welsch et al., 2014) in the OSeMOSYS version of the model. Therefore, aspects not present in the Cyprus MESSAGE model such as ramp up and ramp down rates of thermal plants and minimum stable generation levels were incorporated in this new model. In this way, aspects relating to the flexibility of the system were addressed. In essence, these improvements aimed at reducing the uncertainty gap in a way that outputs from the long-term focused OSeMOSYS model provided a more likely technically feasible solution. In this regard, outcomes of the JRC grid stability analysis (JRC, 2016a) were used to inform the assumptions taken in the generation sector.

A comparative study was conducted with the Electricity Authority of Cyprus (EAC) in order to align the two model assumptions and improve the accuracy of the results in the OSeMOSYS model. Within the framework of this study, a set of assumptions and data was agreed, which formed the baseline for the electricity supply sector. The main general assumptions include:

[3] Rapid drops of generation are no uncommon as output from wind and PV generation fluctuates.

a) No Electricity Interconnection or any New Energy Intensive Investment was assumed (such as LNG Terminal, Ethanol Production plant etc).
b) The generation system must have at least two conventional generation points, one at each power station online at all times, for maintaining the system inertia requirements. For this purpose, it was assumed that the installation of the next new CCGT unit (if the installation is deemed cost-optimal) will be at Dhekelia Power Station. Before the installation of the next new CCGT unit at Dhekelia Power Station, two units of ICE (2x17MW) at Dhekelia Power Station and one Steam Unit at Vasilikos Power Station or one Gas Unit of one of the CCGT Units at Vasilikos Power Station will operate as must-run[4]. After the installation of the next new CCGT unit at Dhekelia Power Station, one Gas Unit of the new CCGT unit at Dhekelia Power Station and one Steam Unit at Vasilikos Power Station or one Gas Unit of one of the CCGT Units at Vasilikos Power Station will operate as must-run.
c) From 2020 onwards Low Sulphur HFO will be used instead of 1%S HFO at Dhekelia's ICE and steam units. In case natural gas becomes available earlier in Cyprus, the date was shifted to the earliest date of natural gas use.
d) Only Vasilikos Power Station was allowed to consume natural gas from the existing thermal plants.
e) All new Conventional units were assumed to use Natural Gas as the primary fuel, if this fuel is available. However, it is important to mention that this implies new installations will occur in a location that can be supplied with natural gas. In scenarios without natural gas, Low-S HFO and diesel are used as the alternative primary fuels, which are significantly costlier.
f) Storage Technologies (pumped hydro, flow batteries and Li-ion batteries) are available as candidate units.
g) New Conventional Units are available to be selected by the cost-optimization process. These include Combined Cycle Gas Turbines, Gas Turbines, Internal Combustion Engines and Steam Turbines.
h) In the scenarios with natural gas availability, no interruption in natural gas supply is assumed at any time.
i) Forced Investments, based on Political Decisions are exogenously included in the model:
    - 50 MW CSP end of 2018 (appears in 2019 in model).
    - Total minimum wind capacity of 175 MW by 2018.
    - For the fulfilment of the target of 16% RES in final electricity consumption by 2020, adequate investments on PV systems are forced (utilizing Net-Metering and Self-Generation), in case those are not selected by the model.
j) A discount rate of 6% (provided by Ministry of Finance) was used. However, sensitivity analysis on the effects of using a higher (e.g. 10%) or lower (e.g. 3%) discount rate on the technology mix should be conducted to investigate the effect of such a change.
k) An exchange rate of 1 EUR = 1.1 USD was assumed throughout the model horizon.

2.1.1 Final Electricity Demand

The electricity demand forecast was provided by Dr. Zachariades (Cyprus University of Technology), under the framework of a parallel study conducted by GIZ for MECIT. From these projections, the forecasted electricity demand in road transport was subtracted, as the use of electricity in transport would be determined by the model. To provide a sense of the potential impact of this assumption, in the demands provided by Dr. Zachariades, it was foreseen that electricity demand in transport would be 14 GWh and 95 GWh by 2030 and 2040 respectively. These are thus minimal quantities as compared to the total forecasted demand (Table 1).

Table 1 – Final Electricity Demand (GWh) as a total of all sectors (forecast provided by Dr. Zachariades).

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
GWh	4,084	4,227	4,339	4,463	4,593	4,724	4,828	4,913	5,004	5,076	5,130	5,218	5,315
	2028	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
GWh	5,422	5,518	5,600	5,694	5,798	5,909	6,026	6,150	6,272	6,394	6,515	6,635	6,754

[4] This policy of must-run Dhekelia units was studied in further detail in the JRC grid stability analysis and is an aspect that merits further investigation.

2.1.2 Generation options

All existing generating options were included in the model (Table 2). The units at Vasilikos, Dhekelia and Moni were modelled separately based on the type of technology. Existing renewable energy technologies (RET) were included, while future thermal and RET were allowed for investment as part of the optimal solution. Gas turbines (62 MW), internal combustion engines (17 or 100 MW), steam turbines (57 MW) and combined cycle gas turbines (110 or 220 MW) were modelled as potential available options.

As an enabler of variable RET, storage options were incorporated in the model, with the corresponding setup of the preceding IRENA study (IRENA, 2015). As such, pumped hydro storage, flow and Li-ion batteries were added as options in the model. The first date for potential installation of batteries was set for 2020, while due to the assumed more demanding planning required for pumped hydro, the first available date for this option was set for 2023.

Table 2- Installed generation capacity at the end of 2015 (EAC, 2015; TSO Cyprus, 2016).

Facility	Technology Type	Fuel	Rated Capacity (MW)
Vasilikos Power Plant	Combined Cycle Gas Turbine	Diesel (or gas once available)	440
	Steam Turbine	HFO (or gas once available)	390
	Gas Turbine	Diesel	38
Dhekelia Power Plant	Steam Turbine	HFO	360
	Internal Combustion Engine	HFO	102
Moni Power Plant	Gas Turbine	Diesel	150
Wind	--	--	157.5
Biomass	--	--	9.7
Solar PV	--	--	76.5
		Total	1723.7

2.1.3 Renewable Energy Technologies

Performance data for RET were obtained from IRENA's Cyprus report (IRENA, 2015), while costs were based on IRENA's updated costs provided through the REMAP work (Appendix B). These costs were cross-checked with the actual investment cost of the respective technologies in Cyprus, and were assumed to be in line with the data and economic proposals submitted to RES Fund from various RES investors. No investment cost was taken into consideration for the land purchase, utility connection and spare parts costs. A retirement schedule was assumed for existing and future RET facilities, as indicated in Table 3.

Table 3 - Retirement schedule of existing and upcoming RES Technologies.

RES Plants	Total Capacity (MW)	Availability	Retirement	Lifetime (years)
PV Large scale	8	1/1/2015	1/1/2035	20
PV rooftop	20	1/1/2013	1/1/2033	20
Wind	157.5	1/1/2013	1/1/2038	25
CSP 2 (Solar Tower)	50	1/1/21	1/1/2051	30
CSP 1 (Sterling)	50	1/1/18	1/1/2048	30
PV Rooftop net-metering	26	1/1/15	1/1/2035	20
Biomass	10	1/1/10	1/1/2035	25

However, in order to prevent complete decommissioning of RET, the model was allowed to repower solar and wind installations, thus prolonging their lifetime and keeping these in the system until the end of the model horizon. It was assumed that the repowering cost would correspond to approximately an average of

60% of the cost of a new installation of the same technology[5]. This approach was adopted at the end of the study, which did not allow for further code improvements regarding repowering. Thus the additional cost was incorporated on the fixed annual cost of each technology instead. In future enhancements of this work, a more detailed analysis of the potential for retrofits can be included, both for renewable energy technologies as well as conventional thermal technologies.

2.1.4 Crude oil and CO_2 price

Price of all fuels was assumed to be correlated to the crude oil price. The baseline crude oil price was agreed with DEFA, EAC and CERA as part of a parallel study and was based on a relatively low oil price scenario. This is comparable to the corresponding scenario of the International Energy Agency (IEA, 2015). Similarly, a CO_2 ETS price was incorporated, based on values provided by the Department of Environment. Since the model outputs are based on cost-optimization, a sensitivity analysis on a range of fuel prices is important and should be carried out prior to any major energy policy decision.

Table 4 – Crude oil price and CO2 ETS cost projections (real USD) assumed in the model.

		2015	2016	2017	2018	2019	2020	2021	2022	2023
Crude oil	$/bbl	48	34.4	46.55	47.575	48.6	51.2	53.9	56.8	59.8
CO_2 ETS	$/ton	7.82	11	12.1	13.2	15.4	16.5	17.6	18.7	19.8
		2024	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Crude oil	$/bbl	62.9	66.3	67.04	67.78	68.52	69.26	70	73	76
CO_2 ETS	$/ton	20.9	22	23.1	24.2	25.3	26.4	27.5	28.6	29.7
		2033	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	
Crude oil	$/bbl	79	82	85	87	89	91	93	96	
CO_2 ETS	$/ton	30.8	31.9	33	34.1	35.2	36.3	37.4	38.5	

Publically available official price forecasts provided from international organizations, such as the International Energy Agency, do not extend beyond 2040. Due to unavailability of data, cost of technologies and fuel prices were kept constant for the period 2040-2050. This conservative approach did not affect the competitiveness of RET, as during early scenario runs it was indicated that, for instance, solar PV becomes more cost-competitive than thermal generation in the period 2035-2040.

2.1.5 Capacity reserve

A capacity reserve margin of 20% higher than the yearly peak demand, as suggested by CERA, was assumed as the lower limit allowed for the entire model horizon after 2019. Storage options and conventional thermal plants were allowed to contribute 100% of their rated capacity, while RET without storage were allocated a lower capacity credit, since their availability is intermittent (Table 5).

Table 5 – Capacity credit of each technology.

Technology	Capacity credit (% of capacity)
Conventional thermal	100%
Biomass	33%
CSP with storage	100%
Wind	0%
PV	20%
Storage Technologies	100%

[5] Even though repowering of RET at the end of their lifetime may lead to improved performance, a conservative approach was taken, assuming that the average output per kW of installed capacity (i.e. Capacity Factor) remains the same.

2.1.6 Spinning reserve

The assumption used regarding spinning reserve in the IRENA work (IRENA, 2015) was adopted in this analysis as well, since this was proven valid by the JRC study (JRC, 2016a) in regards to system stability purposes. The demand for spinning reserve was expressed throughout the model horizon as:

a) A constant 60 MW demand;
b) Plus, an additional 50% of the instantaneous wind generation;
c) Plus, an additional 10% of the instantaneous PV generation.

All thermal conventional technologies were allowed to contribute to this reserve. Additionally, storage options were included, for which the capacity to provide spinning reserve was defined as a function of the level of electricity charge on a ratio of 1:1. Storage options were allowed to provide operational reserve based on the findings of the JRC grid stability analysis (JRC, 2016a).

2.2 Transport Sector

Preparatory work for this module of the model was completed (Wiking, 2015) separately and used as a basis for the present effort. Lessons learned and best practices as reported in the literature (Dodds and McDowall, 2014) were used as a guide for an appropriate representation of the transport sector. In order to examine all potential transport technologies that can become available in the Cypriot market, a detailed breakdown of options was included in the model (Table 6). A variety of alternative fuels were considered, while the transport sector was divided into freight and passenger transport, which were further split into different vehicle modes; such as passenger cars, motorcycles and public buses. The majority of the techno-economic performance characteristics for this sector was taken up from IEA ETSAP technology briefs (IEA ETSAP, n.d.).

The main connection with the other model modules relates to the use of electricity by electric vehicles and plug-in hybrids. As shown in previous studies, the use of electricity in the transport sector can be used to complement a grid network with shares of variable renewable technologies, by providing means of coping with rapid shifts in generation (JRC, 2016a; Soares M.C. Borba et al., 2012). Furthermore, the continued sharp decline in battery technology will affect the cost-competitiveness of battery electric vehicles (Nykvist and Nilsson, 2015), so the potential deployment of these vehicles in the system had to be assessed in the present study. The renewable energy contribution of electricity was based on the average projected renewable energy in generation for the EU28, as provided by the 2016 EU Reference Scenario (European Commission, 2016).

Table 6 – Technology options considered for the transport sector.

		Passenger Transport				Freight Transport
Technology	**Fuel**	**Cars**	**Busses**	**Light Trucks**	**Motorcycles**	**Heavy Trucks**
Internal Combustion Engine	Gasoline	×			×	
	Diesel	×	×	x		×
	CNG	×				×
	LPG	×				
Fuel Cell	Hydrogen	×	×			
Battery Electric Vehicle	Electricity	×	×	x	×	×
Plug-in Hybrid	Electricity & diesel	×		x		
	Electricity & gasoline	×				
Hybrid Electric	Electricity & diesel	×	×	x		
	Electricity & gasoline	×				

Note: For each type shown above, a further split between existing and new technologies was used in the model to allow different characterization of efficiency between the current and the future fleet.

Even though a political decision has been reached to postpone the introduction of natural gas in the Cypriot market, as the interim gas solution negotiations have not been successful, the proven presence of natural gas in the exclusive economic zone of the island and the political decision to make gas available indicate that gas will likely become available in the future. As such, vehicles consuming natural gas were considered since Cyprus is obliged through directive 2014/94/EU to ensure that an appropriate number of CNG refuelling points become accessible to the public by 31/12/2020[6]. Similarly, since according to Directive 2014/94/EC Cyprus is obliged to provide infrastructure for the use of alternative fuels in the transport sector, hydrogen and LPG are potential fuels that can be used. Finally, the use of bioethanol was not used in the form of a blend with gasoline; biodiesel and bioethanol can be blended with diesel and gasoline respectively, in conformation with the maximum share of blend. Nonetheless, oil companies in Cyprus argue that bioethanol cannot be blended with gasoline, as due to the high temperatures on the island, this would not respect the vapour pressure limits as set by the European Union's Fuel Quality Directive (2009/30/EC). However, since ethanol is used extensively as a fuel in other warm countries (such as Brazil), it may be possible to blend bioethanol in gasoline at least during the colder months of the year. This is a highly significant aspect that affects the scenario results considerably, as shown in section 4.2 of the report and it will be further analysed in the upcoming study of GIZ and Ifeu.

2.2.1 Modelling Approach

As mentioned above, OSeMOSYS is a cost-optimization long-term energy model. This means that the most cost-effective mix of technologies and fuels is chosen to cover a specified demand, under a certain set of constraints (e.g. technical, financial, environmental limitations). In the transport model of Cyprus, we split this sector into passenger and freight transport, both of which are defined as projected demands. This split was done so as to allow competition between different modes in the case of passenger transport; for instance, public transport could claim a share of the demand that is now satisfied with the use of private vehicles. In order to achieve this, measures are needed to make public transport more attractive. First of all, adequate infrastructure is needed; such as additional bus routes, more frequent buses, bus and car pool lanes or even the development of a small rail system. Once the infrastructure is put in place, policy measures can promote the shift away from personal vehicles to public transport. For instance, vehicle or fuel taxation adjustments could be done to achieve this, while a congestion charge could be introduced for vehicles using particular roads in the main cities at specific periods during the day.

The technology categories used to satisfy the aforementioned demands were based on the breakdown adopted by the PRIMES model. The five categories used were light duty vehicles, motorcycles, busses, light trucks and heavy trucks; the former four are used for passenger transport, while the latter was used for freight transport. For each of these categories, different technologies of vehicles were considered, as shown in Table 3.

Existing fleet

Data on number of registered vehicles in each category at the end of 2014 were provided by the Department of Labour Inspection. For each of the categories, an average annual distance travelled and an average consumption was assumed; for the latter a different fuel consumption was assumed for diesel and gasoline vehicles. The total calculated fleet fuel consumption is matching the recorded fuel sales for 2014. It was assumed that as old vehicles are slowly retired, the existing fleet will become more efficient, based on rates reported in literature (IEA, 2012).

Demands

Demands are defined in terms of billion tonne kilometres (Gtkm) in the case of freight transport and billion passenger kilometres (Gpkm)[7] in the case of passenger transport. In the former, since only heavy trucks can satisfy the demand, the assumed tonnage carried by each vehicle did not matter and was only used as an index. However, in the case of passenger transport, the assumed occupancy rate was important. The

[6] This aspect is examined in detail in a parallel study conducted for MECIT.

[7] One vehicle carrying two persons for a distance of 10 km gives an output of 20 passenger kilometres.

occupancy rate is an assumption that was needed if we were to investigate competition between modes (e.g. bus vs private cars[8]). If we avoided making such an assumption in the analysis, the alternative would be to assume that busses, motorcycles and private cars would continue to have exactly the same share for the entire model horizon.

Fuel prices

Gasoline and diesel price calculation contains a number two main components: cost of fuel and minimum obligatory taxation levels. In the case of natural gas, infrastructure costs were also taken into account, since this is currently lacking. If natural gas is to become a fuel for transportation, investments are needed to allow refuelling of vehicles running on natural gas. A fixed cost for investments per amount of gas consumed was considered in the study, but a more detailed study can provide further insights.

Future fleet

For each vehicle technology included in the model, the main parameters consisted of the capital cost, operation and maintenance cost, energy intensity (i.e. fuel consumption/vehicle efficiency) and vehicle lifetime. For potential technologies of the future fleet, current estimates for these parameters were taken from the literature (IEA ETSAP, n.d.). Cost (OpenEI, n.d.) and energy intensity (IEA, 2012; OpenEI, n.d.) projections were used to represent the expected improvements in conventional and unconventional vehicle technologies. Specific technologies, such as fuel cell and battery electric vehicles, may be too expensive at present but could gain cost-competitiveness once their costs reduce.

Use of LPG by existing gasoline vehicles

As a measure to achieve the 10% RE target in transport by 2020, the government has promoted the use of LPG in vehicles. Even though this fuel is not a renewable energy source, since its consumption is not counted in the denominator[9], it reduces the need for gasoline and thus helps indirectly in the achievement of the target. In the model it was assumed that starting from 2017, approximately up to 4000 gasoline passenger cars could be converted to LPG, if deemed cost-optimal.

Emissions

In the case of SO_x and CO_2, emissions for the transport sector were calculated based on the amount of fuel that is consumed. However, in the case of PM and NO_x, this calculation is based on the distance travelled. The emission ratio for each technology varies significantly by the type of vehicle and its age (e.g. Euro 1, Euro 2 etc.), while predictions would have to be made for future vehicles and their associated emission standards. For instance, in the case of passenger cars, data exists as regards to the upper limits for emissions, but if these are used, we overestimate the amount of emissions and greatly surpass the emission target. Lack of data for these pollutants, in terms of future technologies, did not allow the incorporation of PM and NO_x emission limits as part of the optimization. As such, this is an aspect that merits further analysis as part of future relevant studies.

Renewable energy and greenhouse gas emission targets

Besides the 10% renewable energy share in 2020 according to the Directive 2009/28/EC, the European Commission is pushing forward additional targets for the period 2021-2030. These set a maximum share of energy to be contributed from liquid biofuels produced from food or feed crops, a minimum share of energy originating from advanced biofuels and biogas, renewable transport fuels of non-biological origin, waste-based fossil fuels and renewable electricity, as well as a minimum share of energy from advanced biofuels and biogas. The projected evolution of these shares is provided in Appendix C.

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[8] Undoubtedly, assuming a high occupancy rate, busses are more efficient in terms of cost and emissions, but the extent to which they can be deployed cannot be assumed as limitless. Constraints that reflect reality in Cyprus will be added on the rate of investment in any of the assessed technologies.

[9] Based on Directive 2009/28/EC and ILUC Directive (EU) 2015/1513.

Additionally, Directive 2009/30/EC calls for a 6% reduction in lifecycle greenhouse gas emissions in the transport sector by 2020 as compared to the average of 2009-2010. This was not set as a constraint in the model, but the target is likely achieved for road transport in all scenario runs due to (a) the achievement of the renewable energy target and (b) the substitution of older vehicles with newer fuel-efficient vehicles. If the model outputs indicate that the target is not achieved, additional measures can be adopted that are outside the scope of this study (for instance in maritime or aviation).

2.3 Heating and Cooling

Information for the heating and cooling module of the model has been drawn primarily from a separate JRC study focusing on this sector (JRC, 2016b). Demand forecasts for heating and cooling as well as techno-economic characteristics of technology options were provided from this report (Tables 7 and 8).

Four levels of demand were defined here, following the breakdown of technologies to be evaluated; namely residential cooling, residential heating, cooling in all other sectors, and heating in all other sectors. The seasonal variation in demand for heating and cooling was estimated based on historical measurements of heating and cooling degree days, provided by MECIT. An estimate of the demand profile within each day had to be assumed for each of the demands. In the case of cooling, this was based on the recorded electricity demand profile of each sector (Figure 1). However, analysis providing a more accurate demand profile may be needed for future enhancements of the model.

Table 7 – Technoeconomic characteristics of technologies in the industrial, services and agricultural sectors (JRC, 2016b)

Resource	Technology	Investment cost (EUR/kW)	Fix O&M (EUR/kW)	Lifetime (years)	Heat efficiency	Electric efficiency	Cooling efficiency
Electricity	Heat pumps	810	16.2	20	3	--	4
Electricity	Resistance heaters	98	1.1	15	0.9	--	0.63
Gas oil, kerosene, light fuel oil	Boilers	77	3.9	20	0.77	--	0.54
Gas oil, light fuel oil, livestock/industrial waste, LPG	CHP	1200	16.1	20	0.47	0.34	0.33
Gas oil, kerosene, light fuel oil	Efficient Boilers	314	15.7	20	0.9	--	0.63
LPG	Boilers	182	9.1	20	0.66	--	0.46
Municipal waste, biomass	CHP	1400	19	20	0. 47	0.34	0.33
Livestock/industrial waste, LPG	Efficient Boilers	316	22.1	20	0.96	--	0.67
Biomass	Boilers	338	16.9	20	0.77	--	0.54
Municipal waste, biomass	Efficient Boilers	702	7.9	20	0.81	--	0.57
Solar	Solar panels	863	17.3	20	6.54	--	4.58

Additionally, high and medium heat requirements were taken into consideration, as it was assumed that only boilers and CHP technologies can provide heat at the required temperatures. Similarly, data were provided from MECIT regarding each technology's contribution in the current energy mix. This formed the basis of estimating the existing installed capacity of each technology. Following the historical production of technologies provided through the JRC heating and cooling study, it was assumed that only heat pumps/split-unit heat pumps from the current stock of technologies could satisfy the cooling demand[10]. Thus, if other technologies (e.g. LPG boilers) were to provide energy for cooling, new installations would be necessary.

[10] Geothermal applications and solar cooling were not proven to be cost-competitive.

Table 8 – Technoeconomic characteristics of technologies in the residential sector (JRC, 2016b)

Resource	Technology	Investment cost (EUR/kW)	Fix O&M (EUR/kW)	Lifetime (years)	Heat efficiency	Electric efficiency	Cooling efficiency
Electricity	Heat pumps	1221	9	20	3.79	--	2.65
Electricity	Resistance heaters	176	1.9	15	0.9	--	1
Gas oil, kerosene, light fuel oil	Boilers	209	10.5	20	0.77	--	1
Gas oil, light fuel oil, LPG	CHP	1500	21.4	10	0.5	0.4	0.35
Gas oil, kerosene, light fuel oil	Efficient Boilers	314	15.7	20	0.96	--	1
LPG	Boilers	182	9.1	20	0.77	--	1
LPG	Efficient Boilers	418	20.9	20	0.96	--	1
Biomass	Boilers	487	24.4	20	0.77	--	1
Biomass	CHP	1700	27	10	0.5	0.4	0.35
Biomass	Efficient Boilers	926	23.3	20	0.85	--	1
Solar	Solar panels	1151	23	20	6.54	--	1

The existing renewable energy share in this sector originates from use of biomass in boilers, renewable electricity and solar thermal panels. According to JRC estimates, solar thermal panels in Cyprus currently provide 580 GWh of useful heat demand, mainly for residential hot water use. Estimates on the annual yield of this technology in Cyprus were obtained from international literature (IEA Solar Heating & Cooling Programme, 2014). As in the case of other technologies in this sector, only new installations of solar thermal panels were allowed to contribute towards meeting the cooling demand. This is because from the existing stock of technologies, currently only heat pumps provide cooling.

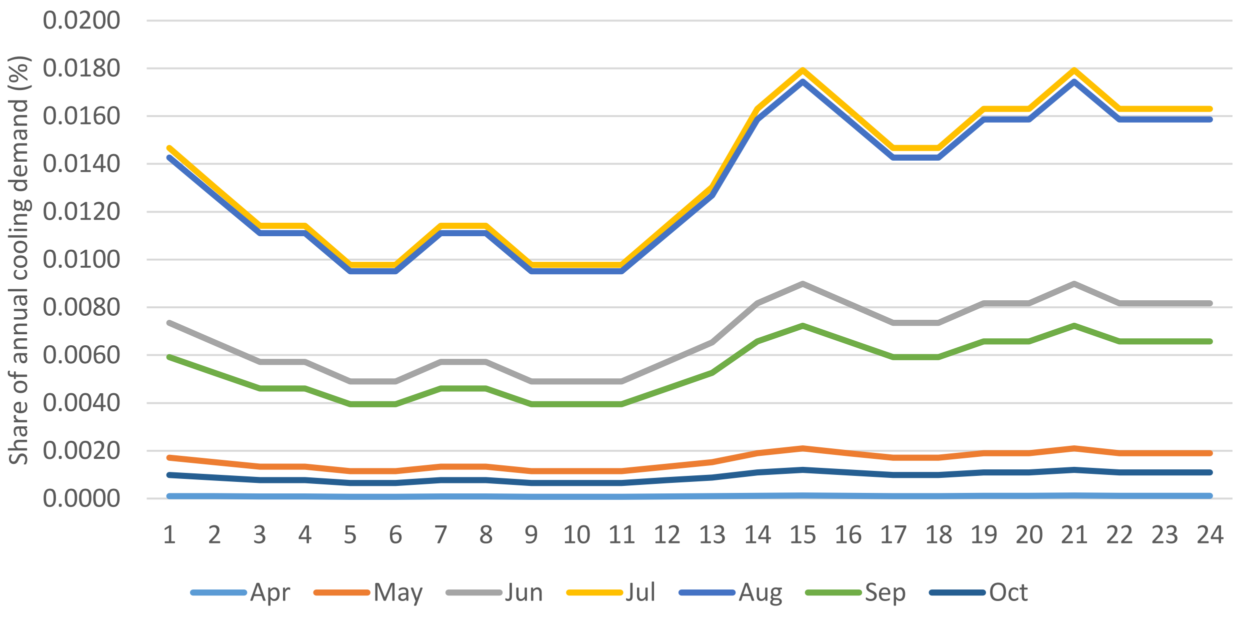

Figure 1 – Assumed share of annual cooling demand for each hour within each month.

The demand profile for each of the fuels driving the heating and cooling sector could potentially change in the future. For instance, if energy efficient heat pumps are installed, the peak electricity demand of the hot summer days may drop, while if the use of heat pumps for heating increases, electricity demand may rise in the winter. Further, once natural gas enters the market and sufficient infrastructure is put in place, this fuel might take up a substantial share in the island's energy intensive (e.g. cement and brick) industries or be used for space heating purposes. Even though of importance, the aspect of natural gas use in the heating and cooling sector was not taken into consideration. This was due to the fact that considerable investments would be required to distribute this fuel to the respective consumers as indicated in JRC study (JRC, 2016b). Once cost estimates for a potential domestic gas network arise in the future, this aspect can be revisited.

Similarly, the JRC heating and cooling study indicated that much waste heat could be recovered from the thermal power plants of Vasilikos and Dhekelia and be used for district heating for the cities of Limassol and Larnaka respectively. However, this aspect was not taken into consideration in this version of the model, due to lack of data on what heat network costs, timeframe and pipeline capacities would be required to utilize this waste heat. Including this in future enhancements of this work, if the option is deemed to be feasible and politically acceptable, is encouraged.

2.4 Policy context influencing the Cyprus Energy System

Since the submission of the initial Cypriot National Action Plans for Renewable Energy (Ministry of Energy, Commerce, Industry and Tourism, 2010) and Energy Efficiency, the energy outlook of the island has changed. Key important developments concern the discovery of offshore natural gas reserves, which in the long-term have the potential to completely redefine the energy mix of the economy, and the rapid decrease in the cost of solar photovoltaics. Since the primary energy supply of the island is currently dominated by oil-products, a potential fuel shift has relevance to a number of other pieces of legislation, such as promotion of alternative fuels in the transport sector and reduction of industrial air pollutant emissions. Table 9 lists regional EU and international legislations that have been adopted in national policy and informed the present effort.

Table 9 – Relevant legislation to be accounted for in the modelling framework.

Legislation	Relevant to	Comments
Directive 2009/28/EC	Promotion of the use of energy from renewable energy sources	13% of final energy consumption should originate from renewable energy sources by 2020. In the transport sector an obligatory 10% share should be achieved, while the remaining can be distributed to electricity generation and heating and cooling (16% and 22.5% respectively in the case of Cyprus (Ministry of Commerce, Industry and Tourism, 2010)).
Directive 2014/94/EU	Deployment of alternative fuels infrastructure	Development of appropriate infrastructure projects should occur to allow the use of alternative fuels (e.g. LPG, CNG, hydrogen etc).
Regulation (EC) 443/2009	Emission performance standards for new passenger cars	
Directive 2012/27/EU	Energy efficiency	In the case of Cyprus, measures should be put in place that achieve a reduction of 14.5% of total primary energy supply from a reference scenario by 2020.
Directive 2010/31/EU	Energy performance of buildings	
Directive 2010/75/EU	Industrial emissions	Derogation exists
Directive 2009/30/EC	Fuel Quality	Obligation to suppliers to reduce life cycle greenhouse gas emissions by 6% in the transport sector as compared to 2010.
Directive 2015/652/EU	Calculation methods and reporting requirements for quality of petrol and diesel fuels	
Directive (EU) 2015/1513	ILUC- amending Fuel quality directive (98/70/EC) and promotion of the use of	

	energy from renewable energy sources directive (2009/28/EC)	
Directive 2001/81/EC	National emission ceilings for certain atmospheric pollutants	Upper limits are set on national emissions of sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia.
Directive 2009/33/EC	Promotion of clean and energy-efficient road transport vehicles	
Decision No 406/2009/EC	Effort of EU Member States to reduce their greenhouse gas emissions	
1999 Gothenburg Protocol	Abatement of Acidification, Eutrophication and Ground-level Ozone	National emission ceilings for up to 2020 and beyond for four pollutants: sulphur dioxide (SO2), nitrogen oxides (NOx), volatile organic compounds (VOCs) and ammonia (NH3).

It should be highlighted that the relevant articles of legislation shown in Table 9 have a rather short- to medium-term focus, setting goals primarily up to 2020 and to some extent 2030. Even though individual national targets have not yet been defined, the most recent EU framework for climate and energy from 2020 to 2030 indicates that significant contribution is expected from each member state. The majority of the greenhouse gas emission reductions are to be allocated to the ETS sector. That would have to deliver a reduction of 43% in 2030, while the non-ETS sector would have to achieve a reduction of 30%; both compared to 2005 emission levels (European Commission, 2014). However, demand for energy services, such as transportation, is not limited to either ETS or non-ETS sectors. For instance, deployment of electric vehicles affects power generation, so energy-planning decisions cannot be taken in isolation from each sector.

At the same time, the legally binding COP21 agreement in Paris calls on nations to peak their greenhouse gas emissions as soon as possible, while the goal is to keep the global average temperature rise well below 2 ^{o}C and take adequate measures to limit it to 1.5 ^{o}C as compared to preindustrial levels (UNFCCC, 2015). As such, taking into account that investments in energy infrastructure are long-lasting, with technical lifetimes of 30-40 years, decisions have to be taken based on long-term goals.

2.5 Data and assumptions used in the model

A large amount of data was required to develop the entire energy system model. Separate databases for each sector have been created and shared with MECIT and other stakeholders for their input and approval before entering the data in the model. The key data used are provided in the Appendices and in more detail as separate supplementary spreadsheets to this report.

3. Scenario Description

In order to fully understand the challenges faced by the Cypriot energy system and explore the impact of the different potential pathways, a deliberately limited set of main scenarios was formulated. Scenarios, whose impact had already been covered in the previous IRENA study (IRENA, 2015) were not assessed again. For instance, the potential development of and electricity interconnector was not repeated here. The main characteristics of the utilized scenarios were influenced by the timing and availability of natural gas as a primary energy source and have varying difficulty in achieving the Renewable Energy, Energy Efficiency and air pollutant emission targets. Specifically, the three key scenarios were:

- **Reference Scenario (S1):** The first scenario of the study assumed that natural gas will become available for use in the electricity supply sector by the beginning of 2019 via an LNG regasification facility. This means that the supplied gas does not necessarily originate from the domestic gas reserves, but could be from any potential supplier. Natural gas was allowed to gradually commence supply of the transport sector by 2020, assuming that a small transition period will be required before the necessary infrastructure is set in place. No electricity interconnector becomes established, while investments in new technologies were allowed in all the sectors. A fixed 10% RES target in transport was defined for 2020, while additional targets relating to the used of advanced biofuels and renewable electricity were set for the period 2021-2030. The 13% renewable energy target in final energy consumption for 2020 was developed as an overall target, meaning that the share of renewable energy can originate either from electricity supply or the heating and cooling sector. Emission targets were set for SO_x as provided for the period 2020-2030, CO_2 in the ETS sector for 2030 and CO_2 in the non-ETS sector for 2020-2030.
- **Delayed Gas Scenario (S2):** This scenario differed from S1 in that natural gas availability was delayed until 2024. This affected the ability to achieve the reduction required in SO_x emissions in the electricity supply sector in the period 2020-2023. An existing derogation will cease to exist in 2020, which means that the current high quantities of HFO with 1% S content consumed will have to be reduced. As such, HFO with lower S content (0.23% or 0.5%) will have to be used as an alternative fuel at Dhekelia and the steam turbines of Vasilikos, along with a potential increase in the use of combined cycle gas turbines at Vasilikos, fired on diesel. It is important to mention that even though the energy efficiency targets of 2020 were not used as a constraint in the present model, the National Energy Efficiency Action Plan of the government had included the shift to natural gas as one of the major measures to be taken by 2020 (MECIT, 2014).
- **No Gas Scenario (S3):** In this case, natural gas does not become available at any point in time within the model horizon. New conventional thermal power plant installations continue to rely on HFO and diesel, while natural gas use was not allowed in the transport sector either. Due to the higher CO_2 emission factors of diesel and HFO as opposed to natural gas, this scenario makes it more difficult to achieve the 2030 target of 43% reduction in the ETS sector in comparison to 2005 levels. Therefore, in order to achieve this reduction, the share of renewable energy technologies in electricity supply will have to be higher in 2030 than in the preceding two scenarios.

The aforementioned scenarios formed the basis of the analysis conducted in this study. Numerous other scenario runs were conducted before reaching this final set, which provided a better understanding of the dynamics of the Cypriot energy system. Some of these were provided as part of the project's Interim Report, while results for others were presented or provided separately to the local authorities. Specifically, a large number of scenarios was developed for the electricity supply sector, as this is the most complex in terms of technical constraints. At the same time, electricity supply is managed centrally, which means that it is easiest to promote change in this sector, thus typically attention is directed in this area.

4. Scenario Results

This section of the report provides an overview of the three main scenarios and discusses implications of the results in each of the sectors. Overall aspects, such as the share of renewable energy in the national final energy demand, electricity costs and emissions are presented separately.

4.1 Electricity Supply

4.1.1 Reference Scenario

The reference scenario is dominated by natural gas-fired generation, once this fuel becomes available (Figure 2). The renewable energy share in generation is limited between 15% and 20% for the period 2019-2036. However, as gas prices and CO_2 costs increase, and investment costs of renewable energy technologies decrease along the model horizon, the share of renewable energy in generation increases to 37% and 40% by 2040 and 2050 respectively. As was illustrated in the corresponding IRENA work (IRENA, 2015), solar PV is the most competitive of the renewable energy technologies and, as such, this is responsible for the increase in renewable energy. Solar PV capacity increases to a total of 1239 MW by 2040 and 1639 MW by 2050.

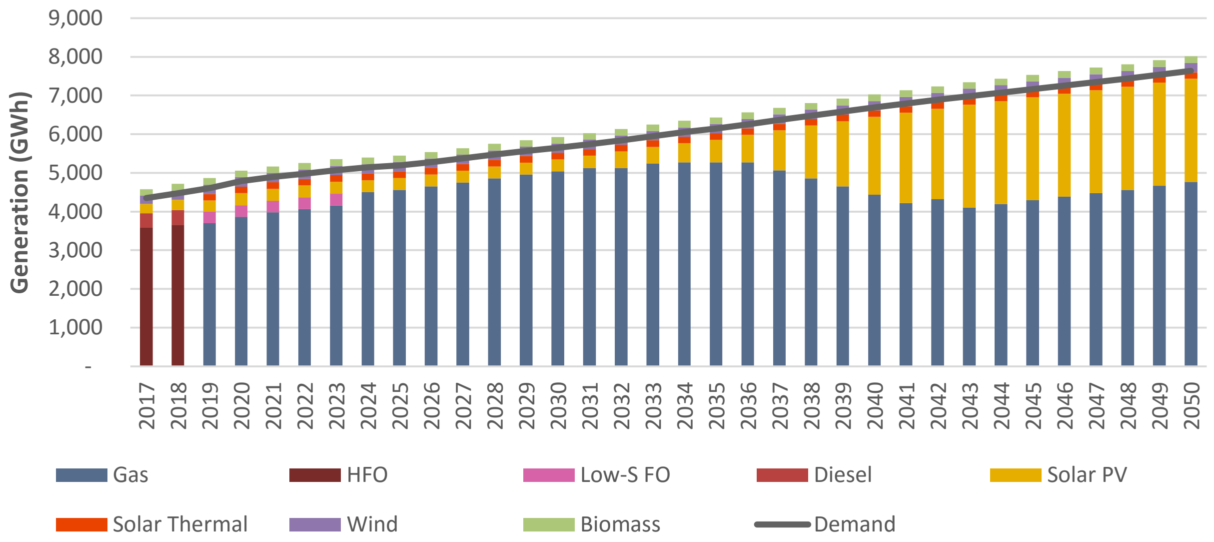

Figure 2 – Evolution of generation mix by each fuel/technology in the Reference Scenario (S1).

All existing thermal power plants are decommissioned within the model horizon (Table 10), according to the expected schedule provided by EAC. On the other hand, an additional combined cycle gas turbine (CCGT) unit is installed by 2024 as an alternative to the decommissioned steam units of Dhekelia and the Internal Combustion Engines (ICE) running on HFO. This new unit is used as a baseload to satisfy increasing electricity demand in a cost-efficient way. Steam turbines and gas turbines also enter into operation in the period 2042-2050. In the case of gas turbines, these are used as peaking plants and to satisfy the capacity reserve requirement. Wind capacity increases by 2018 to 175 MW. Biomass-fired facilities increase from an existing capacity of 10 MW to 40 MW, while a committed solar thermal plant comes into operation by 2019.

Additional to generating capacity, a pumped-hydro facility of 130 MW is installed by 2032, while Li-ion batteries become deployed from 2026 gradually reaching a capacity of 520 MW in 2045. Storage options provide multiple benefits to the system, both in terms of generation and ancillary services. In periods of rapid shifts in variable renewable energy generation, storage can act as a balancing mechanism, while it can also serve as backup in cases of more prolonged infrastructures outages. Furthermore, it can assist with load shifting, allowing for higher shares of variable renewables. Similarly, as observed in the model outputs, storage can assist in maintaining a constant generation level from baseload thermal plants, such as CCGTs, during periods of low demand (e.g. weekends or night-time). This is the reason why Li-ion batteries become deployed even during periods of relatively low RE share in generation.

Table 10 – Evolution of capacity by each technology in the Reference Scenario.

MW	2020	2025	2030	2035	2040	2045	2050
Vasilikos	868	868	868	608	0	0	0
Dhekelia	460	102	102	102	0	0	0
Moni	150	150	150	0	0	0	0
New CCGT	0	216	216	432	864	864	864
New ICE	0	0	0	0	0	0	0
New ST	0	0	0	0	0	0	57
New GT	0	0	0	0	0	62	248
Solar PV	191	191	191	359	1239	1639	1639
Solar Thermal	50	50	50	50	50	50	50
Wind	175	175	175	175	175	175	175
Biogas	40	40	40	40	40	40	40
Pumped Hydro	0	0	0	130	130	130	130
Li-Ion Batteries	0	0	116	260	503	523	479

4.1.2 Delayed Gas Scenario

The main difference with the Reference Scenario in this case is observed in the period 2019-2023. Since natural gas is not made available in 2019, the derogation for the use of HFO with 1% S content remains in force and the fuel can be used on this specific year. However, since this derogation ceases to exist in 2020, generation becomes largely based on diesel and to a lesser extent on HFO with low S content (Figure 3). During the years 2020-2023, the fuel-efficient CCGTs running on diesel seem more competitive than the ICE and steam units at Dhekelia and Vasilikos. Once gas becomes available in 2024, the system shifts almost entirely to the newly introduced fuel. After 2024, the outlook is very similar to that of the Reference scenario. Gas-fired generation dominates the electricity mix, while solar PV generation increases gradually in the period 2035-2050.

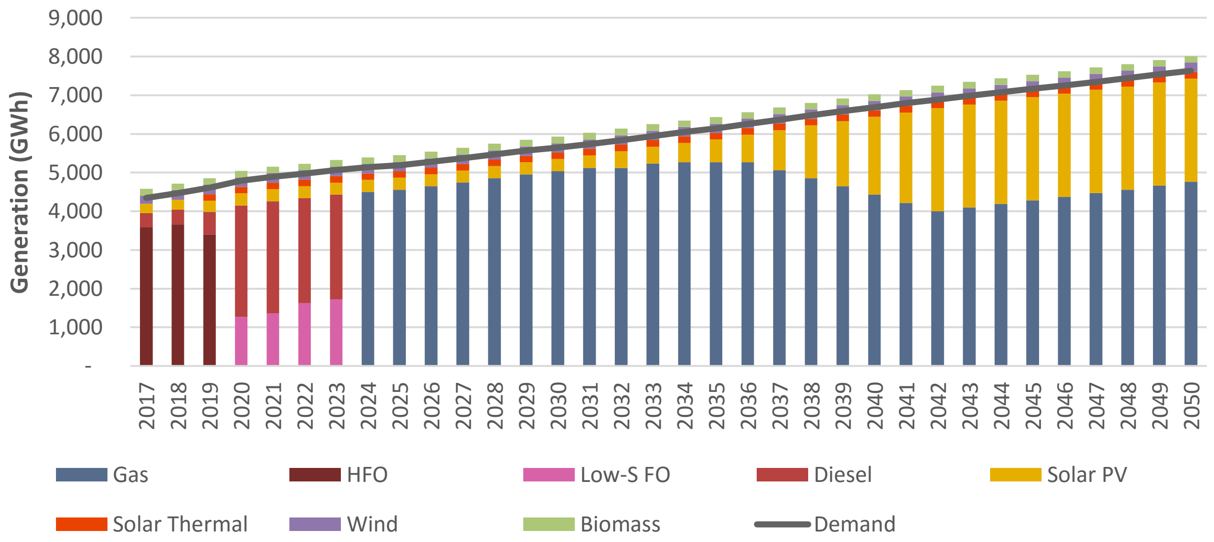

Figure 3 – Evolution of generation mix by each fuel/technology in the Delayed Gas Scenario.

Investments in storage, new CCGTs, solar thermal, biomass and wind remain relatively unchanged compared to the Reference scenario (Table 11). However, investments at the end of the model horizon in new steam turbine, gas turbine units, solar PV and Li-ion batteries are slightly affected but negligible differences can be noticed, as the conditions are identical to the Reference case.

Table 11 – Evolution of capacity by each technology in the Delayed Gas Scenario.

MW	2020	2025	2030	2035	2040	2045	2050
Vasilikos	868	868	868	608	0	0	0
Dhekelia	460	102	102	102	0	0	0
Moni	150	150	150	0	0	0	0
New CCGT	0	216	216	432	864	864	864
New ICE	0	0	0	0	0	0	0
New ST	0	0	0	0	57	57	57
New GT	0	0	0	0	0	0	248
Solar PV	191	191	191	359	1239	1239	1642
Solar Thermal	50	50	50	50	50	50	50
Wind	175	175	175	175	175	175	175
Biogas	40	40	40	40	40	40	40
Pumped Hydro	0	0	0	130	130	130	130
Li-Ion Batteries	0	0	116	260	446	446	478

4.1.3 No Gas Scenario

Undeniably, the biggest impact of this scenario is on the electricity supply mix of the country. As illustrated by the results (Figure 4 and Table 12), in case no gas imports commence on the island, a large share of the generation will have to shift towards renewable energy sources. The rate at which solar PV is installed – which is high - in the early years of the simulation highlights the importance of making timely long-term strategy decisions. In case gas is not to be made available in Cyprus, investments are required in RE generation infrastructure to ensure a lower electricity cost. However, the large share of intermittent renewables necessitates significant investments in storage in order for the system to be stable. Investments in both pumped-hydro and Li-ion batteries occur earlier in the model period as compared to the previous scenarios.

The cost-competitiveness of renewables versus oil-products is not the only aspect that is driving the rapid investments in solar PV, which is the most cost-competitive renewable energy technology. SO_x emission limits also play an important role, as the 2030 limit of 1.9 kilotons is reached in the years 2030-2032. Despite the use of diesel and HFO with low S content, renewable energy contributes approximately 52-57% of the generation needed to cover the final electricity demand in the period 2024-2050. Potentially, the share of renewable energy technologies would decrease if abatement technologies were to be installed at the thermal power plants, so as to reduce SO_x emissions even further. Similarly, with the use of such technologies, the burning of HFO with high S content would be possible, but this would have a negative effect on CO_2 emissions.

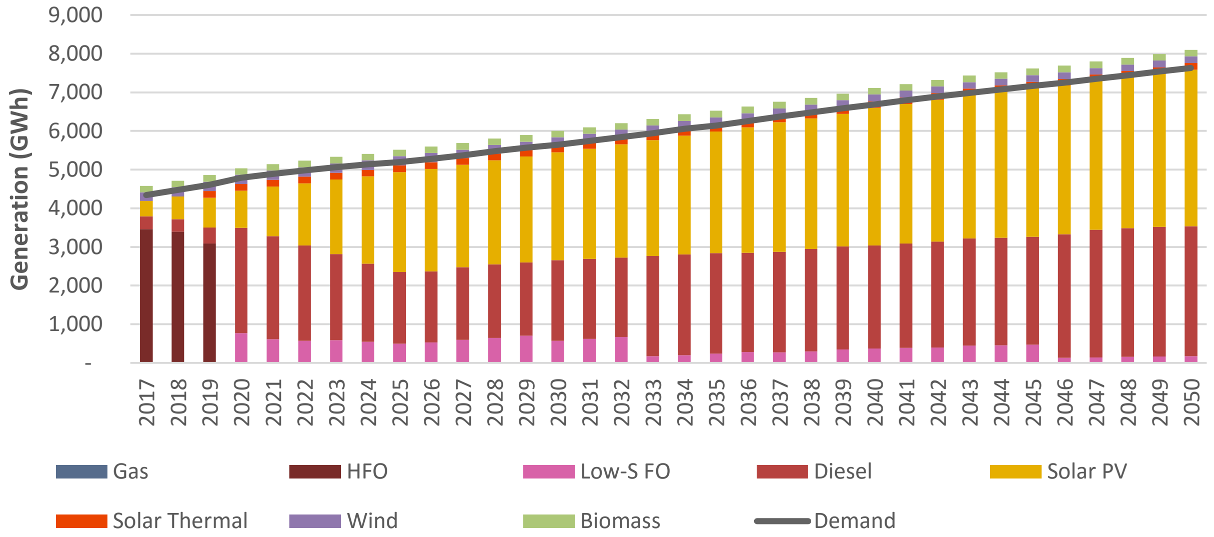

Figure 4 – Evolution of generation mix by each fuel/technology in the No Gas Scenario.

The early investments in solar PV in the No Gas scenario reveal a caveat required of the modelling approach. OSeMOSYS is a perfect foresight model, which means that conditions throughout the model horizon are predefined and visible to the cost-optimization tool. For instance, the lack of natural gas as a fuel in the period 2030-2050 is defined as a fact in the No Gas Scenario, which means that the model chooses to deploy solar PV at an earlier stage as a measure to reduce electricity cost and CO_2 and SO_x emissions in the long-term. Even though the conditions are the same for the period 2019-2023 in the Delayed Gas and No Gas scenarios, solar PV capacity is much higher in the latter due to this foresight.

Table 12 – Evolution of capacity by each technology in the No Gas Scenario.

MW	2020	2025	2030	2035	2040	2045	2050
Vasilikos	868	868	868	608	0	0	0
Dhekelia	462	102	102	102	0	0	0
Moni	150	150	150	0	0	0	0
New CCGT	0	0	0	216	648	648	864
New ICE	0	0	0	0	0	0	0
New ST	0	0	0	0	171	171	171
New GT	0	0	0	0	0	0	0
Solar PV	591	1591	1721	2003	2355	2547	2694
Solar Thermal	50	50	50	50	50	50	50
Wind	175	175	175	175	175	175	175
Biogas	40	40	40	40	40	40	40
Pumped Hydro	0	130	130	130	130	130	130
Li-Ion Batteries	0	110	110	147	325	448	402

A significant consequence of this is that of curtailment. Due to the high share of renewables in this last scenario (55%-57% in 2025-2050), curtailment of solar PV ranges around 7% during the years with high RE share. Instead of consuming expensive oil-products or investing in capital intensive storage options, the waste of a portion of the electricity is deemed economically more attractive. However, this is an aspect that merits further investigation and should be assessed in future work. Rapid-response thermal plants that may be equipped with pollution abatement technologies may be a potentially viable option. Additionally, as indicated by the JRC grid stability analysis (JRC, 2016a) following the IRENA work (IRENA, 2015), demand-side measures could be set in place to reduce the level of curtailment.

4.2 Transport

The main target of this sector is to achieve a 10% renewable energy share in 2020, as well as a reduction in life-cycle greenhouse gas emissions by 6% in the same year as compared to 2010. Further, additional targets regarding the use of advanced biofuels and renewable electricity are being discussed at the EU level for the period 2021-2030. According to the results of all three scenarios, achievement of the renewable energy targets is reached primarily through the use of second generation biodiesel, blended with diesel, as its contribution counts double towards the achievement of the target. Additionally, a considerable share of existing gasoline vehicles is converted into LPG (Table 14). Even though this fuel is not renewable, through its exclusion from consideration in the total energy used it leads to a reduction in gasoline demand, hence enabling an easier achievement of the renewable energy target. Additionally, plug-in hybrid diesel vehicles are deemed as part of the most competitive solution in order to achieve the target. In all scenarios, the EU renewable energy share in generation was considered for the contribution to electricity in 2020 (according to the EU Reference scenario this is 32.6% in 2018 (European Commission, 2016)), as well as throughout the model horizon.

A very significant aspect highlighted by the results of this sector is the preference to diesel instead of gasoline. Gasoline vehicles are almost entirely removed from the fleet in all scenarios by 2030. Diesel vehicles are more energy-efficient as compared to gasoline vehicles, while the cost of diesel per unit of energy is also less. Nonetheless, the main driver for this abrupt change is the non-mixing of bioethanol with gasoline. On the other hand, biodiesel is already being blended with diesel in Cyprus. Since, a blend of biofuels is required to achieve the renewable energy targets of 2020-2030, the withdrawal of gasoline vehicles from the fleet and their replacement with diesel vehicles is seen as the cost-optimal solution. Such a rapid and extensive restructuring of the entire fleet will be highly expensive for consumers. Additionally, this may be exceptionally challenging to achieve in reality, especially since the purchase of vehicles is largely based on social behaviour. Rather, the blending of bioethanol with gasoline, at least during the winter months of the year, may be more achievable. In early scenario runs of the model not included in this report, bioethanol was enabled for the entire year. In this case, even though the passenger car gasoline fleet would reduce to half its current size by 2040, it would not diminish entirely as in the presented three scenarios.

In terms of scenario comparison, due to the fact that natural gas is not chosen by the model as an option in the transport sector, differences are very subtle between the three cases. The amount of diesel plug-in hybrid passenger cars and light trucks at the end of the model horizon seems to be affected to a small extent by the share of renewable energy in electricity. Additionally, in 2030 for the No Gas Scenario, there is a small variation in gasoline, diesel and biodiesel consumed quantities, which can likely be attributed to the fact that the SO_x limit of this year is reached and the model attempts to accommodate demand accordingly.

Table 13 – Fuel Consumption in the transport sector in each scenario.

		Biodiesel 1st gen	**Biodiesel 2nd gen**	**Diesel**	**Gasoline**	**LPG**	**Electricity**
		Litres	Litres	Litres	Litres	Litres	MWh
2020	Reference	-	21,702,417	283,947,677	221,685,198	21,206,381	67,091
	Delayed Gas	-	21,770,639	284,840,282	220,112,208	21,206,381	65,984
	No Gas	-	21,770,639	284,840,282	220,112,208	21,206,381	65,984
2030	Reference	-	21,948,677	296,350,320	10,719,289	-	59,816
	Delayed Gas	-	21,995,998	296,779,601	10,346,067	-	58,829
	No Gas	-	21,995,735	296,779,842	10,346,067	-	58,835
2040	Reference	-	24,870,491	325,779,557	5,115,319	-	31,075
	Delayed Gas	-	24,870,491	325,779,557	5,115,319	-	31,075
	No Gas	-	24,860,010	325,679,756	5,115,319	-	31,136
2050	Reference	-	27,390,355	358,366,896	5,582,372	-	27,686
	Delayed Gas	-	27,359,114	357,958,151	5,956,297	-	28,152
	No Gas	-	27,283,758	356,972,209	6,807,768	-	29,209

Table 14 – Projected Fleet in each Scenario.

		2014	2020			2030			2040		
		Registered	Reference	Delayed Gas	No Gas	Reference	Delayed Gas	No Gas	Reference	Delayed Gas	No Gas
Light duty vehicles	Diesel	54,864	218,820	221,250	221,250	507,373	508,789	508,789	598,226	598,226	599,797
	Diesel hybrid		-	-	-	-	-	-	-	-	-
	Diesel PHV		-	-	-	-	-	-	7,504	7,504	5,933
	Gasoline	421,425	264,147	264,147	264,147	-	-	-	-	-	-
	Gasoline Hybrid	2,107	1,484	1,484	1,484	-	-	-	-	-	-
	Gasoline PHV		35,847	35,002	35,002	35,847	35,002	35,002	-	-	-
	BEV		-	-	-	-	-	-	-	-	-
	LPG		16,909	16,909	16,909	16,909	16,909	16,909	-	-	-
	Natural gas		-	-	-	-	-	-	-	-	-
	Hydrogen		-	-	-	-	-	-	-	-	-
Busses	Diesel	2,578	2,792	2,792	2,792	2,825	2,825	2,825	3,066	3,066	3,066
	Diesel hybrid		-	-	-	-	-	-	-	-	-
	BEV		-	-	-	-	-	-	-	-	-
	Hydrogen		-	-	-	-	-	-	-	-	-
MCs	Gasoline	40,928	40,545	40,545	40,545	44,991	43,027	43,027	38,866	38,866	38,866
	BEV		-	-	-	-	-	-	-	-	-
Trucks	Diesel	11,053	13,463	13,463	13,463	16,295	16,295	16,295	17,661	17,661	17,661
	BEV		-	-	-	-	-	-	-	-	-
	Natural gas		-	-	-	-	-	-	-	-	-
Light Trucks	Diesel	88,479	86,954	86,954	86,954	89,773	89,773	89,773	96,922	96,922	95,564
	BEV		-	-	-	-	-	-	-	-	-
	PHV Diesel		12,682	12,682	12,682	12,682	12,682	12,682	16,437	16,437	17,794
	Hybrid diesel	54,864	-	-	-	-	-	-	-	-	-

4.2.1 The effect of a fixed RES target in the transport sector

The results of the three scenarios indicate that the achievement of the RES targets in transport will be a costly endeavour. In all three cases, a large share of the aging fleet is replaced by new vehicles by 2020, so as to reduce fossil fuel consumption, while a considerable amount of investments is diverted into purchase of plug-in hybrid vehicles and conversion of gasoline engines into LPG-fired engines. At the same time, blending of second generation biodiesel into diesel is the main way of achieving the 10% RES target in transport by 2020, thus increasing the cost of the fuel.

In order to examine the potential for statistical transfer of RE shares between sectors, a parallel scenario was created. As a first step, the RE share in final energy demand for the system as a whole was extracted from the Delayed Gas scenario results and was introduced as a minimum share in this side scenario. Then, the mandatory biofuel blending and RE targets in transport were removed from the model, so as to allow other technologies (e.g. solar PV in the generation sector or solar thermal panels in the Heating and Cooling sector) to contribute to the corresponding RE target. Finally, all other conditions in the Delayed Gas scenario were kept constant and the scenario was analysed.

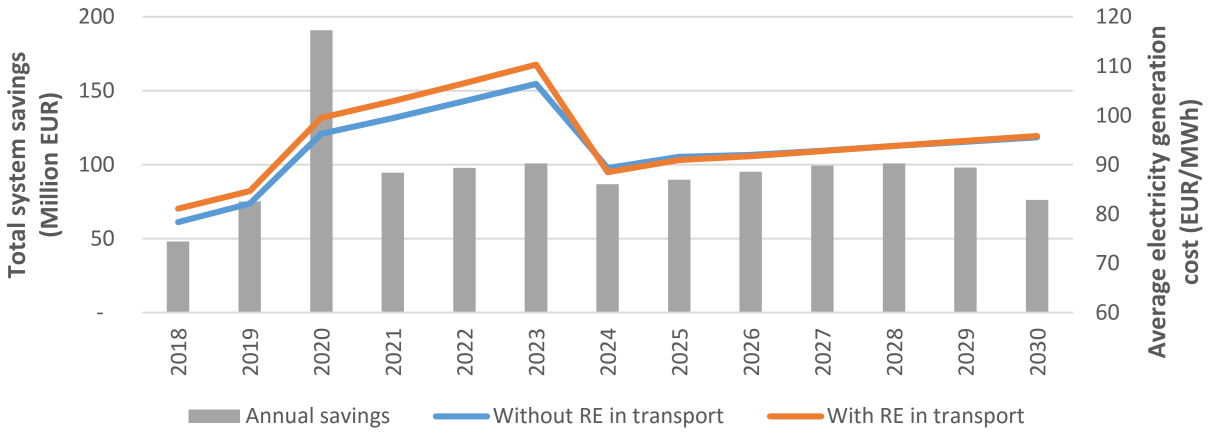

Figure 5 – Cost savings achieved by statistical transfer of RES from transport to electricity generation and the effect on electricity price.

Consequently, when the model was allowed to select in which RET to invest so as to meet the new implemented RE target, the installed capacity of solar PV increased by about 100 MW. Since the choice of increasing RE in transport was still an available alternative, this is a strong indication that use of RET in generation, namely solar PV, is more cost-effective than enforcing a renewable energy share in transport. Figure 5 illustrates the substantial cost savings realised if the obligatory RE targets in transport are treated as non-mandatory. Despite the higher investments in solar PV in generation, savings of 1,250 million EUR are achieved across the system in the period 2018-2030. Considering the fact that the GDP of Cyprus was 17,600 million EUR in 2015 (Eurostat, 2017), the savings are substantial. The highest amount of savings attained within a specific year occurs in 2020, due to the fact that in this period the use of second generation biodiesel reached its peak in the case with obligatory RE targets in transport. It is interesting to note that despite the higher investments in solar PV, electricity cost reduces slightly in the medium-term (as it competes with oil-fired generation until 2023) and only increases marginally in the long-term (when it competes with gas-fired generation).

In light of these results, it is recommended that the Cypriot authorities investigate the possibility of negotiating the option of statistical transfer of RES from the transport sector to other areas of the energy system. In turn, the savings could potentially be recirculated in the economy to incentivise the further deployment of RET and associated enabling technologies (for instance, storage options) in a manner that would provide the maximum socioeconomic benefit to the local economy.

4.3 Heating and Cooling

Similar to the case of transport, the analysed scenarios have negligible variations between each other. Since natural gas is not made available in this sector, the availability of the fuel in the domestic market is only influenced through the electricity cost. However, in the provided scenario outputs, it was assumed that the level of generation would not divert from the projections by Dr. Zachariades. As such, electricity consumption in this sector is kept steady in all the cases.

In terms of heating demand, heat pumps/heat pump split units are the most competitive technology, as these increase their share substantially, displacing oil boilers and electric resistance heaters (Table 15). Additionally, fuel-efficient oil boilers provide a considerable amount of heating in the services, industrial and agricultural sectors. Solar thermal panels in these sectors also increase their contribution by about twice their current yield, while solar thermal panels in the residential sector stay stable at the current levels. However, in the residential sector heat pumps/heat pump split-units take up the majority of the heating demand, as they are conceived to be the most cost-competitive technology. On the other hand, electric resistance heaters are not seen as efficient or cost-competitive and are phased out. Similarly, heat pumps/heat pump split-units take up the entire cooling demand throughout the model horizon, as currently is the case, with minimal contribution from efficient oil boilers. It should be clarified that the biomass CHP plants providing part of the heating demand refer to existing and future agricultural facilities making use of biogas, both for heating purposes as well as to generate electricity.

The outlook of this sector could potentially change substantially, if the electricity demand is allowed to vary. For instance, even though fuel efficient oil boilers contribute to the heating demand in services, industry and agriculture, if the level of electricity was allowed to increase, the contribution of heat pumps/heat pump split-units would likely increase further, since this is deemed to be the most cost-competitive option in this sector. Of course, this would also depend on the respective scenario. In a scenario without natural gas or with high fossil fuel prices in electricity generation, the average cost of electricity increases considerably. In this case, other technologies may be deemed more competitive. For this reason, it is advised that a sensitivity analysis be carried out before making any drastic policy decisions.

The aspect of decommissioning of aging renewable energy technologies from the system arises in this sector. As seen in the results, contribution from solar thermal panels in the residential sector does not change over time. This is due to the assumed refurbishment that occurs at the end of the technology's lifetime. Even though this assumption does not increase the technology's cost-competitiveness in the residential sector, it affects the level of solar panel deployment in the rest of the economy. This relates to the difference in investment costs, as indicated in Tables 7 and 8.

Table 15 – Useful heating demand (PJ) provided by each technology in the three scenarios.

			2013	2020			2030			2040		
	Resource	**Technology**	**Estimated by JRC**	**Reference**	**Delayed Gas**	**No Gas**	**Reference**	**Delayed Gas**	**No Gas**	**Reference**	**Delayed Gas**	**No Gas**
Services, industry and agricultural sector	Electricity	Heat pumps/split units	1.543	1.70	1.56	1.56	4.97	4.97	4.80	6.84	6.73	7.30
	Electricity	Resistance heaters	0.309	0.19	0.19	0.19	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Boilers	3.734	2.31	2.38	2.31	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	CHP	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Efficient Boilers	-	2.21	2.28	2.35	2.43	2.43	2.60	1.26	1.36	0.78
	LPG	Boilers	0.247	0.15	0.15	0.15	-	-	-	-	-	-
	Biomass/waste	CHP	-	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
	LPG	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	Boilers	0.780	0.48	0.48	0.48	-	-	-	-	-	-
	Biomass	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Solar	Solar panels	0.296	0.36	0.36	0.36	0.54	0.54	0.54	0.71	0.71	0.73
Residential sector	Electricity	Heat pumps/split units	0.846	4.85	4.85	4.85	6.17	6.17	6.17	6.34	6.34	6.34
	Electricity	Resistance heaters	1.080	0.67	0.67	0.67	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Boilers	0.518	0.32	0.32	0.32	-	-	-	-	-	-
	Gas oil, light fuel oil, LPG	CHP	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	LPG	Boilers	0.004	0.003	0.00	0.003	-	-	-	-	-	-
	LPG	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	Boilers	0.011	0.01	0.01	0.01	-	-	-	-	-	-
	Biomass	CHP	-	-	-	-	-	-	-	-	-	-
	Biomass	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Solar	Solar panels	1.804	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78

Table 16 – Useful cooling demand (PJ) provided by each technology in the three scenarios.

			2013	2020			2030			2040		
	Resource	**Technology**	**Estimated by JRC**	**Reference**	**Delayed Gas**	**No Gas**	**Reference**	**Delayed Gas**	**No Gas**	**Reference**	**Delayed Gas**	**No Gas**
Services, industry and agricultural sector	Electricity	Heat pumps/split units	5.86	6.099	6.099	6.099	6.746	6.746	6.746	7.389	7.389	7.389
	Electricity	Resistance heaters	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Boilers	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	CHP	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	LPG	Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass/waste	CHP	-	-	-	-	-	-	-	-	-	-
	LPG	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Solar	Solar panels	-	-	-	-	-	-	-	-	-	-
Residential sector	Electricity	Heat pumps/split units	6.05	7.459	7.582	7.582	9.282	9.284	9.369	10.994	11.048	10.422
	Electricity	Resistance heaters	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Boilers	-	-	-	-	-	-	-	-	-	-
	Gas oil, light fuel oil, LPG	CHP	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Efficient Boilers	-	0.123	-	-	0.087	0.085	-	0.149	0.094	0.720
	LPG	Boilers	-	-	-	-	-	-	-	-	-	-
	LPG	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	CHP	-	-	-	-	-	-	-	-	-	-
	Biomass	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Solar	Solar panels	-	-	-	-	-	-	-	-	-	-

4.4 Final Energy Demand

According to the European Union's Renewable Energy Directive (2009/28/EC), renewable energy should contribute to 13% of the final energy consumption by 2020 in Cyprus. This target is achieved in the Reference (14.6%) and Delayed Gas Scenarios (14.7%), while it is greatly surpassed in the No Gas Scenario (19.8%) due to the substantial increase in solar PV generation. After 2020, the renewable energy share in final energy demand is no longer the constraint driving investments. Rather, CO_2 and air pollutant emission limits begin to affect the system to a greater extent.

4.5 CO_2 and SO_x Emissions

A fuel shift to natural gas has direct benefits for CO_2 and SO_x emission reductions. Since the island has long relied on HFO for its electricity supply, substitution of this fuel with gas will dramatically reduce emissions of both pollutants (Table 17). This allows for the achievement of the CO2 emission reduction target in the ETS sector for 2030[11], even though fossil-fired generation provides approximately 85% of the electricity supply in that year in the Reference and Delayed Gas scenarios.

A similar case is observed for industrial air pollutants. Results from the three scenarios indicate that currently power generation is the main polluter in terms of SO_x emissions. This is illustrated by the fact that SO_x emissions are the highest in the No Gas scenario for 2030 and 2050. In this case, the emission limit is reached in 2030-2032 and further fuel consumption is blocked by the model to conform with the target. Since diesel has a lower S content than HFO, when new CCGTs consuming this fuel come into operation in 2033, they replace the Dhekelia ICE units that consume HFO (with low S content) and the level of fossil-fuel generation increases once again.

Table 17 – Projected CO_2 and SO_x emissions in each scenario.

		CO2 emissions (ETS sector)	CO2 emissions (non-ETS sector)	SOx emissions
		Mtons	Mtons	ktons
2015	Model Estimate	2.58	2.32	14.63
2020	*Limit*	--	5.50	6.46
	Reference	1.70	1.66	0.70
	Delayed Gas	2.33	1.65	3.67
	No Gas	1.92	1.65	2.54
2030	*Limit*	1.98	3.18	1.90
	Reference	1.94	0.96	0.08
	Delayed Gas	1.94	0.96	0.08
	No Gas	1.45	0.97	1.90
2040	*Limit*	1.98	3.18	1.90
	Reference	1.66	0.94	0.07
	Delayed Gas	1.66	0.94	0.07
	No Gas	1.63	0.96	1.68
2050	*Limit*	1.98	3.18	1.90
	Reference	1.80	0.97	0.07
	Delayed Gas	1.80	0.97	0.07
	No Gas	1.86	0.98	1.46

Another important aspect is that of future emission limits for the period beyond 2030. Current European Union and international legislation provides targets until 2030 and these were kept constant in the model for

[11] EU targets for a 43% decrease in CO2 emissions in the ETS sector by 2030, as compared to 2005 levels.

the period 2031-2050. As seen in Table 15, the 2030 targets are overachieved by 2040 and 2050 in all scenarios, but generally plateau in the period after 2030. However, the targets will likely become more stringent for the period 2031-2050, which would likely necessitate additional investments in renewable energy infrastructure or the use of pollution abatement technologies. This would lead to a higher cost of energy services, which can potentially become much higher if decisions are not taken in the appropriate time. Once negotiations at the EU level provide an indication of future targets, the model can be updated accordingly and new analysis be carried out.

4.6 Financial Implications

Since the biggest variation observed in the three scenarios is in the electricity supply sector, the cost of electricity in each scenario can provide insights as to the preference of each pathway. As shown in Figure 5, the Reference Scenario is the cheapest case for the majority of the model horizon, while the No Gas Scenario is the most expensive. This was as expected, since in the latter case substantial investments are necessary in generation infrastructure. The average generation cost in the period 2020-2023 is the highest in the Delayed Gas scenario, due to the use of diesel and HFO with low S content. Since in this scenario it is predetermined that natural gas will become available at a lower cost in 2024, the model chooses to bear the high short-term variable cost, instead of investing in capital-intensive renewable energy technologies, as in the No Gas scenario. The sudden drops in cost, seen in the Reference and Delayed Gas cases in 2034 and 2039 respectively, relate to the assumed full amortization of the gas importing infrastructure within a period of 15 years.

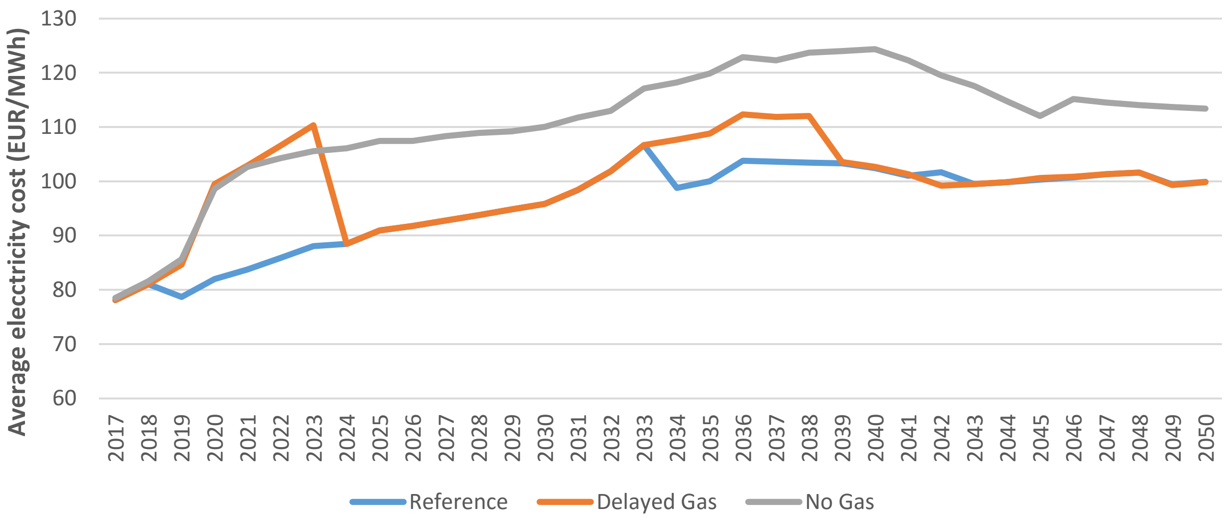

Figure 5 – Average electricity cost in each scenario.

Electricity cost increases across time due to investments and increasing fuel and CO_2 costs in all scenarios. In the years 2030-2050, electricity cost varies between 95-110 EUR/MWh in the Reference and Delayed Gas scenarios, while in the No Gas scenario the price climbs from 110 EUR/MWh in 2030 to 125 EUR/MWh in 2040. At its peak difference, the No Gas Scenario has a price that is 25% higher than the reference case. The higher cost observed here is a function of both the elevated investment costs, as well as the high fuel cost for diesel and HFO with low S content.

It should be mentioned that in case additional options of reducing the level of curtailment in the No Gas Scenario are found, the financial competitiveness of high renewable energy shares in generation would increase. The potential development of an electricity interconnector could offer an alternative, through exports of excess variable electricity generation. Similarly, establishing other domestic industries or services that could absorb this excess electricity could be an option to boost the local economy. Finally, a more comprehensive analysis of the benefits offered by storage options would potentially lead to a higher deployment of batteries in the system. A breakdown into fixed, variable, capital and CO_2 costs per scenario is provided in Appendix D, along with the annualized investment cost per technology type for each scenario.

As shown in Table 18, a substantial amount of investments is required for the electricity supply of the country in all scenarios. The No Gas scenario is the most demanding due to the capital intensive investments in solar PV. Additionally, the earlier deployment of this technology in this scenario affects the rate at which capital is needed. Since Cyprus has not yet fully recovered from the recent financial crisis, access to such capital may be challenging. However, as natural gas reserves become exploited revenue will be collected from exports. These funds can then be directed for investments in domestic energy infrastructure to ensure a secure and uninterruptible supply of all energy services for the coming decades.

Table 18 – Cumulative annualized investments in the electricity supply sector for each scenario (Million EUR).

	2020	2030	2040	2050
Reference	309	1,528	3,140	5,496
Delayed Gas	202	1,259	3,143	5,515
No Gas	311	2,204	4,775	6,980

5. Concluding remarks

The scenario results shown above indicate the importance of introducing natural gas in the electricity supply system of the country. Even though, based on the inherent assumptions taken, the fuel is not deemed competitive enough for use in the transport sector, natural gas is expected to have a considerable impact on the generation profile of the country. As illustrated by the results of the No Gas Scenario, if a total lack of the fuel persists in the long term, an aggressive deployment of solar PV will be required to achieve emission reduction targets and maintain electricity costs at relatively low levels. An array of, primarily EU, legislations affect the course that needs to be taken but each member state has the flexibility to decide on how to enforce adequate measures. Policy on a regional and global scale is shifting towards low-carbon economies, thus long-term planning should strive in this direction.

As an EU member state, Cyprus is not an isolated system, which can exclude itself from international obligations regarding climate and environmental pollution. A coherent vision for the energy system is required and development pathways for achieving the associated goals of this vision need to be investigated. From an analytical point of view, since policy measures in one sector can adversely affect another sector, the entire energy system was treated as a whole and the effect on each of the sectors on the rest of the energy system was assessed. Further, ambitions may increase. An 80% reduction of CO2 emissions by 2050 is currently being discussed in Brussels. Actions that enable this (i.e. a move to RET) in the short term, may have significant long term gains.

5.1 Future work and recommendations

Aspects not considered in the present study should be examined in further enhancements of this work. For instance, since it was assumed that the cost of all fuels are correlated to crude oil, a range of crude oil price scenarios should be examined. Similarly, technology or fuel options that were not included in the analysis should be investigated in the future. Specifically, district heating to take advantage of waste heat from existing thermal plants, as well as the potential use of blended bioethanol with gasoline in the transport sector are two areas that merit consideration. Separate studies are also required to establish a consolidated demand profile for heating and cooling, as the respective profiles used here were based on the load profile of electricity consumption by different customer categories and were an assumption.

Another important aspect to evaluate is that of different demand projections in all the sectors. This will implicitly evaluate the benefit offered by energy efficiency measures. Furthermore, the effect of NO_x and PM emissions was not addressed in this study, and these are very important in the transport sector. This is of significance especially since the model indicates a shift of the vehicle fleet towards diesel engines; these have high NO_x and PM emissions. As such, once data is made available on vehicle emission factors for these pollutants, the assumptions used in the present study will have to be revisited. Last but not least, the option of abatement technologies should be assessed in case no gas is available for electricity supply. Instead of importing expensive fuel with low S content, the utility could potentially invest in abatement technologies that reduce SO_x flue gas emissions and continue to use HFO with high S content. However, in this case CO_2 emissions would remain high in the long-term. As such, this is not a trivial issue and the quantitative analyses are needed to account for all impacting factors. This is particularly the case, as GHG mitigation ambition is likely to increase, not decrease[12].

In order to avoid promotion of technologies that could potentially affect the reliability of the energy system or increase the cost of energy services, such efforts should be taken up by the local government and relevant stakeholders. Outputs from efforts of this kind should not be considered as predetermined development pathways to be taken blindly. Rather, such analyses aim at offering insights as to the dynamics of the system and should be conducted systematically, so as to formulate energy policy decisions that are resilient and

[12] EU Action on 2050 low-carbon economy (https://ec.europa.eu/clima/policies/strategies/2050_en).

robust. As such, it would be more sustainable and efficient for the authorities in Cyprus to develop the capacity to operate the model developed in this project. The final form of the model has a modular structure that enables easy update of the input data and assumptions, so that its longevity and usefulness can be ensured when it is handed over to the official authorities of Cyprus.

Once capacity is built within the government, multiple scenarios can be run to explore a larger array than the set presented here. Aspects such as oil prices, capacity sizing of pumped storage, development of an interconnector, a scenario without any specified targets are all options for future assessment. By changing any of the parameters, a comprehensive understanding of the potential opportunities for development can be gained. For instance, even though battery electric vehicles did not appear as part of an optimal solution in the provided three scenarios, perhaps with a more ambitious reduction in vehicle cost will lead to a different result. This is just one of the many parameters that could be altered in the model, which means there is a large number of plausible scenarios. Scenario discovery analyses (Gerst et al., 2013) provide insights as to the dynamics of the system and the most influential parameters, thus facilitating robust decision making.

To sum up, this study does not take into account the effect of different technology deployment choices on the broader society and economy. For instance, the potential benefits of rooftop PV deployment on job creation are not accounted for. A coupling of this energy system model with a macroeconomic model, as has been done in previous studies (Krook-Riekkola et al., 2013; Martinsen, 2011; Merven et al., 2017), can be part of future analysis.

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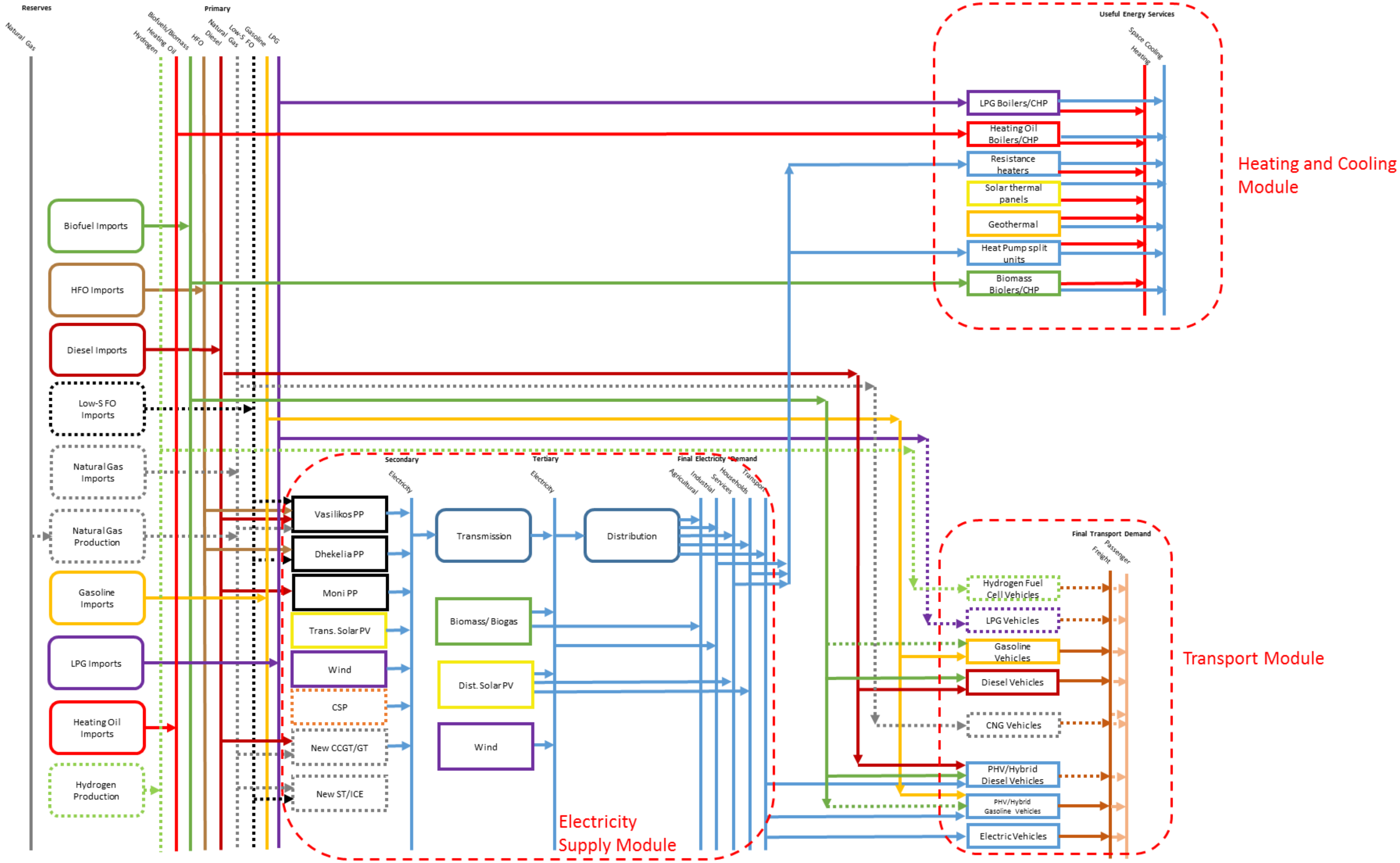
Appendices

Appendix A – Reference Energy System for Cyprus



Appendix B – Key Assumptions

Table B.1 – Technoeconomic characteristics of RET in generation.

	Investment Cost (EUR/kW)				Fixed Cost O&M cost (EUR/kW)	Capacity Factor	Lifetime (yrs)
	2015	**2020**	**2030**	**2040**			
Trans. PV	1,332	1,191	909	627	9.1	18.5%	20
Wind	1,462	1,429	1,364	1,298	54.5	16.0%	25
Biomass-biogas	2,537	2,524	2,500	2,476	63.6	48.5%	30
Rooftop PV	1,619	1,504	1,273	1,042	12.7	18.5%	20
CSP with storage	3,440	3,440	3,440	3,440	109.1	39.3%	30

Table B.2 – Fuel price projection in the generation sector.

		2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
Brent crude	**$/bbl**	46.55	47.58	48.60	51.20	53.90	56.80	59.80	62.90	66.30	67.04	67.78	68.52
CO2	**$/tCO2**	12.10	13.20	15.40	16.50	17.60	18.70	19.80	20.90	22.00	23.10	24.20	25.30
HFO (1% S)	**$/GJ**	6.73	6.88	7.03	7.40	7.79	8.20	8.63	9.08	9.57	9.67	9.78	9.89
DFO	**$/GJ**	10.69	10.89	10.01	10.53	11.06	11.63	12.22	12.83	13.50	13.64	13.79	13.93
HFO (0.5% S)	**$/GJ**	--	--	9.20	9.69	10.08	10.50	10.92	11.37	11.86	11.87	11.98	12.09
HFO (0.23% S)	**$/GJ**	--	--	9.96	10.49	10.88	11.30	11.72	12.17	12.66	12.64	12.75	12.85
Natural gas	**$/GJ**	5.29	5.41	5.53	5.82	6.13	6.46	6.80	7.15	7.54	7.62	7.71	7.79
		2029	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Brent crude	**$/bbl**	69.26	70.00	73.00	76.00	79.00	82.00	85.00	87.00	89.00	91.00	93.00	96.00
CO2	**$/tCO2**	26.40	27.50	28.60	29.70	30.80	31.90	33.00	34.10	35.20	36.30	37.40	38.50
HFO (1% S)	**$/GJ**	9.99	10.10	10.53	10.96	11.39	11.82	12.25	12.25	12.25	12.25	12.25	12.25
DFO	**$/GJ**	14.08	14.22	14.81	15.41	16.00	16.58	17.18	17.57	17.96	18.36	18.75	19.34
HFO (0.5% S)	**$/GJ**	12.19	12.30	12.80	13.22	13.65	14.08	14.51	14.79	15.08	15.37	15.66	16.09
HFO (0.23% S)	**$/GJ**	12.96	13.06	13.59	14.01	14.44	14.87	15.29	15.58	15.87	16.15	16.44	16.87
Natural gas	**$/GJ**	7.88	7.96	8.30	8.64	8.99	9.33	9.67	9.90	10.12	10.35	10.58	10.92

Table B.3 – SOx emission limit.

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
ktons	39.00	6.46	6.01	5.55	5.09	4.64	4.18	3.72	3.27	2.81	2.36	1.90

Table B.4 – Technoeconomic characteristics of pumped-hydro facility (Poullikkas, 2013).

Location of Facility	Kourris
Earliest Year of Operation	2023
Nominal Capacity	130 MW
Overall efficiency	77%
Full load operation for electricity production	8h
Capital cost Euro/kW	1185
O&M cost Euro/kWyr	10.98

Table B.5 – Technoeconomic characteristics of Li-ion batteries (IRENA, 2012).

Level	Centralized
First Year of Operation	2020
Capital cost USD/kW	700
Capital cost USD/kWhcap	1000
Fixed OM cost USD/kW-yr	25
Efficiency	90%
Lifetime (yrs)	12.5

Table B.5 – Technoeconomic characteristics of flow batteries (IRENA, 2012).

Level	Centralized
First Year of Operation	2020
Capital cost USD/kW	1600
Capital cost USD/kWhcap	575
Fixed OM cost USD/kW-yr	30
Efficiency	78%
Lifetime (yrs)	10.0

Table B.6 – Vehicle cost in the transport sector (EUR/unit); prices are provided without tax (IEA ETSAP, n.d.).

		2015	2020	2025	2030	2035	2040
Passenger cars	Diesel	17,497	17,497	17,497	17,497	17,497	17,497
	Gasoline	16,643	16,643	16,643	16,643	16,643	16,643
	Hybrid Gasoline	20,581	20,267	20,136	20,005	20,191	20,378
	Hybrid Diesel	21,151	20,155	19,954	19,755	19,543	19,333
	PHEV Gasoline	27,682	27,359	27,039	26,724	26,351	25,983
	PHEV Diesel	28,533	28,200	27,871	27,545	27,161	26,781
	BEV	34,904	29,279	28,680	28,093	27,776	27,463
	LPG	18,057	18,057	18,057	18,057	18,057	18,057
	CNG	18,833	18,833	18,833	18,833	18,833	18,833
	Hydrogen	49,913	44,471	41,824	39,334	38,613	37,904
	LPG Conversion	1,500	1,500	1,500	1,500	1,500	1,500
Motorcycles	Gasoline	5,909	5,909	5,909	5,909	5,909	5,909
	BEV	9,194	7,712	7,555	7,400	7,316	7,234
Busses	Diesel	300,000	300,000	300,000	300,000	300,000	300,000
	Hybrid Diesel	411,973	392,569	388,659	384,787	380,657	376,570
	BEV	450,000	377,481	369,753	362,183	358,099	354,062
	Hydrogen	1,575,528	1,403,724	1,320,172	1,241,594	1,218,818	1,196,459
Trucks	Diesel	32,500	32,500	32,500	32,500	32,500	32,500
	BEV	151,470	127,060	124,459	121,911	120,536	119,177
	CNG	57,500	57,500	57,500	57,500	57,500	57,500
Light Trucks	Diesel	20,295	20,295	20,295	20,295	20,295	20,295
	BEV	56,160	47,110	46,146	45,201	44,691	44,187
	PHEV	32,890	32,506	32,127	31,752	31,309	30,871
	Hybrid diesel	24,812	23,643	23,407	23,174	22,925	22,679

Table B.7 – Fuel prices in the transport sector (including minimum taxation levels).

$/GJ	2015	2020	2025	2030	2035	2040
Gasoline	25.5	26.6	31.4	32.6	37.4	40.9
Diesel	22.8	23.8	28.4	29.5	34.0	37.3
LPG	18.2	19.2	24.1	25.3	30.2	33.7
Natural Gas	8.1	8.4	10.1	10.6	12.3	13.5
Biodiesel (1st gen)	50.4	50.4	50.4	50.4	50.4	50.4
Biodiesel (2nd gen)	61.0	61.0	61.0	61.0	61.0	61.0

Table B.8 – Final Electricity Demand projections (GWh) – provided by Dr. Zachariades (Cyprus University of Technology).

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Total	4,084	4,227	4,339	4,463	4,593	4,724	4,828	4,913	5,004	5,076	5,130	5,218
Excluding transport	4,084	4,227	4,339	4,463	4,593	4,724	4,828	4,913	5,004	5,076	5,130	5,215
	2027	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**
Total	5,315	5,422	5,518	5,600	5,694	5,798	5,909	6,026	6,150	6,272	6,394	6,515
Excluding transport	5,310	5,415	5,507	5,586	5,676	5,776	5,881	5,992	6,110	6,224	6,336	6,447
	2039	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Total	6,635	6,754	6,874	6,993	7,112	7,231	7,356	7,488	7,628	7,776	7,933	8,099
Excluding transport	6,554	6,659	6,761	6,859	6,953	7,042	7,133	7,225	7,318	7,412	7,508	7,605

Table B.9 – Useful Energy Demand projections (PJ) in the Heating and Cooling sector.

		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Services, industry, agriculture	Cooling	5.780	5.844	5.918	5.987	6.045	6.099	6.161	6.222	6.284	6.345	6.408	6.471
	Heating	8.164	8.178	8.195	8.209	8.218	8.225	8.253	8.281	8.309	8.337	8.365	8.445
Residential	Cooling	6.594	6.839	7.022	7.220	7.417	7.582	7.766	7.932	8.108	8.285	8.464	8.659
	Heating	7.381	7.489	7.503	7.556	7.608	7.633	7.677	7.702	7.736	7.770	7.803	7.846
		2027	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**
Services, industry, agriculture	Cooling	6.535	6.602	6.672	6.746	6.816	6.885	6.951	7.016	7.078	7.142	7.205	7.267
	Heating	8.526	8.607	8.689	8.771	8.848	8.923	8.998	9.073	9.146	9.247	9.348	9.448
Residential	Cooling	8.820	9.002	9.185	9.369	9.567	9.724	9.907	10.092	10.276	10.464	10.613	10.789
	Heating	7.863	7.892	7.921	7.950	7.985	7.996	8.019	8.041	8.062	8.085	8.088	8.101
		2039	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Services, industry, agriculture	Cooling	7.328	7.389	7.458	7.525	7.593	7.659	7.725	7.791	7.856	7.920	7.984	8.047
	Heating	9.548	9.648	9.731	9.813	9.896	9.978	10.060	10.103	10.145	10.187	10.229	10.271
Residential	Cooling	10.965	11.142	11.315	11.489	11.663	11.837	12.012	12.181	12.351	12.521	12.691	12.863
	Heating	8.113	8.125	8.134	8.143	8.152	8.161	8.169	8.174	8.179	8.183	8.188	8.192

Note: Heating includes demand for hot water use.

Table B.10 – Freight and transport demand projections - adjusted from EC Reference Scenario 2016 (European Commission, 2016).

		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Passenger	**Gpkm**	8.987	9.127	9.266	9.402	9.536	9.666	9.735	9.805	9.876	9.946	10.016	10.076
Freight	**Gtkm**	0.527	0.531	0.537	0.543	0.550	0.557	0.568	0.579	0.591	0.603	0.615	0.627
		2027	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**
Passenger	**Gpkm**	10.137	10.197	10.258	10.320	10.417	10.516	10.616	10.719	10.825	10.937	11.051	11.170
Freight	**Gtkm**	0.638	0.650	0.662	0.674	0.680	0.686	0.692	0.699	0.707	0.710	0.715	0.720
		2039	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Passenger	**Gpkm**	11.292	11.418	11.539	11.663	11.792	11.925	12.062	12.183	12.308	12.437	12.569	12.704
Freight	**Gtkm**	0.725	0.731	0.733	0.735	0.738	0.741	0.744	0.747	0.750	0.753	0.757	0.761

Table B.11 – Assumed high heat requirement (PJ) in the Heating and Cooling sector, which can only be satisfied by boilers and CHP.

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
PJ	0.621	0.620	0.620	0.619	0.618	0.617	0.618	0.620	0.621	0.622	0.624	0.631
	2027	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**
PJ	0.639	0.646	0.654	0.661	0.668	0.675	0.682	0.689	0.696	0.706	0.716	0.726
	2039	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
PJ	0.736	0.746	0.753	0.761	0.769	0.777	0.785	0.788	0.791	0.794	0.797	0.801

Appendix C – Renewable energy targets in the transport sector.

Table C.1 – Maximum contribution from liquid biofuels produced from food or feed crops to the EU renewable energy target

2021	7.00%
2022	6.70%
2023	6.40%
2024	6.10%
2025	5.80%
2026	5.40%
2027	5.00%
2028	4.60%
2029	4.20%
2030	3.80%

Table C.2 – Minimum shares of energy from advanced biofuels and biogas, renewable transport fuels of non-biological origin, waste-based fossil fuels and renewable electricity

2021	1.50%
2022	1.85%
2023	2.20%
2024	2.55%
2025	2.90%
2026	3.60%
2027	4.40%
2028	5.20%
2029	6.00%
2030	6.80%

Table C.3 – Minimum shares of energy from advanced biofuels and biogas

2021	0.50%
2022	0.70%
2023	0.90%
2024	1.10%
2025	1.30%
2026	1.75%
2027	2.20%
2028	2.65%
2029	3.10%
2030	3.60%

Appendix D – Scenario results.

Table D.1 – Natural gas quantities consumed (bcm) in each scenario.

	Reference	Delayed Gas		Reference	Delayed Gas
2019	0.75	0	**2035**	1.03	1.03
2020	0.79	0	**2036**	1.03	1.03
2021	0.82	0	**2037**	0.99	0.99
2022	0.84	0	**2038**	0.95	0.95
2023	0.86	0	**2039**	0.91	0.91
2024	0.89	0.89	**2040**	0.87	0.87
2025	0.90	0.90	**2041**	0.82	0.83
2026	0.92	0.92	**2042**	0.85	0.78
2027	0.95	0.95	**2043**	0.80	0.80
2028	0.97	0.97	**2044**	0.82	0.82
2029	0.99	0.99	**2045**	0.84	0.84
2030	1.01	1.01	**2046**	0.86	0.86
2031	1.03	1.03	**2047**	0.88	0.88
2032	1.03	1.03	**2048**	0.90	0.90
2033	1.03	1.03	**2049**	0.92	0.92
2034	1.03	1.03	**2050**	0.94	0.94

Figure D.1 – Cost breakdown and average electricity cost in the Reference Scenario.

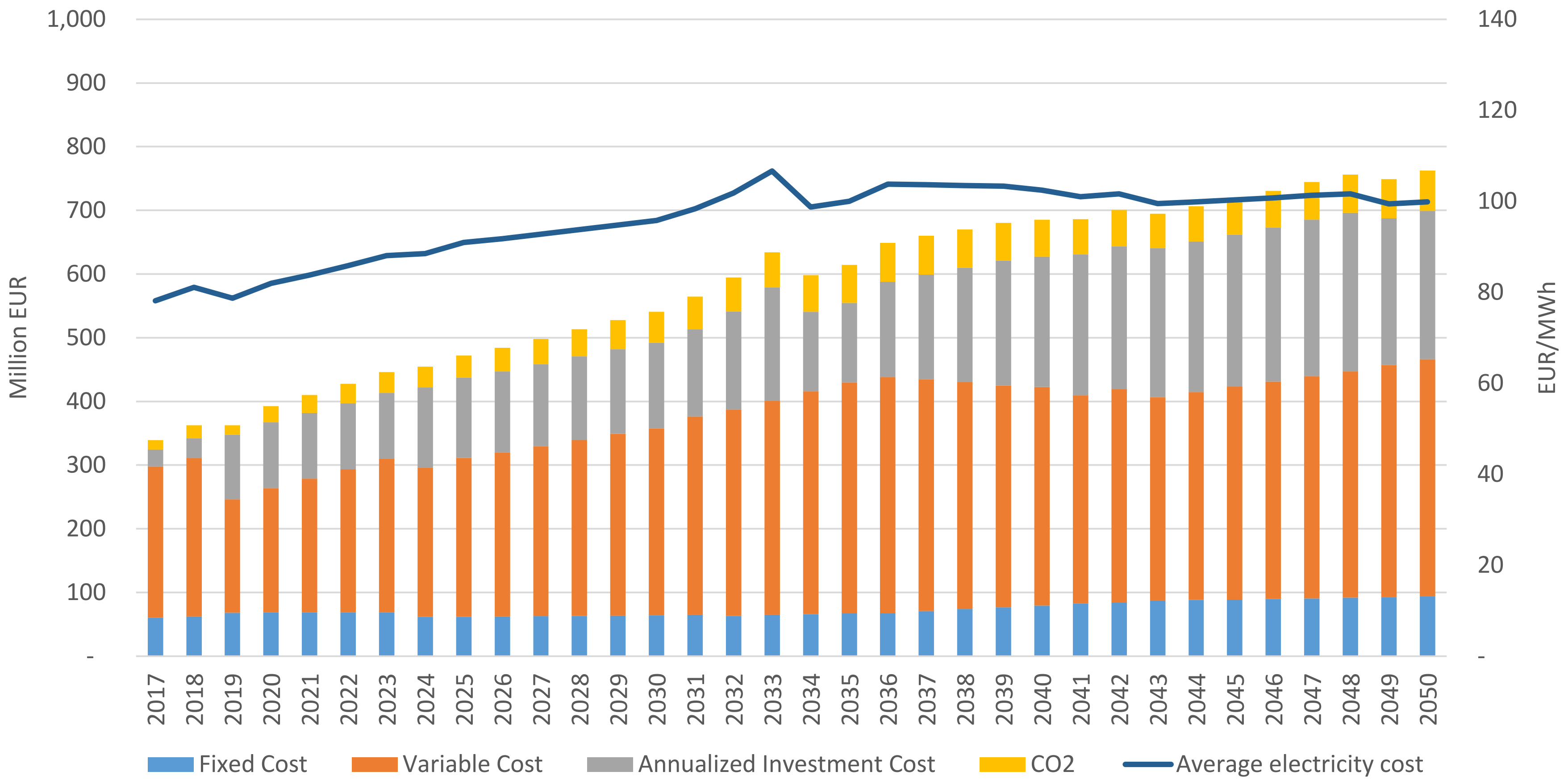


Figure D.2 – – Cost breakdown and average electricity cost in the Delayed Gas Scenario.

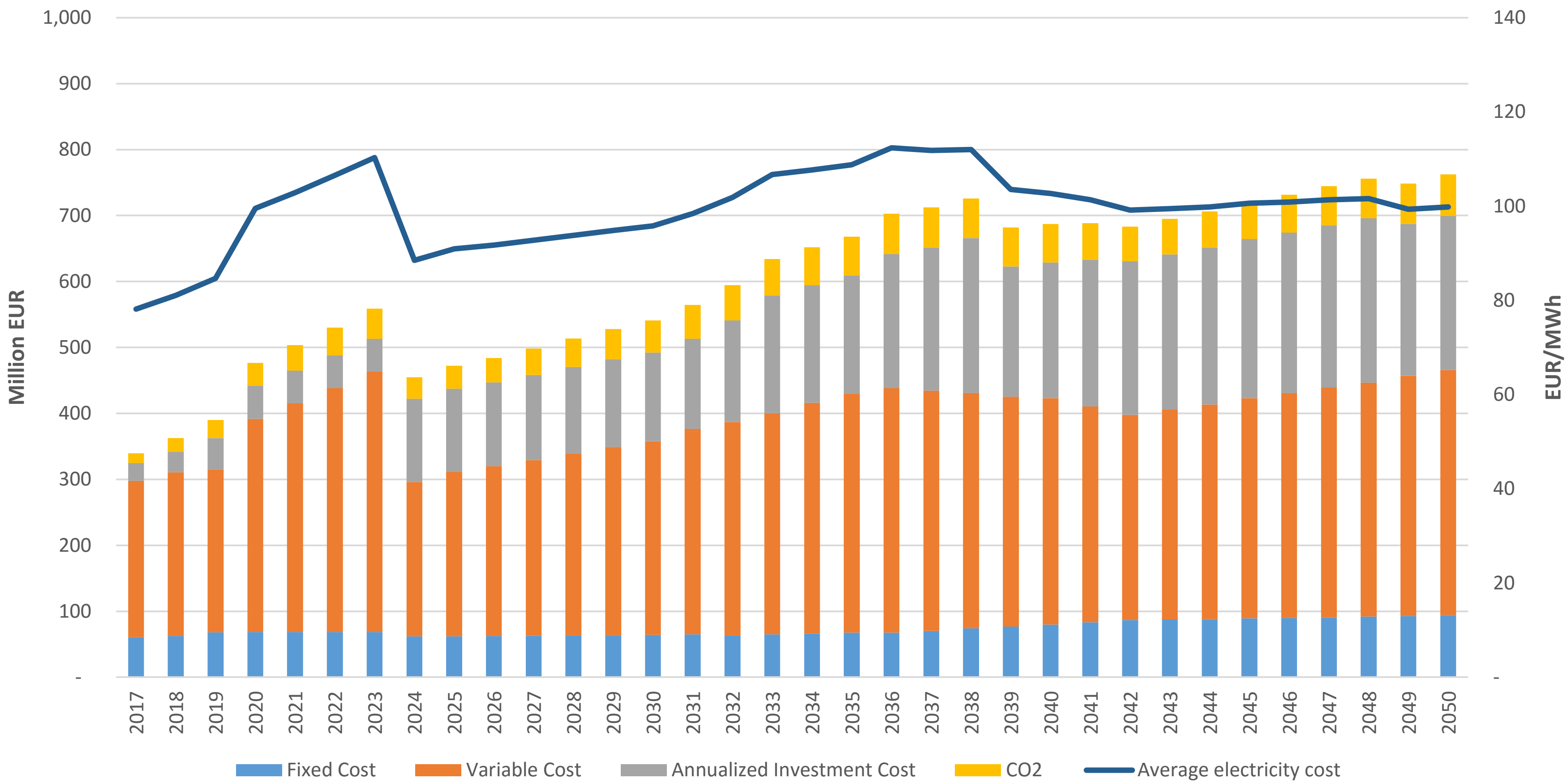


Figure D.3 – – Cost breakdown and average electricity cost in the No Gas Scenario.

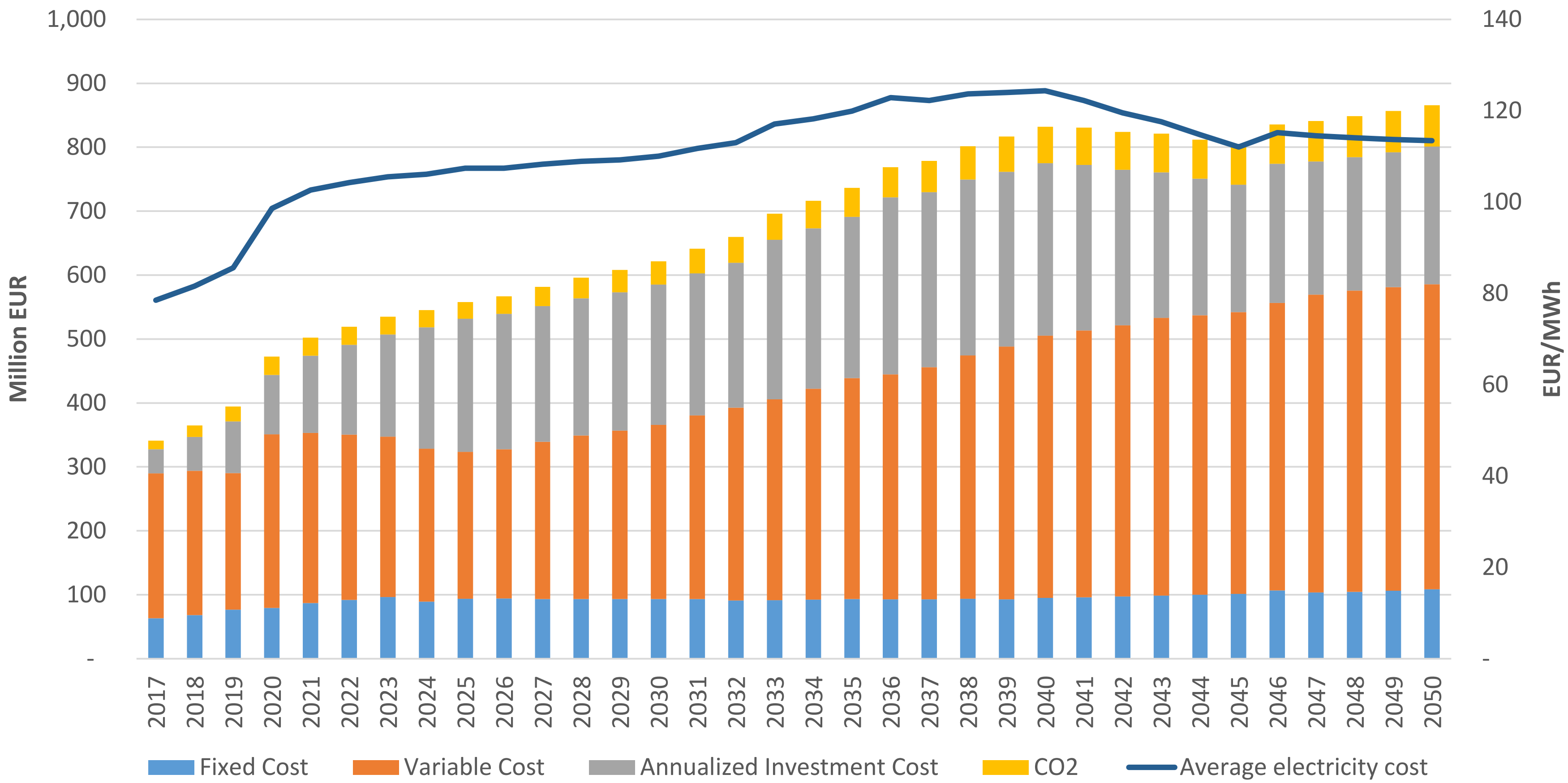


Figure D.4 – Annualized investment cost per technology type in the Reference Scenario.

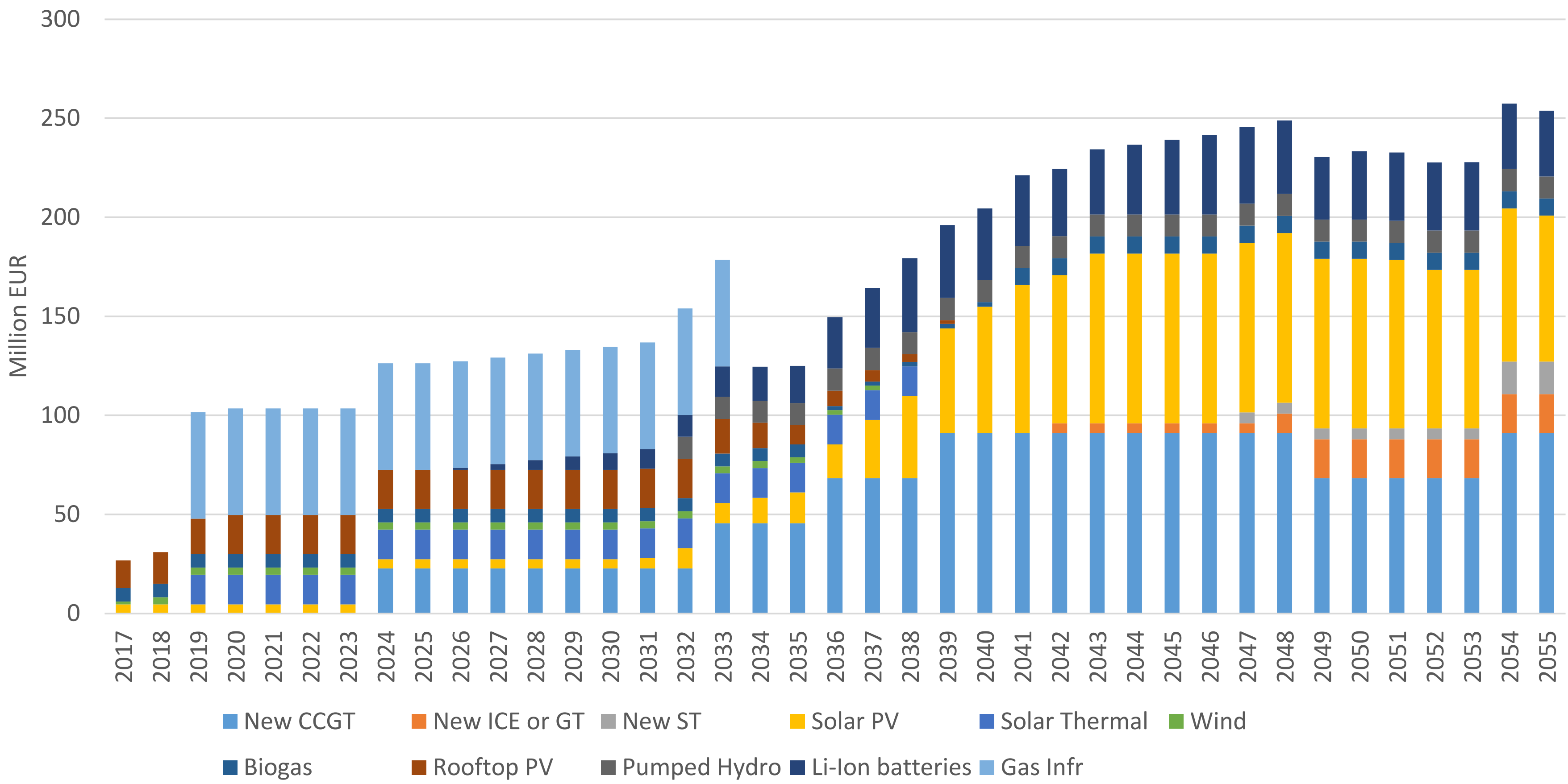


Figure D.5 – Annualized investment cost per technology type in the Delayed Gas Scenario.

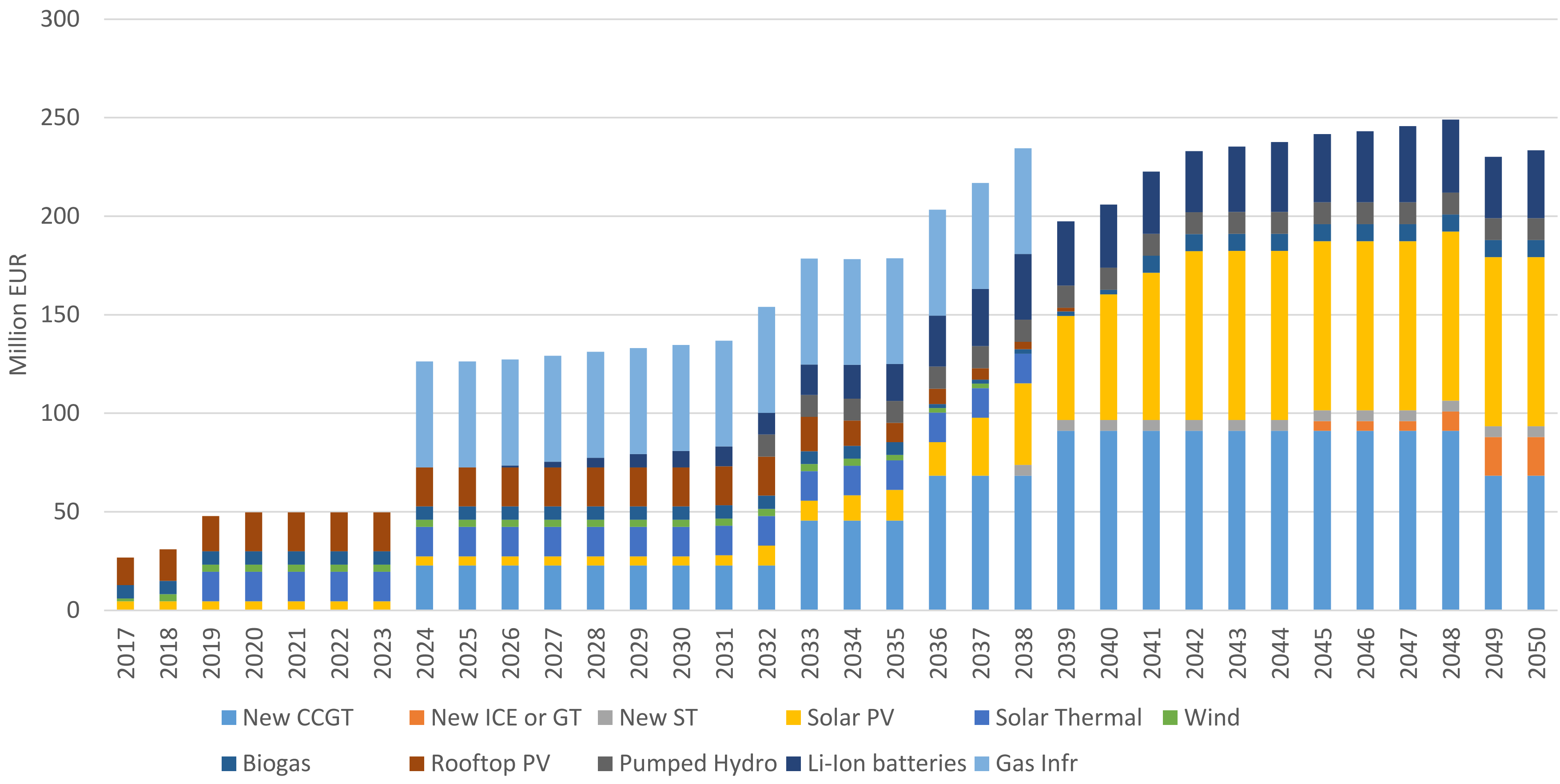


Figure D.6 – Annualized investment cost per technology type in the No Gas Scenario.