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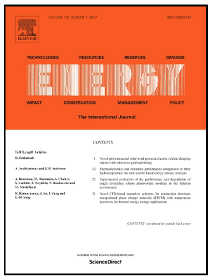

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Renewable Energy Technology integration for the island of Cyprus: A cost-optimization approach

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Abstract
In light of the ongoing financial crisis, Cyprus is called to transform its energy sector. The high electricity cost has been recognized as a priority issue and authorities on the island are considering several available options to reduce electricity tariffs. A fuel switch from oil to gas, domestic or imported, an electrical cross-border interconnection and a rapid increase in the share of renewable energy are among the major options being considered. Focusing on the power supply of Cyprus, the present study uses a cost-optimization tool to investigate the impact of different combinations of policy decision, resulting in a series of different scenarios, with some common key findings, with the aim of directly informing future energy policy decisions. Results indicate that renewable energy technologies will play a major role regardless the decisions taken. However, a set of enabling regulatory and market changes on the horizon might prevent least-cost deployment of renewables to take place. This study will review the findings and make some recommendations on the achievement of this optimal pathways for the evolution of Cyprus electricity sector.

Keywords: Renewable energy; cost-optimization; Cyprus; power supply optimisation; scenarios; energy policy; electricity markets; MESSAGE.

1. Introduction

The Republic of Cyprus is confronted with significant decisions about how energy infrastructure, particularly in the power sector, should develop in the coming decades. As this island-country presently imports all of its required oil products, 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 EU renewable energy targets for 2020 and achieving the national aspirational goals for 2030.

There are certain aspects that make the case of Cyprus particularly interesting. First, the electricity supply system of the island is completely isolated, as there are currently no interconnections to the electrical grids of neighbouring countries (a grid interconnection, the EuroAsia Interconnector, between Israel, Cyprus and Greece is currently under investigation [1]). Therefore, Cyprus needs to meet its electricity demand at all times using domestic generation resources, and faces more challenges for integrating a high share of variable renewable energy technologies in the power grid, due to the low inherent flexibility of the system.

At present, thermal power generation in Cyprus relies on heavy fuel oil (HFO) and to a lesser extent diesel. Both fuels are imported, which exposes the price of electricity to international oil price fluctuations. In the current low oil price environment in early 2015, power system planning may be induced into maintaining such a reliance on HFO. On the other hand, recent discoveries of offshore natural gas reserves in the exclusive economic zone of Cyprus might eliminate the necessity for importing oil products for generating electricity, improving the trade balance and reducing cost of power generation. The extent of the estimated volumes of potential gas reserves provide a strong incentive for the government to evaluate a range of options, including the prospect of exports, for which an onshore gas liquefaction terminal was the key option discussed in 2014. It is presently expected that production of indigenous natural gas could commence by 2022.

In order to reduce the price of electricity until domestic natural gas extraction commences, the Government of Cyprus is considering an interim solution, in which gas may be imported up to 2023, due to its comparatively lower price than oil and the ability to use existing highly efficient combined cycle gas turbines. However, important investments in infrastructure (for instance, a regasification terminal or gas pipelines from Israeli offshore gas fields to the power plants) will be required in such a scenario.

Due to the uncertainty and risk associated with any such set of decisions, energy planners must consider a wide set of scenarios. The primary aim of this paper is to examine the cost-competitiveness and provide insights on the future role of renewable energy technologies in the electricity mix, ensuring a cost-optimal power supply mix that takes into account policy targets. The paper can be considered as an academic summary of an assessment conducted directly for the Ministry of Energy, Commerce, Industry and Tourism (MECIT) of the Republic of Cyprus [2], in response to a request for assistance to the International Renewable Energy Agency (IRENA). The impetus for the analysis includes three main drivers. The policy driver is the EU renewable energy target for Cyprus in 2020 (Directive 2009/28/EC), and the country's own aspirational targets for 2030. The economic driver is the need to reduce the high power generation cost that has been observed in recent years on the island [3]. The geopolitical driver is linked to the reduction of import dependency so as to strengthen the country's energy security.

An optimization model, based on WASP, has previously been employed to examine effects on the country's electricity cost by the set 2020 renewable energy target [4]. This model focused solely on electricity generation. Additionally, a model of Cyprus for the entire energy system exists within a regional model, which is used for informing energy policy decisions of the European Union [5]. However, not all the assumptions used are clearly stated, which does not allow replication of the analysis. In the present study, a quantitative assessment making use of a cost-optimization approach is employed to investigate plausible pathways for the development of the power sector in Cyprus for a set of scenarios. To this end, building on existing work [6], an electricity supply model is developed using the long-term energy modelling platform called Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) [7].

Section 2 of the paper presents the basic structure of the constructed model and describes the scenarios that have been formulated for the purposes of this study. In addition, since a model's outputs are heavily reliant on the inputs, the key assumptions are briefly discussed in this section. Main results and a scenario comparison are shown in section 3, while a short sensitivity analysis is also included. In section 4 the key insights that can be extracted from the results are discussed along with highlights regarding implications for policy makers. The paper ends with a summary of the study's conclusions in section 5.

2. Methodology

2.1 Model development

The analysis is based on a previously developed model [6] and constructed in MESSAGE [7][1]. MESSAGE is a dynamic multi-period optimization model for medium to long term energy system planning, energy policy analysis and scenario development. It minimizes total discounted energy system cost while ensuring that all energy demands, system constraints and policy objectives are met. It does so by accounting for the vintage structure of the stock of existing plant and equipment and related infrastructure, the domestic energy resource endowment, energy trade links and prices, specific technology options for both capacity expansion and replacement of retired units, and relevant energy policy constraints and objectives. The model is a web of chains linking energy sources, supply, transmission and demand-side technologies, thus enabling the user to construct a mathematical image of an energy system, i.e., from resource extraction to final energy use (Figure 1).

In order to allow for a more detailed representation of the power infrastructure on the island, the model is updated to account for all existing and future power generating technologies. Thermal power plants are disaggregated by fuel and technology (e.g. steam turbine, gas turbine etc.).

2.2 Current system status, future plans and key assumptions

The most recent installations of Combined Cycle Gas Turbines increased the total installed power generation capacity to approximately 1685 MW, of which 1478 MW are operated by the Electricity Authority of Cyprus at the sites of Vasilikos, Dhekelia and Moni (Table 1). This capacity provides a sizable reserve margin; recorded fifteen-minute peak demand transmission system generation was just below 1000 MW in 2012 and 815 MW in 2013 (total load approximated as 839 MW - Transmission System Operator - Cyprus, 2014b, 2014c). Recently, reserve capacity has increased due to the economic downturn and its dampening effect on electricity demand; maximum system demand in 2010 was 1148 MW [10].

Once natural gas becomes available, either through domestic production or an interim solution, as a result of provisions made in the plant, the units at the Vasilikos site can switch to this fuel instead of diesel and heavy fuel oil. As such, infrastructure already exists in place to accommodate for the potential arrival of this fuel.

Beyond the existing installed technologies, there are a number of additions that are either committed or assessed. These include a committed wind installation of 30 MW, a committed solar thermal (CSP) facility of 50 MW with graphite as a storage medium (for 12 hours), and an expected annual installation of 15 MW up to 2020 in solar PV under a net metering scheme[2]. For the purposes of this study and after indications from the Ministry of Energy, Commerce, Industry and Tourism (MECIT), the net metering annual additions of 15 MW are considered as committed projects in all scenarios. This is based on the assumption that the savings offered through net metering will be recognized by utility customers and the maximum threshold will be reached in all years until 2020.

[1] MESSAGE, originally developed at the International Institute for Applied Systems Analysis (IIASA), has been widely applied for global energy assessments and climate change mitigation analyses. The model is also used by the International Atomic Energy Agency (IAEA) for energy planning capacity building and numerous national and regional energy systems analyses in IAEA Member States.

[2] In the past, the Republic of Cyprus had in place the highest Feed-in Tariff for solar PV in the European Union [11], but at present new installations fall under a net metering scheme, if eligible.

2.2.1 Demand projections

Final electricity demand projections are taken from a separate assessment developed as part of the IRENA assistance to Cyprus, developed by the Cyprus University of Technology (CUT) [2]. Projections, based on an econometric model, for eight different categories of consumers are aggregated to five (transport, industrial, residential, service and agricultural demands) and used as input in the MESSAGE model. The following two demand scenarios are considered:

a. Energy Efficiency - where it is expected that already planned measures of energy efficiency and Nearly Zero Energy buildings are adopted. This is in line with Cyprus TSO's electricity demand forecast 2014-2023; this scenario reflects the impact of the new directives (Directive 2010/31/EU) on energy efficiency.

b. Extra Efficiency - which assumes a substantial decoupling of electricity demand and economic activity, especially as the levels of electricity consuming equipment in most economic sectors are approaching saturation, and adoption of aggressive policies on energy efficiency and Nearly Zero Energy buildings legislation.

Figure 2 illustrates how electricity demand by customer category is expected to evolve up to 2030 in both scenarios.

Cyprus experiences hot summers and relatively mild winters. As such, electricity demand varies significantly throughout the year. In order to capture seasonal and daily load variability in as much detail as possible, a single year is broken down into a number of time-steps, based on recorded generation in 2012 [8]. Seven seasons have been identified in the present model (Figure 3). The length of each season varies according to the average demand of the period. For example, season 5, which starts on July 16th and ends August 11th, (27 days) has the highest demand in the year (a peak of 997 MW, a low of 468 MW and an average demand of 732 MW), whereas season 3 starts on March 22nd, ends on June 5th (76 days) and has the lowest demand in the year (a peak of 603 MW, a low of 298 MW and an average demand of 430 MW). Additionally, days in each season are broken down into weekdays and weekends, while each day is further divided into six (in the case of weekdays) or three (in the case of weekends) representative segments.

2.2.2 Renewable energy targets

As a European Union member state, Cyprus has to comply with the agreed renewable energy target of 13% in final energy consumption as defined by the Directive 2009/28/EC. This target has been disaggregated for the power sector up to 2020 [12], as shown in Table 2, but no target has been set beyond 2020. Nonetheless, an estimation of the aspirational renewable energy share for the period 2021-2030 has been provided by the government and has been used in the model as shown below. It is important to clarify that the 2030 target has not yet been revised following the recent agreement of a total contribution from renewables of 27% by 2030 across the European Union [13]. Further key modelling assumptions are presented in a supplementary article to this paper [14].

2.3 Scenario definitions

As a first step in the analysis, a baseline of the existing power system is formulated to adequately represent the current status. The potential major infrastructure developments are then combined to define a number of scenarios, as shown in Table 3 and Figure 4.

The significance of the above attributes for the analysis and their effect on the power supply system can be summarized as follows:

Energy Efficiency versus Extra Efficiency demands: As shown in Figure 2, Extra Efficiency demands follow a lower growth rate and remain below the 4 TWh level for the majority of the model period. As such, a lower demand in SC2 implies that investments in electricity generation will be reduced as compared to the other scenarios.

Interim Gas Solution: In all scenarios, with the exception of SC1, it is assumed that the negotiations regarding arrival of natural gas for the period 2016-2022 will be successful. In this case, all the units at the Vasilikos power plant will shift from heavy fuel oil and diesel to natural gas.

Electricity Storage and Interconnector: As explained in section 2.2.4.3, storage is assumed to become necessary beyond certain levels of wind and solar PV penetration. However, in scenarios where the EuroAsia Interconnector is implemented (i.e. SC5 and SC6), constraints on the maximum amount of solar PV and wind that can be deployed without storage are relaxed and the model is allowed to invest in higher capacities of these two renewable energy technologies, without the need to include electricity storage.

LNG Export Terminal: In case estimations about the volume of gas reserves are confirmed, it is possible that a liquefaction terminal will be built to allow export of liquefied natural gas (LNG). In such a case, a dedicated 200 MW plant will be required to serve the electricity demand of the terminal. Therefore, the island will have to deploy more renewables in order to achieve the set renewable energy targets, as the electricity demand of the terminal will substantially increase the yearly electricity demand of the country.

Domestic gas: Based on the current energy plans, it is estimated that domestic gas will become available for the power sector in 2023. As such, it is assumed that no delay will occur in any of the scenarios.

3. Results

3.1 Scenario analysis

In SC1, where heavy fuel oil remains as the main fuel in the period 2013-2019, strict regulations in regards to industrial emissions come into effect in 2020, forcing a switch from HFO to diesel and low sulphur fuel oil. The situation shifts once again as domestic natural gas production begins in 2022 and is fully introduced for power generation in 2023; at this point all fossil-fired generation is based on natural gas. At the same time, generation from renewable energy sources steadily increases primarily due to their increased cost-competitiveness as investment costs reduce over time. Due to the increasing demand and sizable investments in renewable energy technologies, which have a lower capacity factor that fossil-fuel plants, the installed capacity of the island increases gradually from 1.68 GW in 2013 to 2 GW in 2030 (Table 4). It is important to note that solar PV deployment occurs much faster than in any other scenario, exceeding 400 MW by 2020; this is the only scenario without implementation of an interim gas solution.

Final electricity demand is a key driver for the level of production and mix of technologies chosen by the model. When a lower demand is used in scenario SC2, the results change considerably. Even though in this scenario the interim gas solution is assumed to materialize, conclusions can be made through a comparison with SC1 for the latter half of the assessment period (i.e. 2023-2030). In the extra-efficiency demand scenario, the total volume of electricity generated is considerably lower (Figure 5), which is also reflected in the total installed capacity. Total installed capacity by 2030 is lower by about 350 MW in SC2 as compared to scenario SC1 (Table 4). Even though this scenario implies reduced need for investment in the power sector, benefits should be evaluated against the costs of achieving a lower electricity demand (Figure 5).

While fossil-fuelled generation reaches 4,550 GWh in scenario SC1 in 2030, in scenario SC2 this reduces to 3,200 GWh. At the same time, generation from renewable energy sources drops slightly from 1,570 GWh to 1,260 GWh for the same year.

In scenario SC3 the generation mix and total installed capacity are identical to SC1 by the end of the model horizon (i.e. 2030). However, in SC3 investments in renewables generally occur later in the model period. For instance, in 2020 capacities of solar PV and wind amount to 200 and 175 MW respectively in SC3; the corresponding values for the same year are 427 and 213 MW in SC1. This difference can be attributed to the fact that imports of gas through the interim gas solution in SC3 allow generation at lower costs than currently observed, which will reduce the urgency of investing in RE, without however changing the long term need for shifting Cyprus electricity system towards RE.

In case a liquefaction terminal is developed on the island (SC4), additional installations of renewables will be required for the island to meet its aspirational renewable energy targets. This is apparent in the results of this scenario, where solar PV capacity reaches 688 MW by 2030. In order for the capacity of PV to reach such high levels, capacities of 138 MW are served by storage at the distribution level (Li-Ion batteries). At the same time, in this scenario an additional 33 MW of CSP with storage are installed, further to the committed 50 MW. Similarly, capacity of biomass-fired facilities reaches 40 MW. It should be noted that it would not be surprising if Cyprus requests that the 200 MW gas-fired unit at the LNG terminal be exempted from the country's own energy consumption. Since the LNG terminal may potentially serve the interests of other European Union member states, such an argument may be supported.

Results from SC5 provide interesting insights. In this scenario Cyprus becomes interconnected with Greece and Israel, and as such limitations on variable renewables' capacity are removed and a greater flexibility is given to the model. In this case, installed capacities of PV and wind reach 968 and 372 MW respectively by 2030. As a result, the share of renewable energy generation exceeds 40% by 2030.

Similar to SC5, generation from renewables in a scenario with both an interconnector and an LNG terminal (SC6) exceeds aspirational renewable energy targets in 2030, as within this timeframe, the share manages to reach 33%. Contribution from renewables to the generation mix is comparable to SC4 until 2024 (both scenarios consider development of an LNG terminal), but capacity additions of renewables without storage continue to occur in SC6, due to the assumed flexibility offered by the interconnector. As such, wind capacity reaches 352 MW while solar PV capacity is 998 MW by 2030. As this study does not include a detailed engineering feasibility of how this capacity should be integrated in the grid, the key message is that – unless major technical limitations remain in Cyprus grid – an interconnector would allow for large scale deployment of RE as part of a least-cost power generation mix. Some additional cost might be incurred to deploy measures to integrate such large capacity of variable renewables. However, the cost of such measures will not alter the key message that renewables will play a major role in reducing the cost of electricity generation and in ensuring compliance with global and local emissions limits.

As mentioned above and shown in Figure 5, solar PV at the transmission level is the most cost-efficient renewable technology for Cyprus. Solar PV is the dominant renewable energy technology in all scenarios, with limited contributions from CSP, wind and biomass-fired facilities. Investments in solar

PV are quite high in all scenarios; and remarkably high in scenarios SC5 and SC6, which assume deployment of the EuroAsia Interconnector.

In the case of wind, no expansion occurs in scenario SC2 beyond the committed level of 175 MW. In SC1 and SC3 wind capacity amounts to 251 MW in 2030. In SC5 and SC6 wind capacity in 2030 reaches 372 and 352 MW respectively. Finally, in SC4 wind capacity reaches 275 MW by 2030, which is the deployment limit without storage for that year.

In the case of biomass, minimal new installations occur in scenario SC2, while capacity increases by 18 MW in the higher demand scenarios with and without interim gas solution (SC1 and SC3), 30 MW in the scenarios with the development of an LNG facility (SC4 and SC6) and 14 MW in the scenario with only an interconnector developed (SC5). Biomass-fired facilities are allowed to add a total maximum capacity of 30 MW, which means that with the exception of scenarios SC4 and SC6 this option is not as cost-competitive, based on the assumptions adopted in this study.

Based on scenario results from SC5 and SC6, it could be argued that benefits from a grid interconnection are threefold. First of all, Cyprus gains access to separate power supply systems, from which it can import during periods of peak demand to avoid expensive generation options (as in 2020 – Figure 6) or to cover periodic shortages in supply. Secondly, a higher share of variable renewables can be deployed with lower requirements for storage, as variations in renewable energy generation can possibly be balanced via the grid interconnection. At the same time, exports of electricity can occur (although not explicitly modelled in this analysis), thus preventing curtailment. Finally, by replacing gas-fired generation with renewables, a larger volume of indigenous gas is available for exports. It can thus be seen why the European Union gives such importance in projects of common interest that can expand grid interconnector networks in numerous member states [1].

Despite the fact that the technical feasibility of these high level of variable renewables in the case of interconnection should be further examined in a separate grid analysis, examples of countries with good level of interconnection reaching high shares of variable renewables exist in Europe (e.g. Denmark). The case of Ireland is particularly relevant, being an island as well, and having followed a similar assessment for its large-scale deployment of variable renewable energy technologies (RET) [15]. At first, a long-term energy assessment was carried out, similar to the present study, and was then followed by a resource assessment, identification of potential RE project locations, a dispatching study, a grid stability study and finally a cost-benefit analysis. This approach can be regarded as a best practice for smooth integration of high shares of variable renewables in an island power system.

Regardless of the benefits, two highly significant issues are associated to the electrical interconnection. The first relates to system reliability in the case of an interruption of supply from the cable. The second relates to sovereignty issues, where the Cyprus economy may become dependent on electricity supply from a separate system. This should be looked at in terms of both reliability (operational reserves) and security (capacity reserve). These issues are important and are worth keeping into consideration, although they are outside the scope of this study.

3.1.1 Cost-Competitiveness of Renewable Energy Technologies

In order to assess the cost-competitiveness of renewable energy technologies, a comparison of the renewable energy share in each scenario is provided (Table 5). As described in section 2.2.4, a minimum renewable energy share is defined in the analysis. However, results from the scenarios suggest that renewable energy technologies gain competitiveness when compared to fossil-fired generation, as a result of increasing fuel prices and decreasing RET investment cost.

The share of renewable energy generation achieves and exceeds the compulsory 16% target by 2020 in all scenarios. To an extent this can be attributed to committed projects, such as the 50 MW CSP facility to be commissioned at the end of 2017. Similarly, the Net Metering scheme encourages an annual installation of 15 MW distributed PV at households and public buildings until 2020. In the years 2021-2022 some of the scenarios just manage to achieve the aspirational targets. During this period, the interim gas solution is still ongoing, with the exception of SC1, where diesel and low-S fuel oil are the primary fuel sources.

3.2 Sensitivity analysis

3.2.1 Price of Gas for Power Generation

It is anticipated that the fuel shift from heavy fuel oil and diesel to natural gas for power generation will lead to a lower generation cost. However, this is linked directly to the price at which domestic consumers (e.g. Electricity Authority of Cyprus for its power plants) will purchase extracted natural gas, and this is primarily a political decision, which is yet to be made. In order to assess how gas price affects the generation mix of the country, a sensitivity analysis is conducted. At first, scenario SC3 is used as a basis and the price of domestic natural gas is adjusted within a range of prices, from a low netback price (EUR 4.5/Mbtu) to a projected market price, as quoted in section 2.2.3 (approximately EUR 9/Mbtu).

The model does not appear to be sensitive to gas price reductions in such a case, which can be attributed to the following reasons. First of all, the aspirational targets for RE generation during 2021-2030, do not allow gas-fired generation to exceed a threshold, even when the price is significantly lower. Secondly, large capacity additions occur up to 2023 in RE generation and as such contribution from renewable technology options remains at high levels throughout the model period. Thirdly, when a market price is used, in the absence of an interconnector, renewables are limited by technical constraints relating to grid stability (see section A.3 in Taliotis et al. [14]). As renewables reach these limits, requirements for storage reduce cost-competitiveness of RE generation. Thus, another round of sensitivity is conducted by taking scenario SC5, thus removing capacity limits on wind and solar PV, and altering the price of indigenous gas.

As shown in Table 6, generation mix becomes more sensitive to the indigenous gas price in case an interconnection occurs. Since in this case a greater flexibility is assumed and storage constraints are lifted in the model, renewable energy technologies are more cost-competitive when the price of gas is high. Specifically, as discussed above, renewables reach a share in generation of 40% by 2030 when a market price is used. If the price of indigenous gas is reduced slightly to EUR 8.3 from EUR 9/Mbtu, assuming moderate implicit gas subsidies due to a lost opportunity for exporting the gas at higher price, renewable energy share reaches 30% by 2030. This means that renewables still manage to exceed the aspirational target of 25% by 2030. However, once the price of indigenous gas decreases to EUR 7.5/Mbtu, generation share of renewables is limited to the aspirational targets. This suggests that indigenous gas prices below EUR 8.3/Mbtu can affect the deployment of renewables.

3.2.2 Renewable Energy Targets

In order to assess whether the renewable energy targets in the period 2021-2030 are the main driving force for investments in renewables, a simple sensitivity analysis has been conducted. The results above indicate that in SC3 the share of renewable energy is very close to that of the minimum target. Therefore, this scenario is altered so that renewable energy targets remain at the compulsory levels as set by the European Union for 2020; 16% of generation for the period 2021-2030. As shown in Figure 7, differences in generation mix are extremely minute.

Cost differences between the two cases are minimal. Investments are higher, while fuel and CO_2 costs are lower in the case with enforced aspirational renewable energy targets, which lead to a marginal total difference of EUR 4 million over the entire model period. This indicates that, based on the assumptions on costs, performance and technical constraints, and assuming proper market conditions are in place, minimal additional investment requirements are needed for the island to achieve its aspirational renewable energy targets, only in one scenario. In all other scenarios, these targets are exceeded based on a purely economic argument.

Even though in previous studies it has been argued that renewable energy technologies would lead to an unavoidable increase in the cost of electricity [4], results from the sensitivity analysis shown here indicate otherwise. This difference can be attributed to the high price of oil experienced in recent years, along with the significant reduction in investment cost of certain technologies; particularly of solar PV.

3.2.3 Low oil price

Following the recent significant decline in international crude oil prices, concerns are being raised as to the cost-competitiveness of renewable energy technologies. In addition to the existing sensitivity analysis presented above and in the relevant report [2], we conduct a short sensitivity analysis on how the generation mix may look like in the medium-term (2015-2020), in case oil prices remain at levels lower than those previously projected. Table 7 below shows the price difference assumption that is investigated in scenarios SC1 and SC3, so as to investigate effects on renewable energy deployment and the competitiveness of the interim gas solution respectively.

We can see from Figure 8 that when a low oil price assumption is used, the deployment schedule of solar PV is altered. In SC1 it is assumed that the interim gas solution negotiations are not successful and the island remains dependent on oil-fired generation; price of oil in this case is based on IEA projections. As such, generation cost from the fossil-fired power plants is high, which triggers a faster rate of investment in transmission-connected solar PV. However, when a low-oil price is assumed, the cost-competitiveness of solar PV is affected significantly. Even though the share of renewables in the generation mix remains above the predefined target, investments are delayed. For instance, in 2018 transmission-connected solar PV contributes to only 5.7% compared to 11.8% when the original oil price assumption from the IEA [19] are used.

In the case of SC3, which assumes a successful negotiation for the interim gas solution, deployment of PV remains the same even with a low oil price assumption. Nonetheless, the financial viability of the interim gas solution is questioned in an environment of prolonged low oil prices. As Table 8 indicates, if crude oil prices remain at low levels, the economic sense of a proposed early fuel shift by means of gas imports may have to be reevaluated. This is a clear indication of the dilemmas faced by energy planners whose systems are highly import dependent and thus vulnerable to fuel price fluctuations. Of course, this aspect is beyond the scope of this study and requires a far more detailed analysis, which cannot be offered explicitly within the context of the present analysis.

4. Discussion

This study is neither about predicting the evolution of the electricity system of Cyprus nor about prescribing preferences for its development. Rather, it attempts to provide insights on the risk and benefits of different scenarios of electricity system development. A clear message from the analysis is that renewable energy technologies can contribute to a future reduction in the generation cost of the system (see Figure 9).

Utility scale solar PV is the most competitive option, but results from the analysis indicate that investments should occur immediately, as the most aggressive savings can be achieved before natural gas becomes available, when the main fuels that will be offset are diesel and fuel oil. This means that a framework needs to be set in place to accommodate smooth integration of high shares of variable renewables. First of all, supporting ancillary services, such as operating reserves or energy storage, are required to reduce risk of an imbalance in the system [16]. It is argued that variable renewable technologies introduce an indirect cost to the power supply system [17]. Nonetheless, improved forecasting methods and state-of-art technologies for provision of grid support services from variable renewables exist that reduce the need for ancillary services, thus achieving lower system costs; these are discussed in detail in the official IRENA roadmap for Cyprus [2].

Furthermore, regulatory reform is often needed to attract investors. A competitive electricity market that offers system flexibility is recognized as a prerequisite for accommodating distributed generation from a number of producers [18]. Such a market structure does not exist yet in Cyprus, despite the European Commission's recommendation that member states should implement all legislative measures towards the design of competitive energy markets [19]. An electricity market is expected to be established in 2016 for Cyprus. However, concerns remain as to how renewable energy technologies will be treated in such a market.

Energy decision makers in Cyprus face a number of short-term challenges - expanding and diversifying electricity generation are among the highest priority. Each of the options – natural gas (imported and/or domestic off-shore), wind, solar PV or continued use of oil products - has different implications for infrastructure development and carries different risks. For examples, low oil prices over extended time periods can undermine the financial viability of otherwise economically attractive natural gas; natural gas imports, although beneficial for the reduction of generation price, will also pose a limit to the share of RE that can be accepted, based on how the import contract will be designed (e.g. setting minimum amounts of gas that will be purchased under a take or pay contract).

Infrastructure investments have inherently long amortization periods. Investing in gas pipelines linking the island to off-shore fields or building regasification plants for LNG imports lacks economic rationale if only operated for just a few years or for limited volumes. It is important to note that, in spite of current temporary reduction in oil prices, deploying RE will reduce the inherent volatility of electricity generation cost in Cyprus, creating a more stable environment for consumers to plan and budget for their energy costs.

Aggressive efficiency measures can reduce the need for investments in generating capacities, but a comparison of the costs of these measures will have to be conducted separately. One aspect that needs further assessment is the technical feasibility of the results, as the threshold set for maximum penetration of variable renewables needs to be set by a dynamic stability analysis of Cyprus power grid. Similarly, the possible need for energy storage under each scenario has not been examined in depth from the operational and technical point of view and neither has grid stability. Both of these aspects will have to be determined through separate studies. Additionally, similar to the case of Ireland [15], identification of sites where large renewable energy projects can be deployed will be relevant in the future. Once the specific sites for large projects are defined, a separate assessment focusing on grid strengthening will prove valuable for efficient system planning. As part of the ongoing grid study, an assessment of the most cost effective manner to integrate large shares of variable RE technologies should be conducted. For instance, this could be achieved through grid strengthening, introduction of centralized or decentralized storage, implementation of smart grids, use of advanced control methods, improvements in forecasting techniques for variable renewables, investments in an interconnection or most likely a combination of these options.

5. Conclusions

The Republic of Cyprus is faced with important decisions that will define the long-term energy outlook of the island. Major investments in infrastructure are imminent, and are expected to change the energy mix and improve security of supply for this import-dependent country. The present analysis develops a long-term cost-optimization model of the electricity supply system of Cyprus. Through a comparison of a range of scenarios, the analysis illustrates that renewable energy technologies have a significant role to play in the transformation of the electricity mix of the island. The share of RET in generation exceeds 25% in all scenarios by 2030; reaching up to 40% in scenario SC5. Deployment of RET is not only necessary for Cyprus to achieve its EU targets, but results suggest that renewable energy technology deployment will also lead to a reduction of power generation cost up to 2023 in all scenarios examined.

The assessed scenarios show that investments in RET and a fuel switch away from oil to gas can decrease electricity generating costs and achieve generation cost savings compared with the current generating mix. These cost savings correspond to about a third of the electricity price of the base year, dropping from about EUR 125/MWh in 2013 to EUR 80-85/MWh for the majority of the model horizon. This reduction can have multiple benefits to the broader economy of the island as the cost of domestic products and services may decrease substantially.

In terms of generation technologies, solar PV is the most competitive renewable option, with large scale deployment expected in all scenarios. Aggressive deployment in the model starts in 2015, calling for immediate action by policy makers. By 2030, capacity additions of more than 400 MW of solar PV occur in scenario SC2, which assumes increased energy efficiency measures, while the value increases to more than 500 MW in the rest of the scenarios. Additions of about 200 MW occur in other RET by 2030 as well. Taking into account that the total installed capacity of the island at the end of 2015 was about 1700 MW, the magnitude of these additions becomes compelling.

Results from this analysis will be used to inform a future revision of the Renewable Energy Action Plan of Cyprus. However, there are certain limitations that have to be recognized. First of all, the model is sensitive to cost assumptions. As such, further sensitivity analysis on various fuel prices and technology costs will provide insights as to the most robust development pathway to be followed. Additionally, the impact of certain technology choices and resulting energy mix to the entire economy is not assessed in any of the scenarios. To achieve this, the technoeconomic model developed could be coupled with a macroeconomic model, which is a planned enhancement for this work.

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Figures

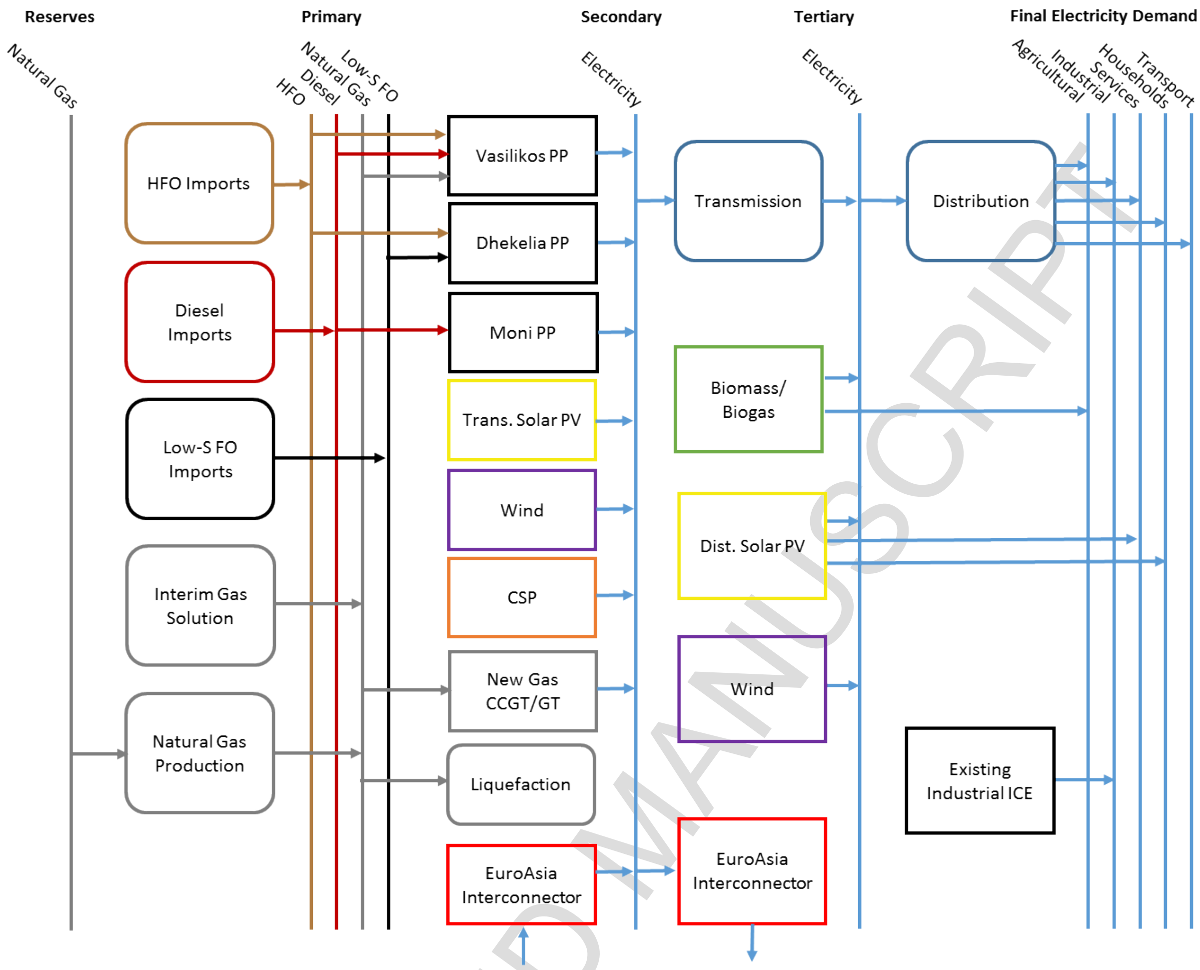

Figure 1. Simplified Reference Energy System of the Cyprus power sector.

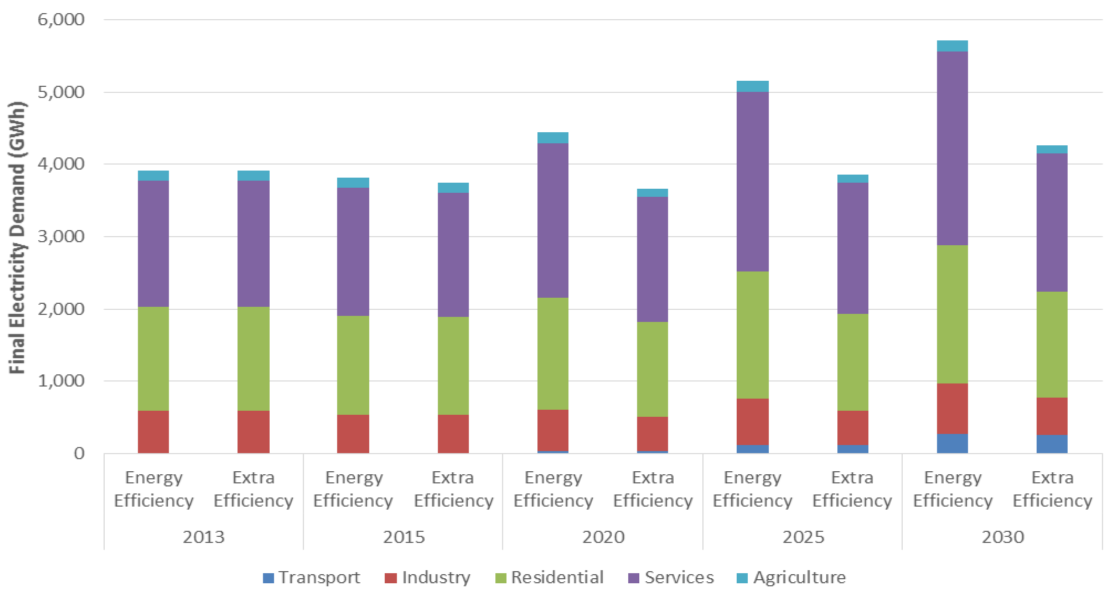

Figure 2. Final electricity demand projections by customer category in the Energy Efficiency scenario and Extra Efficiency scenarios [2].

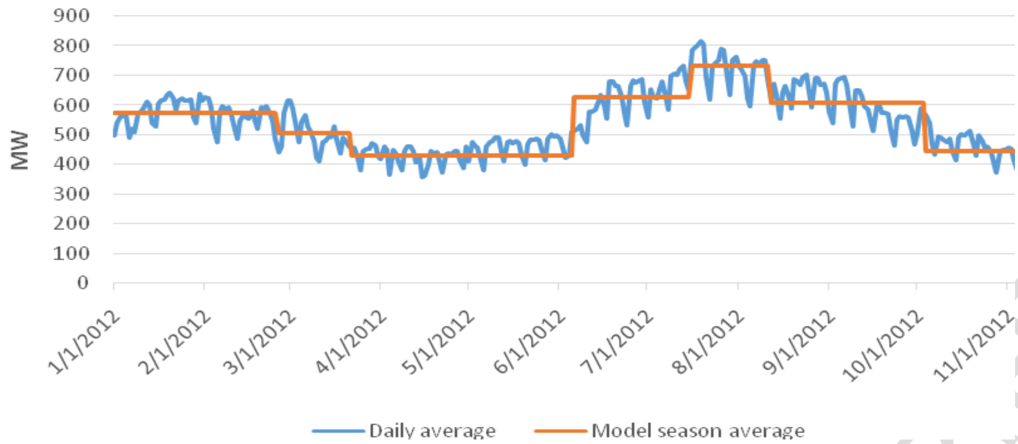

Figure 3. Seasonal variability in demand in 2012 and indication of the chosen 7 seasons

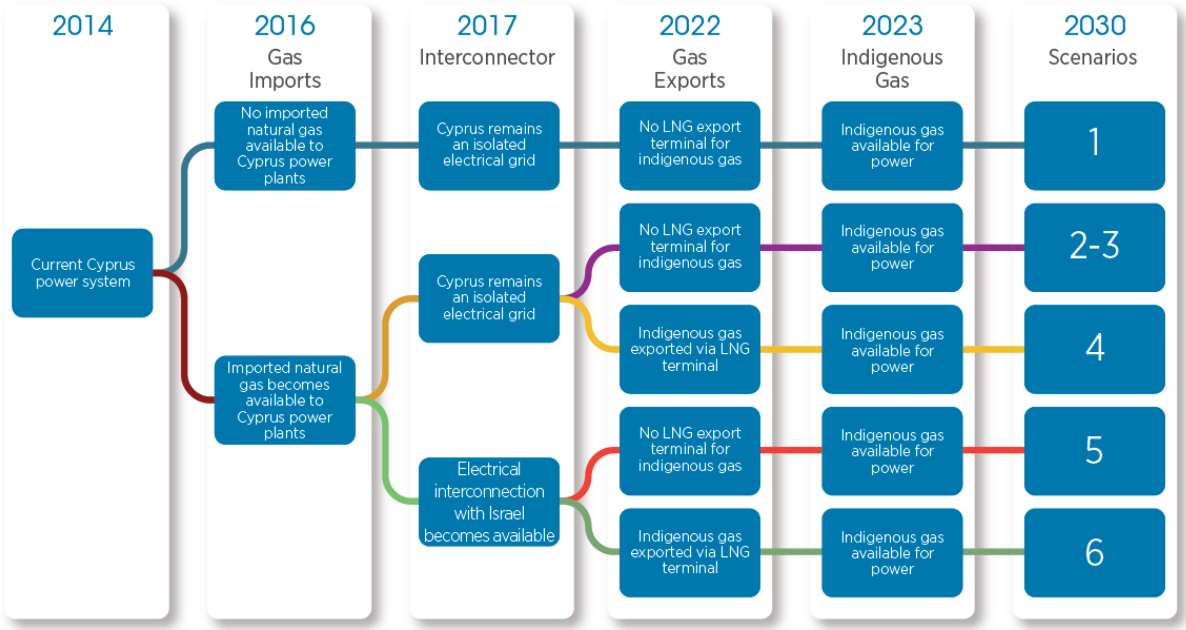

Figure 4. Definition of six scenarios for the evolution of Cyprus electricity system [2]

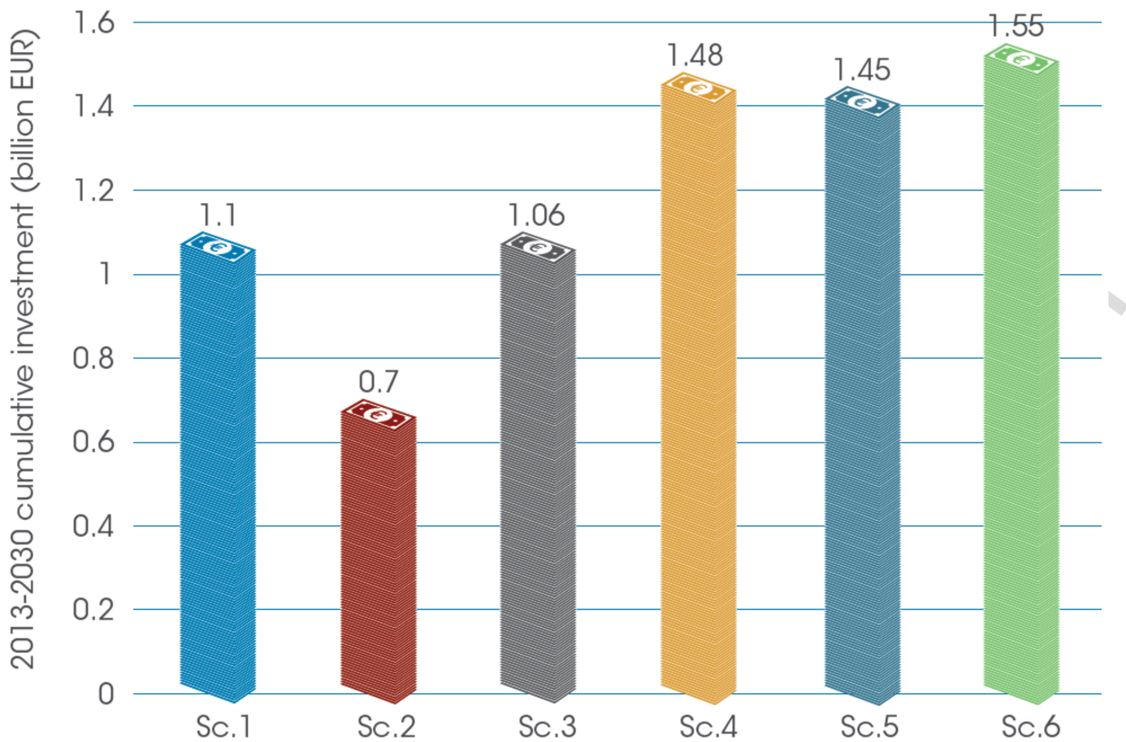

Figure 5 - Investment needs[3] for power generation assets in different scenarios. To be noted the substantially lower needs in scenario 2, where the extra efficiency demand scenario is used (Source: IRENA, 2015 [2]

[3] Billion refers to the short scale of numbering – i.e. 10^9.

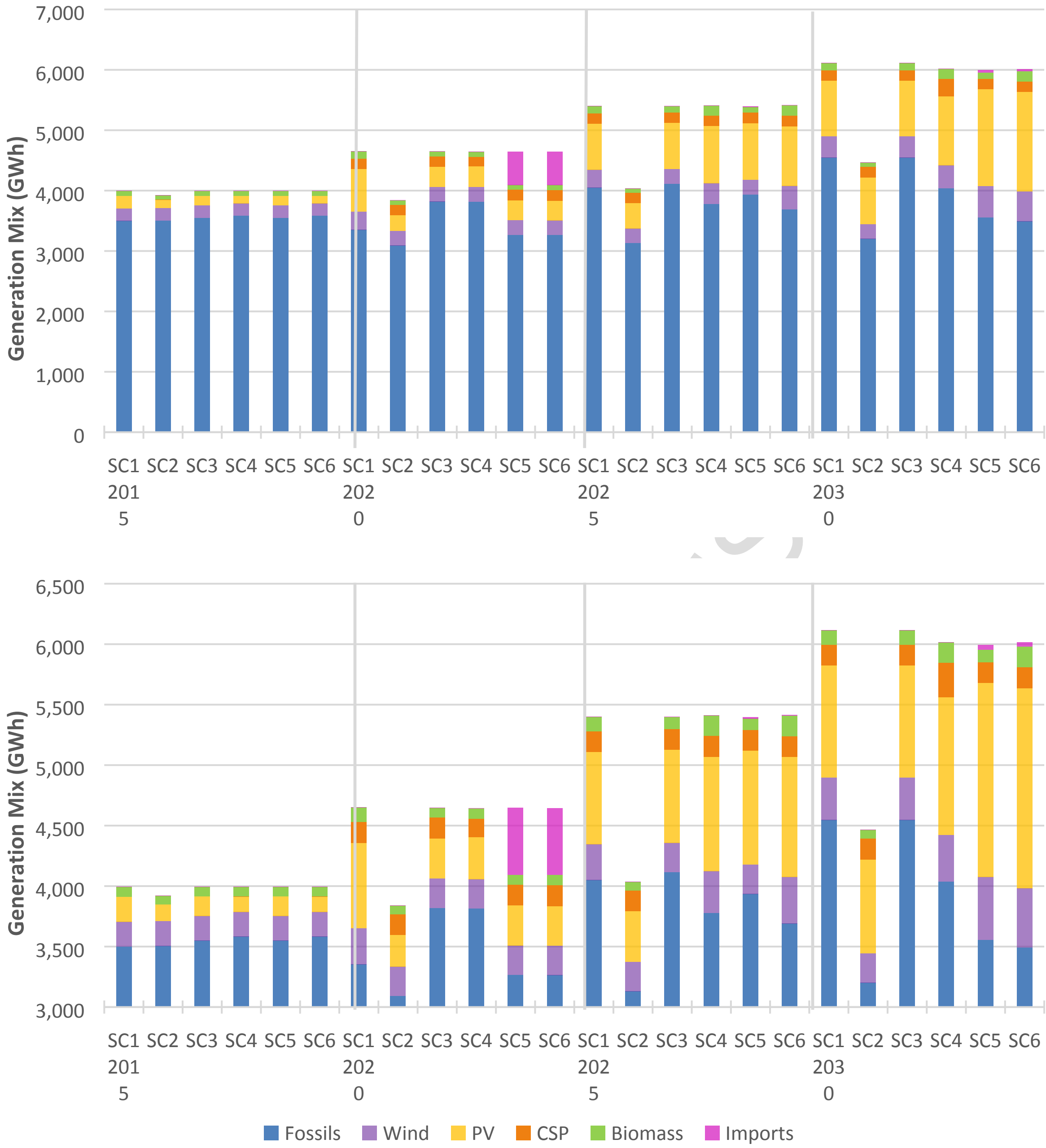

Figure 6. Evolution of generation mix in the six scenarios. The bottom chart provides a more focused overview of differences in renewable energy contribution in different scenarios (self-generation for the LNG terminal is excluded)

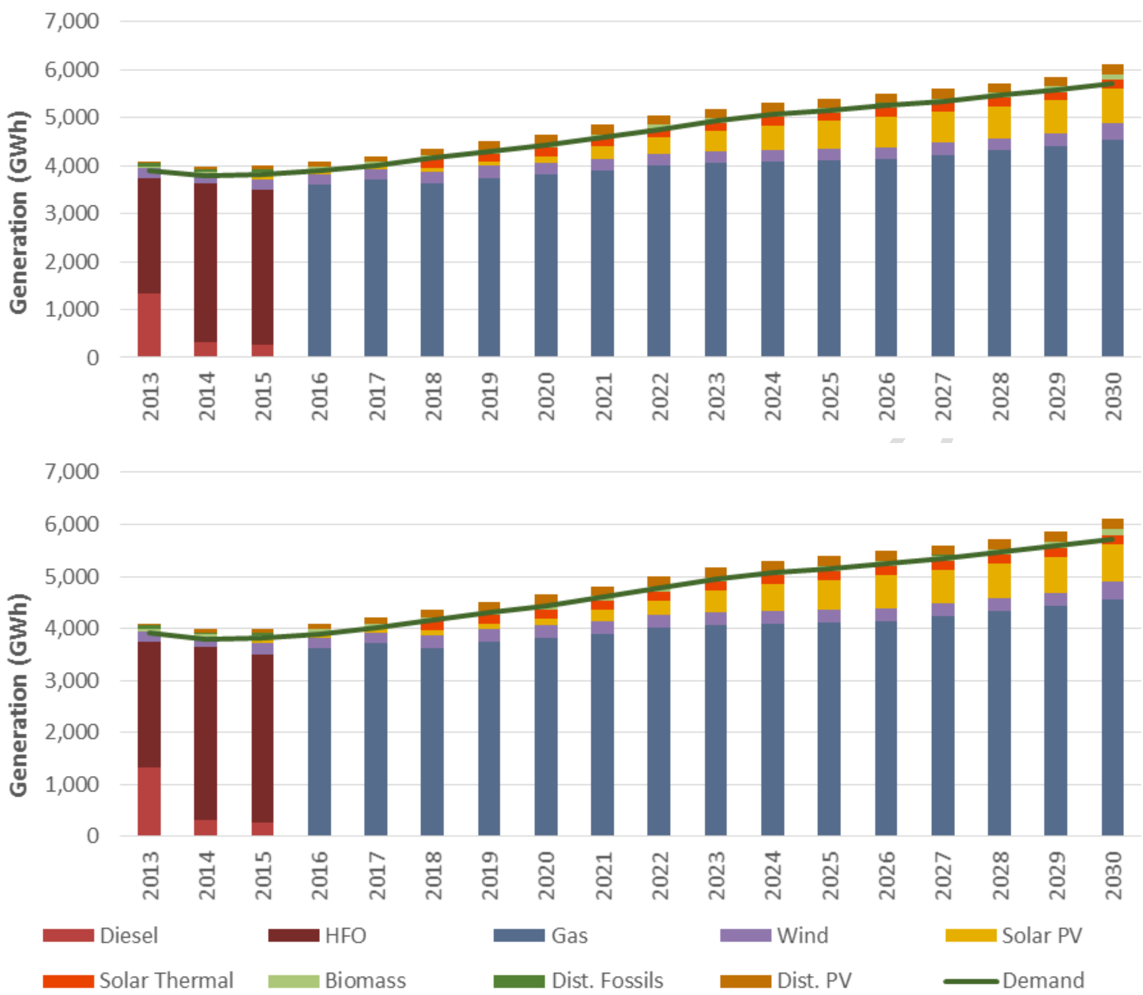

Figure 7. Generation mix in SC3 with (top) and without (bottom) aspirational renewable energy targets

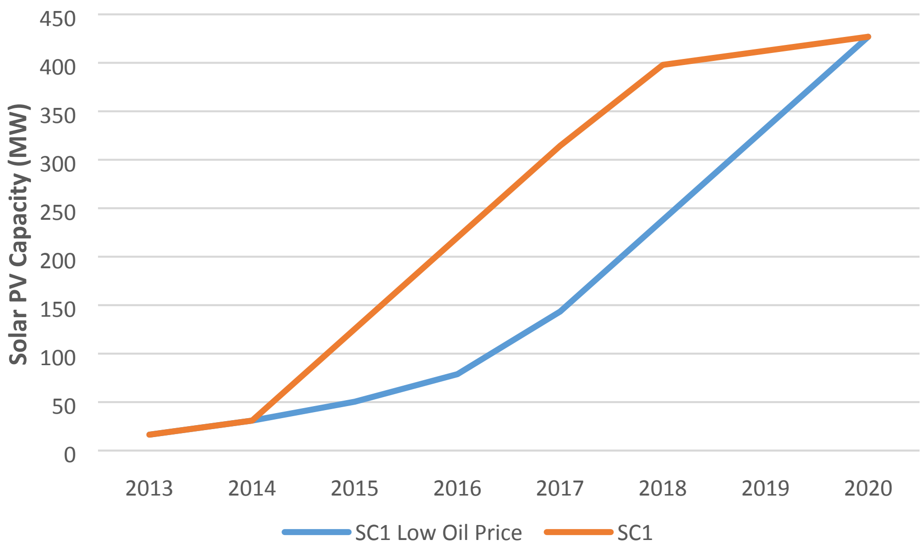

Figure 8. Solar PV capacity evolution with and without a low oil price assumption.

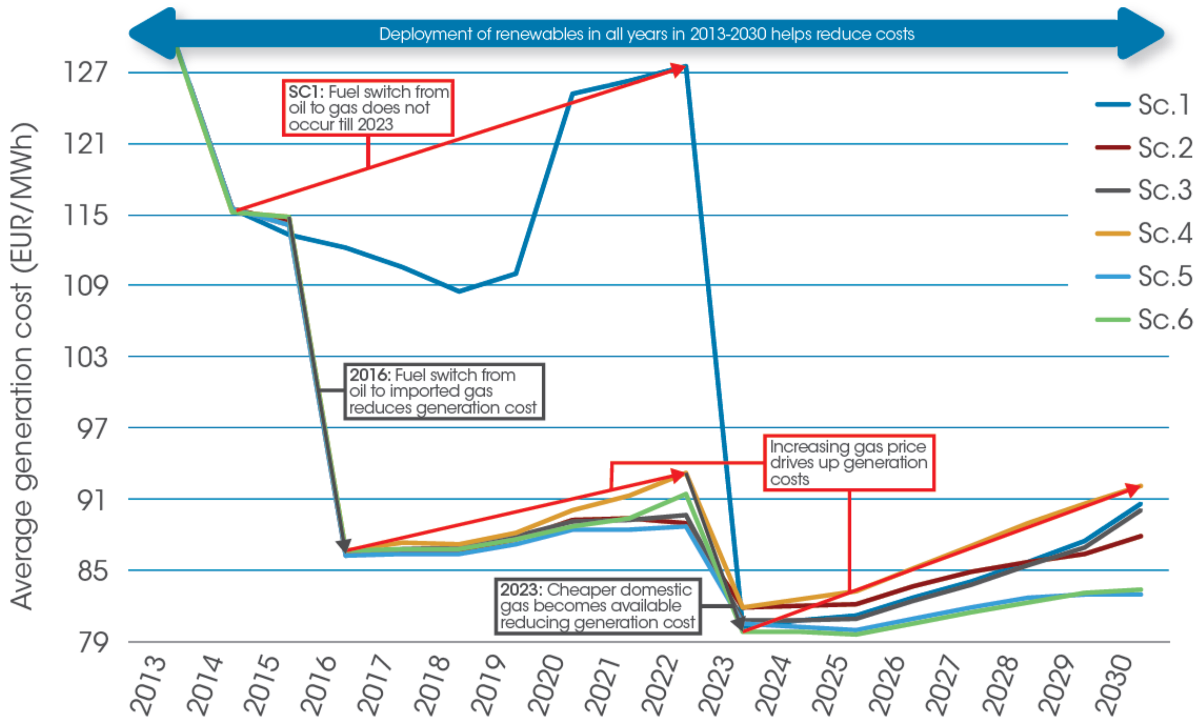

Figure 9 - Evolution of power generation cost in Cyprus under different scenarios [2]

Tables

Table 1. Total installed capacity at the end of 2015 [20], [21]

Installation	Type of Technology	Fuel	Capacity (MW)
Vasilikos	Combined Cycle Gas Turbine[1]	Diesel	440
	Steam Turbine[2]	Heavy Fuel Oil	390
	Gas Turbine	Diesel	38
Dhekelia	Steam Turbine[3]	Heavy Fuel Oil	360
	Internal Combustion Engine[4]	Heavy Fuel Oil	100
Moni	Gas Turbine[5]	Diesel	150
Wind	connected to Transmission	---	157.5
Wind	connected to Distribution	---	2.4
Biomass/biomass	connected to Distribution	---	9.7
PV	connected to Distribution	---	76.5
		Total	**1721.7**

[1] *Consists of 4 gas turbine (75 MW each) and 2 steam turbine units (70 MW each)*
[2] *Consists of 3 units of 130 MW each.*
[3] *Consists of 6 units of 60 MW each.*
[4] *Consists of 6 units of approximately 16 MW each.*
[5] *Consists of 4 units of 37.5 MW each.*

Table 2. Minimum RES contribution to final electricity consumption

2013	2014	2015	2016	2017	2018	2019	2020	2021
6.00%	7.30%	8.40%	9.40%	10.80%	12.40%	14.10%	16.00%	20.06%
2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
21.15%	21.75%	22.26%	22.72%	23.34%	24.19%	24.78%	25.06%	25.29%

Table 3. Attributes considered in each of the scenarios.

Scenario	Energy Efficiency Demand	Extra Efficiency Demand	Interim Gas Solution	Electrical Storage Limitations	Export Liquefaction terminal	EuroAsia Interconnector	Domestic gas for power in 2023
SC1	√			√			√
SC2		√	√	√			√
SC3	√		√	√			√
SC4	√		√	√	√		√
SC5	√		√			√	√
SC6	√		√		√	√	√

Table 4. Total installed capacity evolution in the six scenarios (MW)

		Fossils	Wind	PV	CSP	Biomass	Total
SC1	**2015**	1,509	147	125	0	20	**1,801**
	2020	1,389	213	427	50	28	**2,108**
	2025	1,075	213	460	50	28	**1,826**
	2030	1,113	251	559*	50	28	**2,001**
SC2	**2015**	1,509	147	85	0	17	**1,758**
	2020	1,389	175	157	50	17	**1,789**
	2025	1,075	175	252	50	17	**1,569**
	2030	943	175	468	50	17	**1,653**
SC3	**2015**	1,509	147	98	0	19	**1,773**
	2020	1,389	175	200	50	19	**1,834**
	2025	1,079	175	463	50	24	**1,792**
	2030	1,113	251	559*	50	28	**2,001**
SC4	**2015**	1,509	147	77	0	19	**1,751**
	2020	1,389	175	210	50	20	**1,844**
	2025	1,075	248	571	50	40	**1,983**
	2030	976	275	688**	83	40	**2,062**
SC5	**2015**	1,509	147	98	0	19	**1,773**
	2020	1,389	175	200	50	19	**1,834**
	2025	1,075	175	568	50	22	**1,890**
	2030	943	372	968	50	24	**2,356**
SC6	**2015**	1,509	147	77	0	19	**1,751**
	2020	1,389	175	198	50	20	**1,833**
	2025	1,075	277	598	50	40	**2,039**
	2030	943	352	998	50	40	**2,382**

*9 MW of distributed solar PV are deployed with storage (i.e. Li-Ion batteries)
**138 MW of distributed solar PV are deployed with storage (i.e. Li-Ion batteries)

Table 5. Share of renewable energy generation in each scenario as compared to the renewable energy targets (underlined values exceed the predefined renewable energy target)

	SC1	SC2	SC3	SC4	SC5	SC6	RE target	
2013	6.5%	6.5%	6.5%	6.5%	6.5%	6.5%	6.0%	**Compulsory**
2014	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.3%	
2015	12.4%	10.6%	11.2%	10.3%	11.2%	10.3%	8.4%	
2016	16.5%	11.5%	11.5%	10.9%	11.5%	10.9%	9.4%	
2017	21.6%	12.2%	11.8%	11.4%	11.8%	11.4%	10.8%	
2018	28.0%	18.4%	16.8%	16.6%	16.8%	16.6%	12.4%	
2019	27.9%	18.9%	16.8%	16.8%	16.8%	16.8%	14.1%	
2020	27.9%	19.5%	17.8%	17.9%	17.8%	17.9%	16.0%	
2021	27.5%	*20.1%*	*20.1%*	*20.1%*	*20.1%*	*20.1%*	20.1%	**Aspirational**
2022	27.0%	21.8%	*21.2%*	*21.2%*	*21.2%*	*21.2%*	21.2%	
2023	26.0%	*21.8%*	*21.8%*	22.7%	22.9%	22.7%	21.8%	
2024	25.4%	*22.3%*	22.9%	23.2%	24.8%	23.3%	22.3%	
2025	25.0%	*22.7%*	23.8%	23.7%	26.9%	24.9%	22.7%	
2026	25.9%	*23.3%*	24.6%	24.3%	28.9%	26.4%	23.3%	
2027	25.7%	*24.2%*	24.5%	25.2%	30.7%	27.9%	24.2%	
2028	25.5%	26.1%	*24.8%*	25.9%	32.4%	29.3%	24.8%	
2029	25.3%	28.6%	*25.1%*	26.1%	36.4%	30.6%	25.1%	
2030	25.6%	28.3%	25.6%	26.4%	40.1%	33.2%	25.3%	

Table 6. Share of gas-fired and RE-based generation as a function of gas price in SC5

							Market price	
	EUR 4.5/Mbtu		EUR 7.5/Mbtu		EUR 8.3/Mbtu		~EUR 9/Mbtu	
	Gas	Renewables	Gas	Renewables	Gas	Renewables	Gas	Renewables
2023	78%	22%	78%	22%	78%	22%	77%	23%
2024	78%	22%	78%	22%	78%	22%	75%	25%
2025	77%	22%	77%	23%	77%	23%	73%	27%
2026	77%	23%	77%	23%	76%	24%	71%	29%
2027	75%	24%	76%	24%	75%	25%	69%	31%
2028	75%	25%	75%	25%	73%	27%	67%	32%
2029	74%	25%	74%	25%	71%	28%	63%	36%
2030	74%	25%	74%	25%	69%	30%	59%	40%

Comment: 1% Difference in some years relates to the import of electricity

Table 7. Crude oil low price assumption as compared to IEA projections for 2015-2020.

		2015	2016	2017	2018	2019	2020
US $/barrel	IEA projections [22]	110.5	111	111.5	112	112.5	113
	Assumed low oil price	60	65	75	85	95	113

Table 8. Share of heavy fuel oil versus gas-fired generation during 2016-2020.

	SC3		SC3 Low Oil Price	
	Heavy fuel oil	Gas	Heavy fuel oil	Gas
2016	0%	88%	82%	0%
2017	0%	88%	80%	9%
2018	0%	83%	20%	63%
2019	0%	83%	11%	73%
2020	0%	82%	0%	82%

Renewable Energy Technology integration for the island of Cyprus: A cost-optimization approach

Highlights

- Renewable energy technologies are currently cost-competitive in Cyprus.
- Transmission-connected solar PV is already the most competitive generation option.
- Price of natural gas may affect the share of renewable energy.
- Investments and political decisions are called for immediately.
- The analysis will assist in revising the Renewable Energy Action Plan of Cyprus.

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