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Renewable Energy Roadmap for the Republic of Cyprus

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Cover photo: An old wind pump next to Faneromeni Church, Nicosia, Cyprus (Emanuele Taibi / IRENA).

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for interna¬tional cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowl¬edge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

Acknowledgements

Key components of the analysis have been developed by the Swedish Royal Institute of Technology (KTH) and the Cyprus University of Technology (CUT), respectively for electricity supply and energy demand scenarios. The report benefited from comments and guidance from Dolf Gielen, Director of IRENA Innovation and Tech¬nology Centre, along with the contributions of all members of the roadmap working team, as listed below.

This report has been made possible by a voluntary contribution from the Government of the Federal Republic of Germany. This roadmap was developed by IRENA, in cooperation with the Ministry of Energy, Commerce, Industry and Tourism (MECIT) of the Republic of Cyprus.

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Renewable Energy Roadmap for the Republic of Cyprus

Foreword: Republic of Cyprus

Cyprus has one of the highest electricity prices in Europe, due to high reliance on liquid fuel for power generation. However, a major transition is imminent for electricity supply. On one hand, indigenous natural gas discoveries are to be developed in the coming years. On the other hand, the costs of renewable power supply options have fallen dramatically. Meanwhile, concerns about greenhouse gases and local pollutants have increased, reflecting stringent European Union regulations.

Renewable energy offers a way for Cyprus to reduce both the cost and the environmental impact of generating electricity. In the wake of the recent economic recession, turning to renewables can help to reduce fuel imports, strengthen the trade balance and create local jobs. The success of solar water heaters, for example, can be replicated for solar photovoltaics (PV).

Cyprus has set out to attain a higher share of renewables, and this roadmap helps to assess optimal investment strategies in the power sector. Solar PV and wind power will play a major role in the roadmap to 2030. Roadmap findings will play an important role to revise existing energy policies and develop new ones.

As part of the same engagement, the energy planning model used to quantify the possible pace and benefits of renewable energy deployment given different conditions has been handed over to the Government of Cyprus. The model will remain an important tool for assessing future energy policies and examining different energy pathways. It will assist in determining the optimal penetration of renewable energy for electricity supply and in identifying the technical and economic potential for further increasing electricity production from renewable energy.

We would like to thank IRENA for this support and look forward to a continued close cooperation in the future.

H.E. Yiorgos Lakkotrypis
Minister of Energy, Commerce,
Industry and Tourism
Republic of Cyprus

Foreword: IRENA

The versatility, the diversity and, increasingly, the cost-competitiveness of renewable energy make such sources essential for energy security and access around the world. For islands, in particular, clean, indigenous renewable energy is inherently more attractive than costly fossil-fuel imports. Countries such as Cyprus, which depend heavily on imported petroleum products, are investing in clean energy sources to provide affordable energy, green jobs and modern supply chains, while contributing to reducing greenhouse-gas emissions in the post-2015 world.

As an active participant in global efforts to ensure a sustainable energy future, the Republic of Cyprus has engaged with the International Renewable Energy Agency (IRENA) to develop a renewable energy roadmap for the country. The Ministry of Energy, Commerce, Industry and Tourism, along with a range of stakeholders, has worked closely with IRENA to examine least-cost pathways for the evolution of the power generation mix, the increasing role that renewable energy will play within it, and the impact of key decisions on energy policy that Cyprus is confronted with making today.

I trust this roadmap will prove useful in the country's pursuit of accelerated renewable energy deployment. As our world strives for a future based on clean, secure and affordable energy for all, Cyprus can be the lighthouse that helps illuminate the course for others.

Adnan Z. Amin
Director-General
International Renewable Energy Agency

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Executive summary

Roadmap structure

The Renewable Energy Roadmap for the Republic of Cyprus is based on three complementary sections. The details of what is covered by each section and how each of them relates to the others are described below.

1) Cyprus energy balance and demand forecasts

As a first step to analysing the potential for renewable energy deployment in Cyprus and answering key questions related to the impacts of key policy decisions for the energy sector, it was necessary to develop an extensive understanding of the current energy use in Cyprus, as well as demand forecasts, based on more detailed examination of current energy use and its possible future evolution in each demand sector. This analysis was developed together with the Cyprus University of Technology (CUT) and is detailed in "Cyprus Energy Balance and Demand Forecasts", one section of the full roadmap report, which provides:

- A detailed national energy balance based on official 2012 data and provisional 2013 data, with detailed analysis of residential energy demand by end-use and a breakdown of final and useful energy demand in hotels; and

- forecasts of final energy demand up to the year 2040 for a number of scenarios reflecting different sets of assumptions on Cyprus' economic and energy system development.

The national energy balance, along with two of the demand forecast scenarios developed, were used as key inputs to the second section of the roadmap and the electricity supply model on which that section is based.

2) Electricity supply model

In order to examine options for economically optimal deployment of renewable energy in Cyprus under different scenarios, and to understand the potential impact of key policy decisions on the power generation mix, a long-term energy planning model of the current power system in Cyprus was developed. The Electricity Supply Model for Cyprus (ESMC) has been developed using the long-term energy modelling platform called the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) (IIASA 2012). This is a dynamic, bottom-up, multi-year energy system model allowing the use of linear and mixed-integer optimisation techniques.

This model was used to analyse the optimal evolution of the Cyprus electricity generation mix to meet electricity demand under different sets of assumptions, which led to the definition of six main scenarios (see Figure 1), which are explained below.

- **Energy Efficiency Demand Scenario without Interim Gas Solution Scenario (SC1):** Demand factors for this scenario are taken from an energy efficiency scenario developed in a separate study examining energy demand projections (Zachariadis et al. 2014). None of the major projects under consideration are implemented, except the production of domestic natural gas for the internal market in 2022; a transition period is assumed where indigenous gas for power generation becomes available in 2023. Specifically, the Interim Gas Solution, the EuroAsia Interconnector and the LNG export terminal are excluded from this scenario.

- **Extra Efficiency Demand Scenario with Interim Gas Solution Scenario (SC2):** This scenario follows the same logic as SC1, with the exception of different final electricity demand assumptions and the success of the Interim Gas Solution negotiations. Demands are taken from the Extra Efficiency Scenario (Zachariadis et al. 2014), which also assumes a decoupling between economic growth and electricity demand. Thus, demand in this scenario is lower than in SC1. Also, the interim gas solution is allowed to make gas available for the power sector, which means that a limit is imposed on the maximum contribution of renewables in the generation mix, so as to ensure consumption of a minimum volume of gas based on the likely minimum quantity requirements to be purchased for the Interim Gas Solution to happen.

» **Energy Efficiency Scenario Demand with Interim Gas Solution Scenario (SC3):** This scenario follows the same assumptions and final electricity demand as SC1. However, the Interim Gas Solution negotiations are assumed to be successful, as in the case of SC2. By comparing SC1 with SC3, outputs from this scenario can provide insights regarding the effects of the interim solution.

» **LNG Export Terminal Scenario (SC4):** In this scenario, assumptions are the same as in the previous scenario (SC3), but investment in a liquefaction facility for export purposes is allowed. Since the interconnector is not deployed in this scenario, storage is again deemed necessary beyond certain predefined limits.

» **EuroAsia Interconnector Scenario (SC5):** This scenario assumes that the EuroAsia Interconnector will be implemented as planned, but no liquefaction facility will be developed. Unless a separate grid analysis indicates otherwise, the assumption here is that storage is not a prerequisite in the case of high renewable energy penetration. The Interim Gas Solution is assumed to be successful as in SC3. Final electricity demands are the same as in SC1 and SC3. The aim of this scenario is to identify the price at which imported electricity becomes cost-competitive enough to be part of the Cyprus power generation mix. Since investment cost for development of the cable connection has not been considered in the analysis, the economic and other benefits from the deployment of the interconnector should outweigh the cost of the associated infrastructure for the interconnector to add value to the electrical system. In the presence of an interconnector, the impact on renewable energy deployment would be twofold: no storage would be required and more variable renewable energy can enter the power generation mix without the need for storage, which would reduce its competitiveness.

» **LNG Export Terminal and EuroAsia Interconnector Scenario (SC6):** A combination of Scenarios SC4 and SC5 has been conducted, with both the liquefaction facility and the interconnector considered. Assumptions regarding the Interim Gas Solution are the same as in SC4, while the assumptions regarding the necessity of storage are the same as in SC5.

Additionally, several sensitivity analyses were undertaken. The demand scenarios considered in the MESSAGE model were based on the demand forecast developed by CUT. In particular, one demand scenario was used for five out of six supply scenarios, with the scenario with the lowest electricity demand used only for evaluating the possible benefits in one of the six scenarios (SC2).

The modelling work using MESSAGE was developed together with the Swedish Royal Institute of Technology (KTH) and is detailed in the full roadmap report, in the section *"Electricity Supply Scenarios for the Republic of Cyprus"*. This section considers six specific scenarios examining the optimal deployment of renewable energy and thermal generation for the period 2013-2030. The scenarios were designed by IRENA and KTH in consultation with the Ministry of Energy, Commerce, Industry and Tourism (MECIT), to provide insights into key energy related decisions that Cyprus is facing. This part of the report forms the core of the roadmap and provides key insights into how different policy decisions affect the optimal evolution of the electricity system in Cyprus.

3) Technical studies investigating VRE integration

In order to provide insights and state-of-the-art information on how to accelerate the deployment variable renewable energy (VRE) generation, while maintaining stable operation of the electricity grid, the roadmap includes the results of two studies examining how VRE integration could be supported through:

1. VRE production forecasting

2. State-of-the-art of technologies for the provision of grid support services from variable renewable energy systems

These studies were developed by IRENA, as defined in the scope of work of the Cyprus roadmap, and are included at the end of this report. They provide key insights into the state of the art of some key tools and measures that can be used to facilitate the integration of large shares of VRE into Cyprus' electricity system.

Roadmap key findings

The following key conclusions have emerged from the roadmap analysis:

- To better position Cyprus for the revision of its energy policy and associated plans, this report provides quantitative insights on the impacts of major upcoming policy decisions;

- Several renewable energy technologies (RETs), including photovoltaics (PV) and wind, can already produce electricity at a lower cost than Cyprus' current oil-fired power plants. Based on this analysis, renewable energy could provide 25% to 40% of Cyprus' total electricity supply in 2030. In these scenarios solar PV will be the dominant source with ca. 500 – 1,000 megawatts (MW) of capacity providing 15% to 27% of the electricity supply while wind will be the second most important renewable energy source with ca. 175 – 375 MW of capacity providing 5% to 9% of the electricity supply.

- The deployment of renewable energy in Cyprus has the potential to create between 11,000 and 22,000 jobs in Cyprus by 2030, based on IRENA's estimates of the job-creation potential of different RETs;

- The accelerated deployment of renewable energy along with the shift of thermal generation to natural gas is estimated to lower generation cost to EUR 83-92 per megawatt-hour (MWh) by 2030. Costs in 2013 were ca. EUR 130/ MWh, based primarily on heavy fuel oil and diesel generation.

- The following recommendations would help to minimise electricity generation costs in Cyprus:

  - Create market incentives for investment in increasing the flexibility of thermal generation, to reduce must-run requirements and increase the space for integration of renewable energy into the market;

  - Minimise the requirements for provision of ancillary services from distributed renewable energy in the grid codes and allow renewable energy to participate in the market for ancillary services;

  - Move from a net-metering scheme to net-billing, where renewable electricity that is fed into the grid is sold either at market price or at a feed-in tariff below marginal generation cost; and

  - Maintain the feed-in tariff regime until a well-functioning market, which allows full participation of renewable energy (including provision of ancillary services), is in place.

- Certain features of the electricity market currently being designed would affect the competitiveness of renewables and should be reconsidered:

  - Production forecast closes at 3:00 p.m. of the day before, with no re-denomination allowed on the same day;

  - Limited size of the day-ahead market due to thermal generation must-run and operating reserves constraints, with no incentives to invest in flexibility or dispatchability;

  - RETs are not allowed to provide ancillary services through the market, with compulsory requirements applied to all RETs through grid codes; and

  - Uncapped and non-compensated RET curtailment justified by system security concerns creates a substantial risk for renewable energy investors.

- To improve the quality and reliability of national energy balance it is recommended to:

  - Publish the annual energy balance of Cyprus and extend its coverage to accommodate all available statistical information, e.g., for industrial sub-sectors; and
  - Conduct energy surveys at regular intervals (every few years), particularly for

sectors with diverse energy use such as households and tourism.

- There is substantial potential for energy efficiency improvements and further penetration of renewables in the tourism sector, provided that appropriate policies are implemented.

- The Ministry of Energy, Commerce, Industry and Tourism should consider making a long-term commitment to energy modelling work for both final energy demand and electricity supply as this would greatly expand in-house capacity to assess the potential impacts of energy policy decisions and changes in the energy market conditions.

- Accurate forecasts support high levels of VRE generation by reducing integration costs for the transmission system operators (TSO) and distribution system operator (DSO) while also reducing financial risk and increasing revenues of IPPs and utilities operating VRE assets.

- There is a strong correlation between the value of forecasting and electricity market design. In particular short-term markets and full market access (i.e., including participation in the ancillary services market) for VRE producers increases the effectiveness of forecasting in reducing VRE integration costs and increasing the share of VRE generation.

- Current and near term advances in power electronics allow VRE assets to provide grid support services (GSS). In combination with limited amounts of energy storage, VRE can provide the full range of GSS already today. These capabilities should be factored into Cyprus' proposed market design and future energy planning efforts.

Insights for policy makers

This section provides a review of the main findings and specific policy recommendations that have emerged from the roadmap analysis. It is intended to assist policy makers in identifying the main insights that will affect important upcoming policy decisions.

Key findings

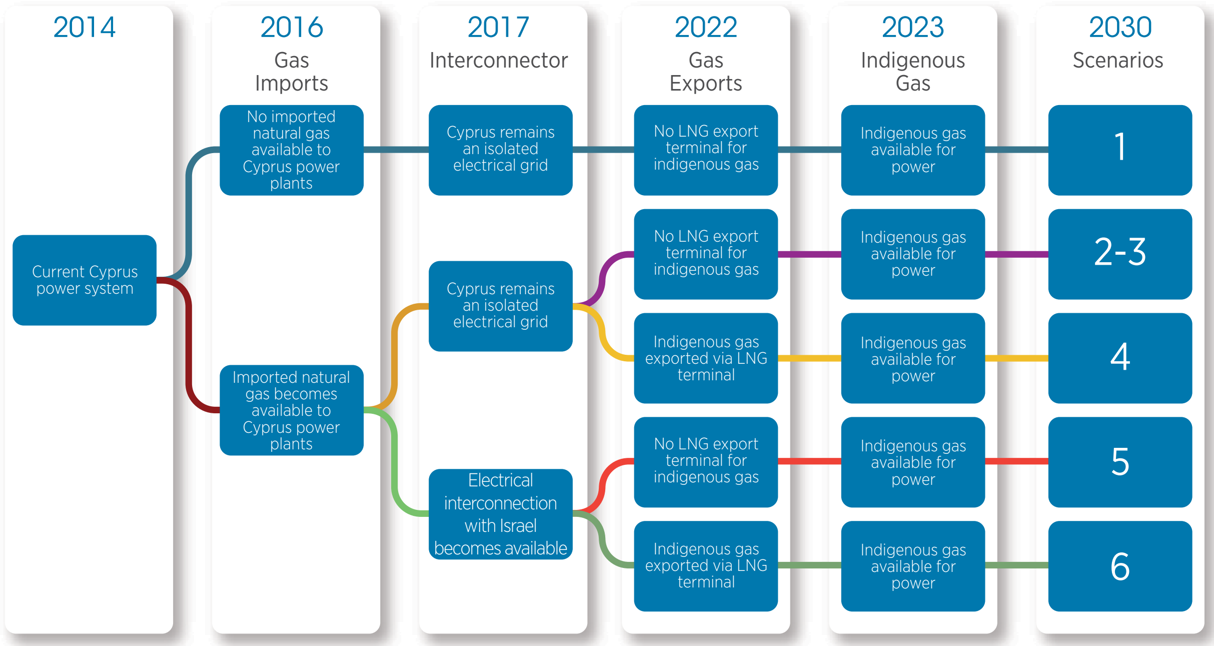
Cyprus is at a major crossroad for the development of its energy system. The key driving elements for the evolution of Cyprus' energy system are:

- the potential availability of natural gas, either imported or indigenous, within this decade;
- the plan to open up the monopolistic electricity market to competition, with a view to reduce cost and give choice to consumers;
- the imminent end of derogations given to the electricity sector of Cyprus with respect to the application of EU emission limits, particularly according to the Large Combustion Plants Directive (Directive 2001/80/EC setting emission limits for SO2, NOx and dust) and the free allocation of CO_2 certificates;
- new techno-economic developments, particularly with respect to RETs, power electronics, smart and energy efficient technologies; and
- the current economic situation of Cyprus, which is seeing increasing need for reduced energy costs in businesses and households.

This is reflected in the analysis through the six key scenarios developed. These scenarios based on possible combinations of major developments for the energy system of Cyprus, particularly: availability of imported gas, availability of an international electrical interconnection, availability of indigenous gas and related infrastructure.

Figure I illustrates a decision tree defining the six key scenarios based on the combinations of the above energy sector developments.

Figure I: Policy decision tree and resulting scenarios

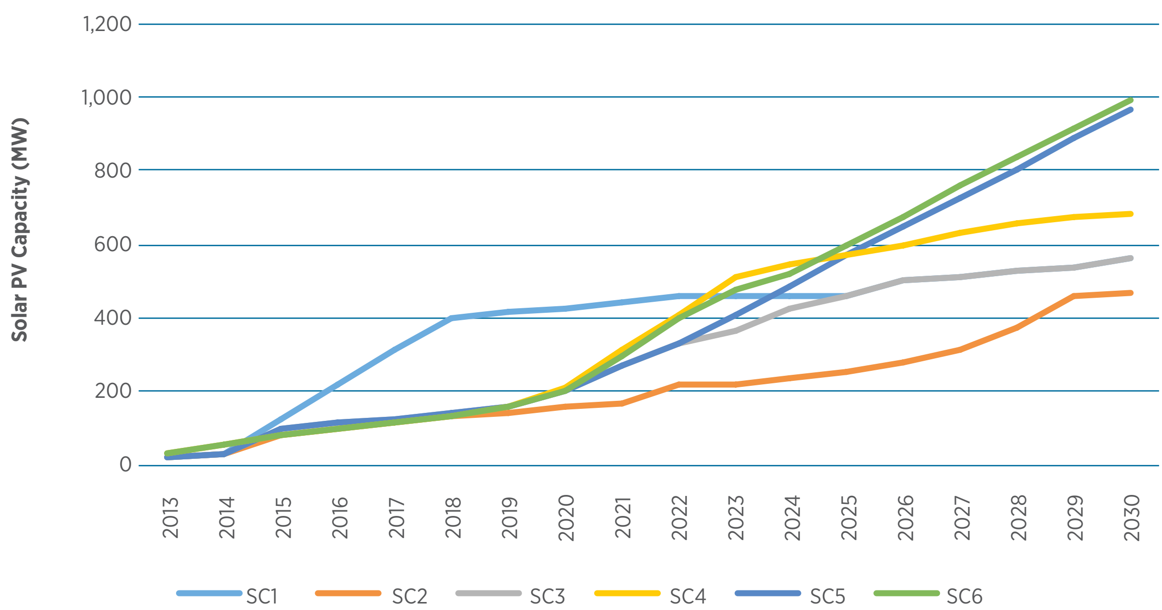


The analysis of these scenarios shows that **several RETs can already produce electricity at a lower cost than power plants fuelled by oil products.**

RETs have the potential to provide a substantial contribution to the electricity mix of Cyprus. Based on this analysis, **between 25% and 40% of Cyprus' electricity supply can come from renewables in 2030,** in the economically optimal mix. Solar PV is the predominant renewable energy technology in all scenarios, supplying between 15% and 27% of the electricity consumed in Cyprus in 2030. Wind is the second most important RET, contributing between 5% and 9%. The scenarios on the low-end of the renewable energy share are limited in penetration of variable RET based on the constraints obtained by the Ministry of Energy, Commerce, Industry and Tourism. The ministry's constraints are based on provisional results from a study on grid stability commissioned by CERA, which will be revised by a subsequent study under development by the Joint Research Centre (JRC) of the European Commission. Nonetheless, mandatory renewable energy targets for 2020 are exceeded in all scenarios. In the absence of constraints related to must-run, operating reserve and stability-related concerns, solar PV will reach higher shares at a steady pace. In the absence of imported gas becoming available for power generation in 2016, solar PV deployment will be strongly accelerated (see SC1 and Figure II). It is recommended to explore scenarios without the availability of natural gas and imposed technical constraints on variable renewables (currently based on a non-finalised study).

This analysis provides insights for the key policy decisions that will determine the evolution of the energy sector in Cyprus. Instead of suggesting one pathway as the optimal to follow, different scenarios provide **quantitative insights on the impacts of different policy decisions,** to better position Cyprus for the revision of its energy policy and associated plans (e.g., the National Renewable Energy Action Plan). Given the game-changing nature of some of the policy decisions to be taken for the energy sector of Cyprus, **this analysis outlines an optimal roadmap for each of the possible scenarios,** without associating a probability to each of them. The difference among different scenarios in terms of cost of generation, investment needs, compliance with policy targets and optimal power generation mix can guide the government in taking policy decisions that will lead to the most desirable scenario and associated optimal roadmap.

Figure II: Development of solar PV capacity under different scenarios



- In combination, **renewables and natural gas** are expected to lower the generation cost to **EUR 83-92/MWh by 2030** (Table I). This is compared to 2013 levels estimated at ca. EUR 130/MWh, where power is generated mostly by burning heavy fuel oil and diesel.

Based on an IRENA analysis titled Renewable Energy and Jobs (IRENA, 2013c), solar PV can provide ca. 18-20 new jobs per additional megawatt-peak (MWp) installed, while wind in a similar context like Cyprus (e.g., Greece) can provide 8.8 jobs per MWp (see Table 2.2, page 42 of IRENA 2013c). The deployment of ca. 1 gigawatt-peak (GWp) of PV over the period 2013-2030 can lead to estimated 20,000 new jobs (see Table II), with estimated additional jobs still exceeding 10,000 in the scenario with the lowest renewable energy deployment (SC2). In the case of Cyprus, synergies can be leveraged between the existing solar thermal industry, which is already well-established, and the rapidly growing solar PV market.

Therefore, a dedicated analysis on the job impact for Cyprus would be a valuable extension of this work.

Policy recommendations

In order to minimise the electricity generation cost for the Cyprus system, the following recommendations can be made.

- **Create market incentives for investment in flexibility for thermal power plants,** to reduce the must-run requirements and increase the

Table I: Renewable energy shares, generation cost and system investment per scenario

	SC1	SC2	SC3	SC4	SC5	SC6
Renewable energy share in 2020	27.9%	19.5%	17.8%	17.9%	17.8%	17.9%
Renewable energy share in 2030	25.6%	28.3%	25.6%	26.4%	40.1%	33.2%
- Solar PV	15.2%	17.4%	15.2%	15.2%	26.8%	22.0%
- Wind	5.7%	5.5%	5.7%	5.1%	8.7%	6.6%
Cumulative generation investments 2013-2030 (billion EUR)*	1.10	0.70	1.06	1.46	1.45	1.55
Average generation cost in 2013-2030 (EUR/MWh)	101.0	91.6	90.4	91.5	88.9	89.1

* *Cost of some investments such as grid investments, electrical interconnector cost, and energy efficiency measures are not included.*

Table II: Estimated additional jobs generated by wind and solar PV deployment in Cyprus

	Installed capacity in 2030 (MW)		Estimated additional jobs	
	Wind	PV	Wind	PV
SC1	251	559	2,209	10,621
SC2	175	468	1,540	8,892
SC3	251	559	2,209	10,621
SC4	275	688	2,420	13,072
SC5	372	968	3,274	18,392
SC6	352	998	3,098	18,962

space for integration of RET into the market (see the case of Denmark, e.g., from Blum and Christensen 2013).

- Minimise the requirements for **provision of ancillary services from distributed RET** (e.g., small-scale residential PV) in the grid codes, and allow RET to participate in the market for ancillary services. In this way, the participation of only a minimal part of the RET generators would be sufficient to compensate for the rest of the variable RET, minimising the cost of providing the needed ancillary services (see Van Hulle et al. 2014).

- Consider moving **from a net-metering scheme towards asymmetric net-billing,** where electricity fed into the grid is purchased either at market price or at a feed-in tariff below marginal generation cost. This would allow both a reduction of windfall profits for net metering customers – due to the large difference between generation cost from PV and the current tariff – as well as the reduction of grid integration costs, as a net-billing scheme would provide strong incentives for maximising self-consumption of electricity produced from PV. Currently all net metering customers pay a fixed fee for grid use, a measure that does not promote self-consumption and penalises all customers equally. Moving to a net-billing scheme can promote smarter consumption patterns, lead to the deployment of small-scale storage systems and intelligent appliances, and generally leverage all the potential benefits from distributed PV. The same policy can replace the existing self-generation support scheme, which has not been very successful up to now, especially in agricultural and other commercial consumers, which are unable to derive benefits from it.

- According to this analysis, acceleration of the deployment of RET can reduce generation cost substantially, especially under the current conditions where oil products are used to generate most of the electricity. However, the slow permitting process slows down the necessary deployment, and current policy and future market uncertainty increase the risk for investors. As PV, concentrated solar power (CSP) and wind are capital-intensive (but have no fuel cost), they are much more sensitive to cost of capital compared to thermal power plants. **Increasing the risk for investors in RET would reduce their competitiveness** much more than would be the case for investors in fossil fuel-powered plants, with a double impact on electricity generation cost for Cyprus. This means that less RET deployment will take place, with a higher generation cost. For each 12 MWp of utility-scale PV that gets delayed compared to the suggested roadmap, this analysis estimates that total generation cost will increase of *ca.* EUR 1 million per year. One suggestion could be to maintain the feed-in tariff regime until a well-functioning market that allows for full participation of RET, including provision of ancillary services, is in place. One possible way to achieve this is to provide a **feed-in tariff** set at marginal generation cost minus grid integration cost for as many years as the estimated break-even time. This should be revised yearly for new installations, to account for reductions in the cost of RET and changes in grid integration costs; however, it **should not be revised retroactively** for existing installations. Once their feed-in period expires, RET generators will be allowed to sell electricity (and services) on the market, which by then should be fully operational.

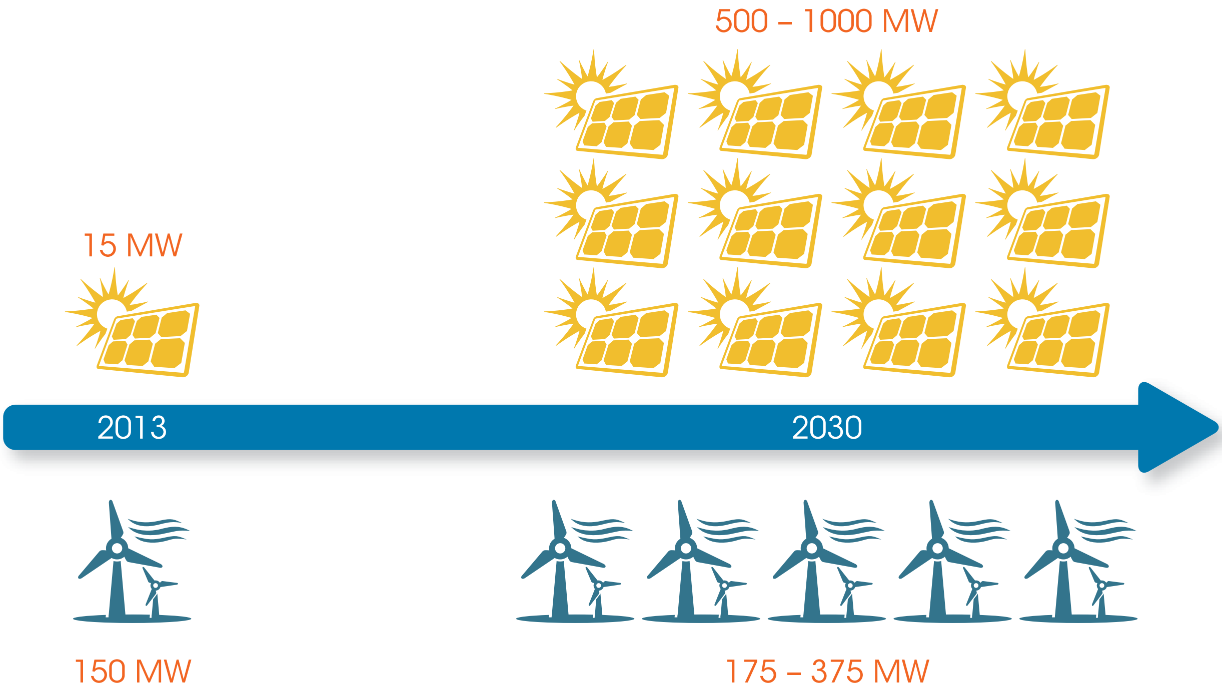
- Based on the decision tree in Figure 1, no fuel switch will happen before 2016, in any of the scenarios. Therefore, for 2015 the best policy option is to **create the enabling conditions** for accelerated deployment of **utility-scale solar PV,** which is the cheapest available generation option. PV generation cost for 2015 in Cyprus is estimated to be below EUR 80/MWh, displacing diesel and less efficient heavy fuel oil (HFO) units, for which the variable generation cost (short-run marginal cost, or SRMC) ranges between EUR 120-130/MWh. However, due to the current uncertainty on permitting, licensing and future market design, the environment in 2015 is not conducive to deployment of RET. In particular, certain features of the future market currently being designed would affect the competitiveness of renewables and likely slow down investments. Key concerns related to current design of the electricity market, related to deployment of renewables, are: production forecast closes at 3:00 p.m. of the day before, with no re-denomination allowed on the same day;

- limited size of the day-ahead market due to conservative constraints on must-run for thermal power plants and operating reserves, with no incentives to invest in flexibility for reducing the must-run requirements;
- RET will not be allowed to provide ancillary services through the market, with requirements being enforced to all RET through grid codes;
- RET can be curtailed without compensation if TSO requests to do so because of system security concerns, and no cap is set on max curtailment, which creates a substantial risk for RET investors.

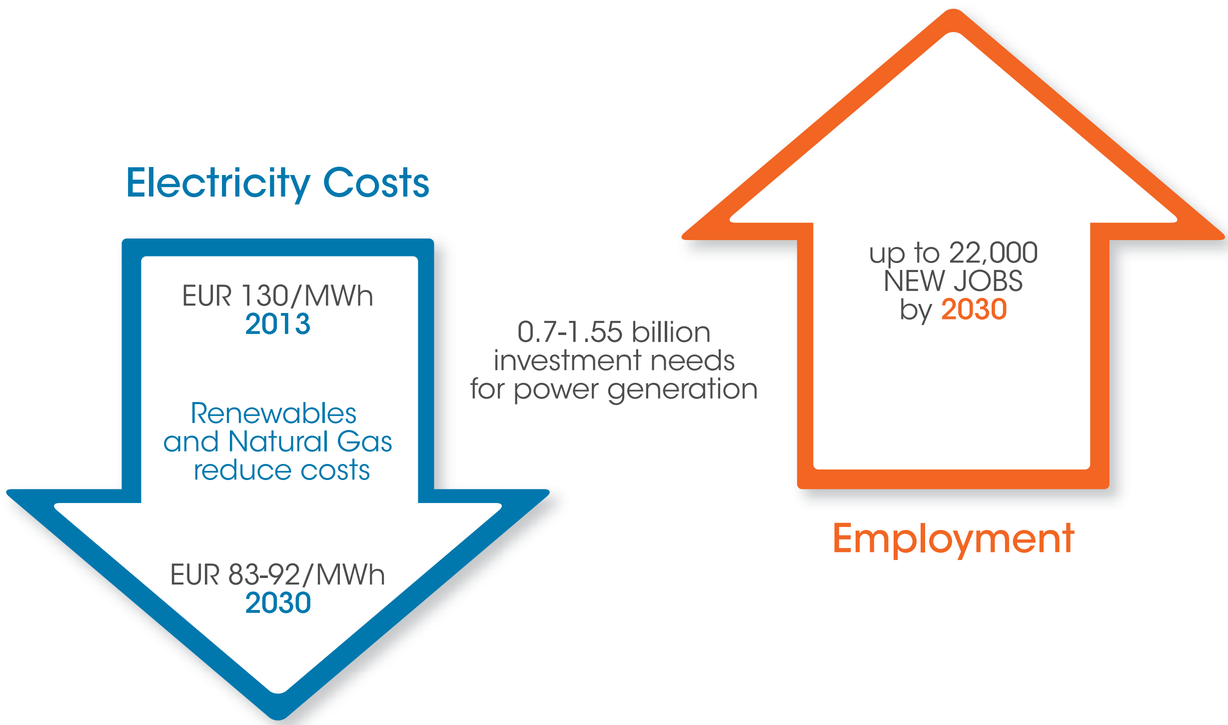
One of the major achievements in the development of this analysis has been the creation of a platform for productive discussions among key stakeholders in the energy sector of Cyprus. The added value of having a modelling platform to support discussions on quantitative results should justify support for creating in-house capacity on energy planning modelling. In this way future policy development will benefit from quantitative-based discussions supported by a commonly agreed modelling platform, which can provide insights on impacts from different policies being considered, and assess sensitivity of results to specific assumptions used.

Infographics

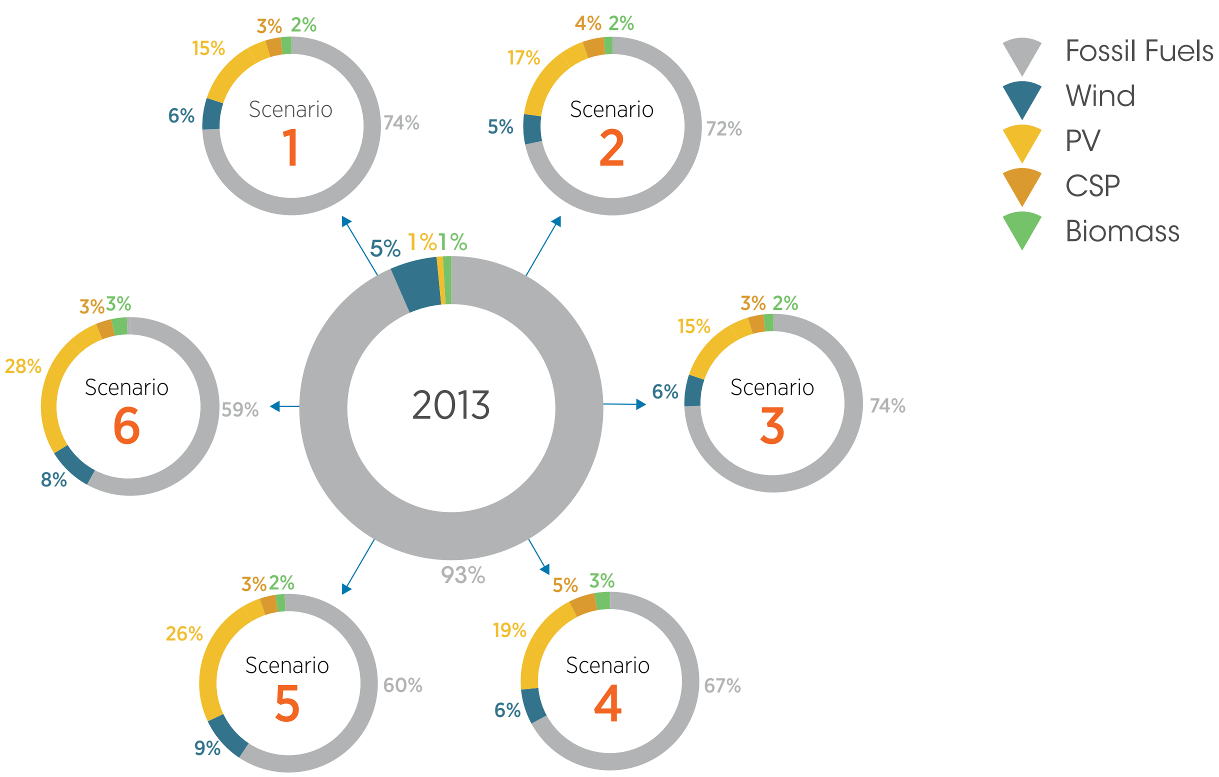
Infographic 1: Renewables in Cyprus: PV adn wind drive deployment



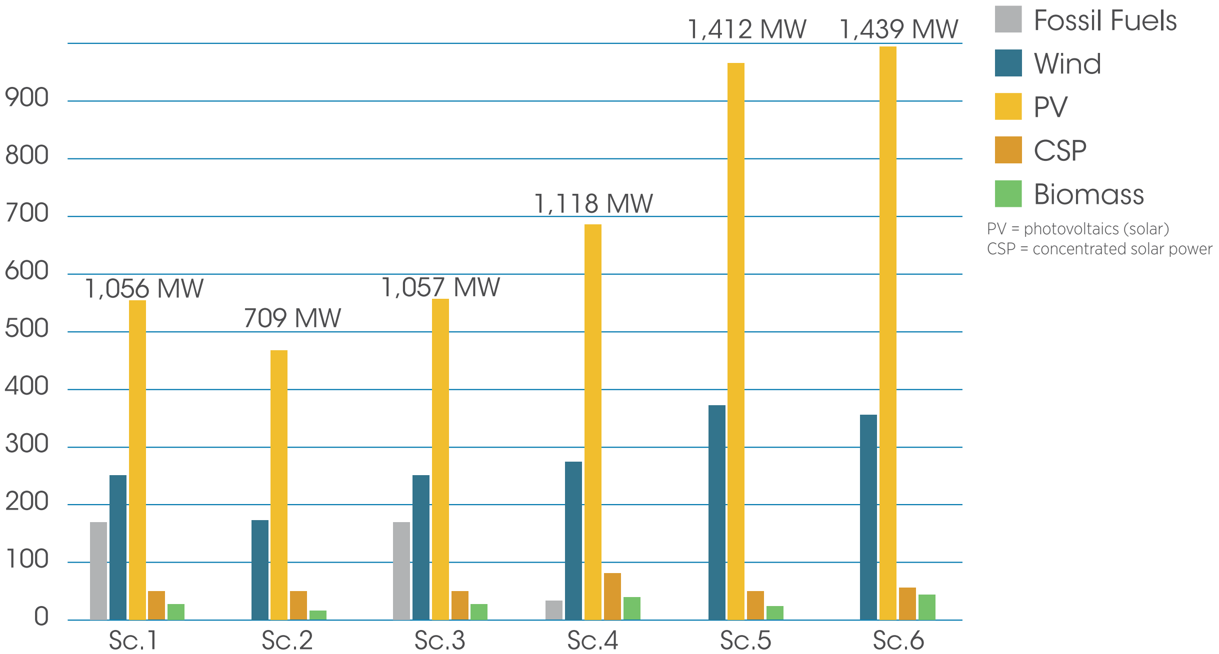
Infographic 2: Local benefits from renewable energy



Infographic 3: Power generation scenarios, 2013 vs. 2030

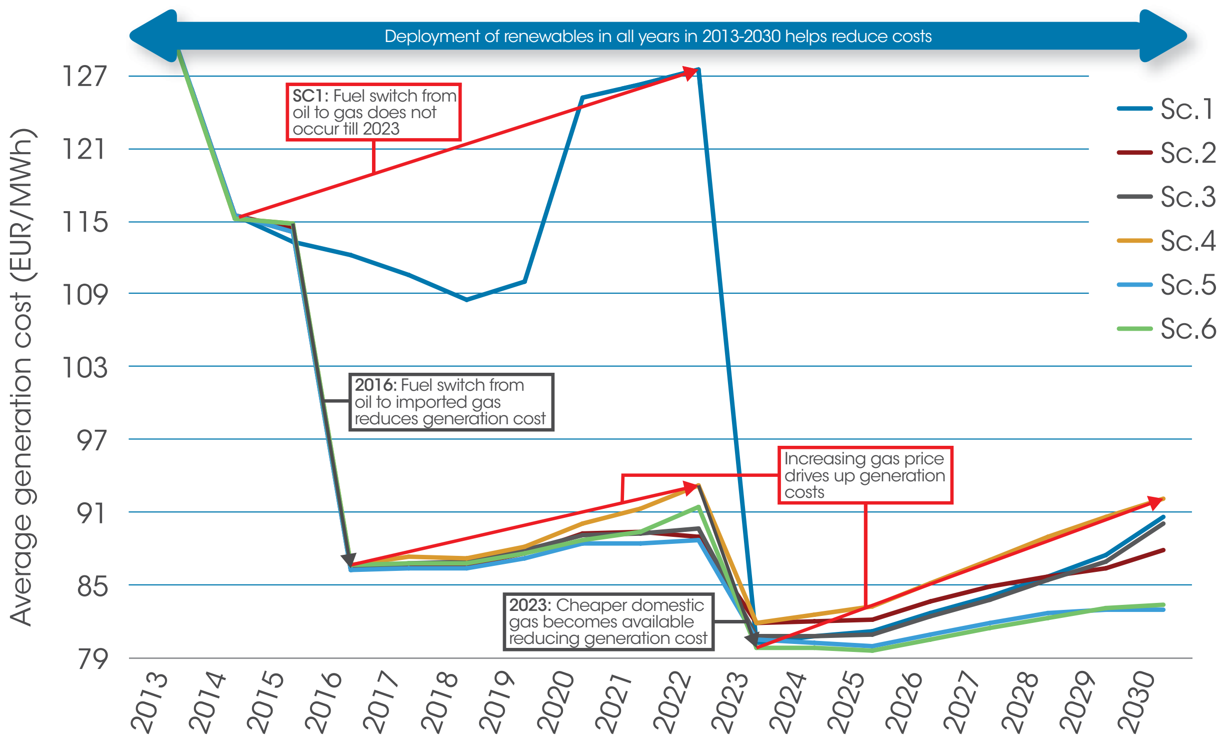


Infographic 4: Power generation capacity additions

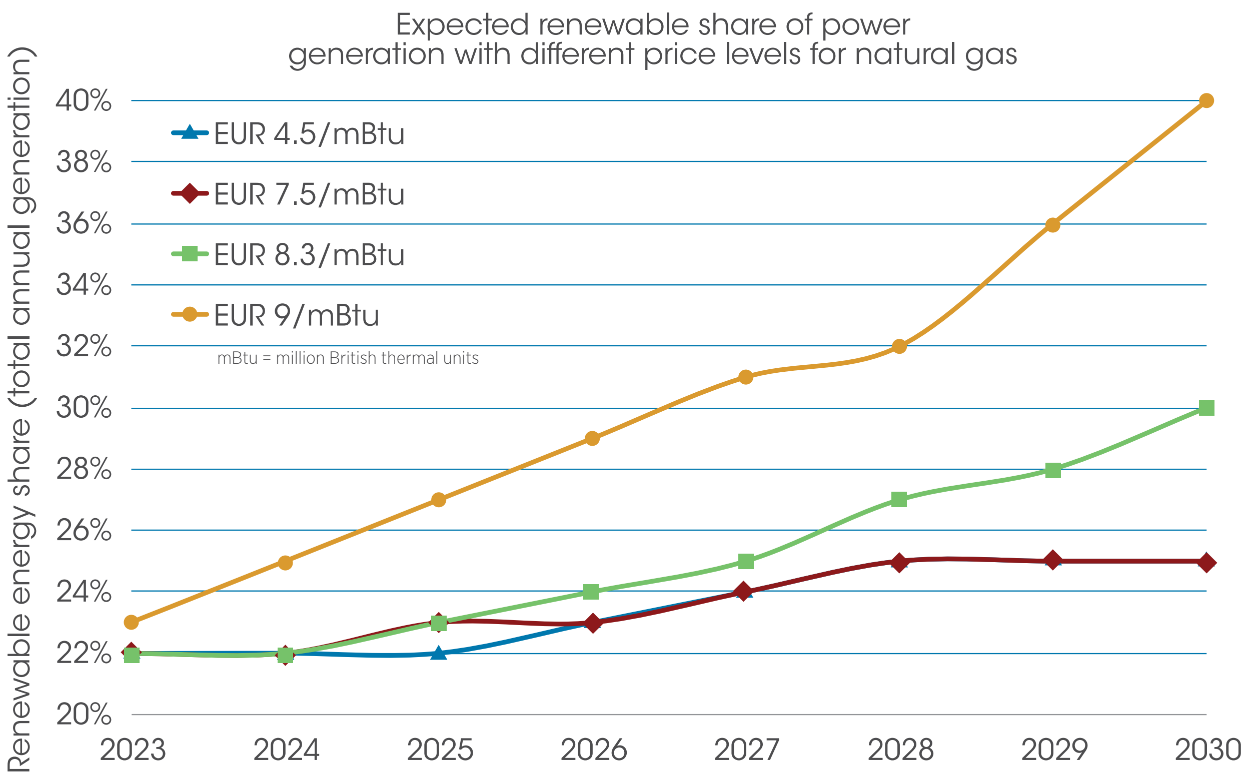


Every scenario assumes 566.72 MW of fossil-fuel power generation capacity will be decommissioned between 2013-2020.

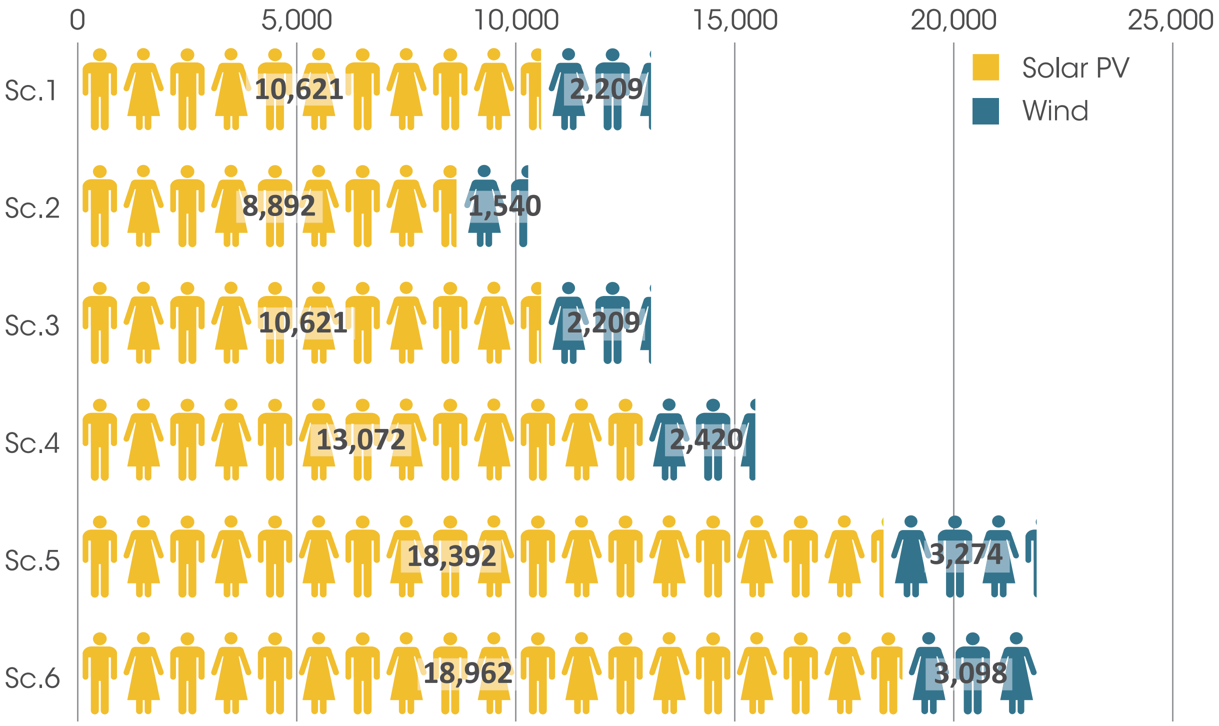
Infographic 5: Power generation costs



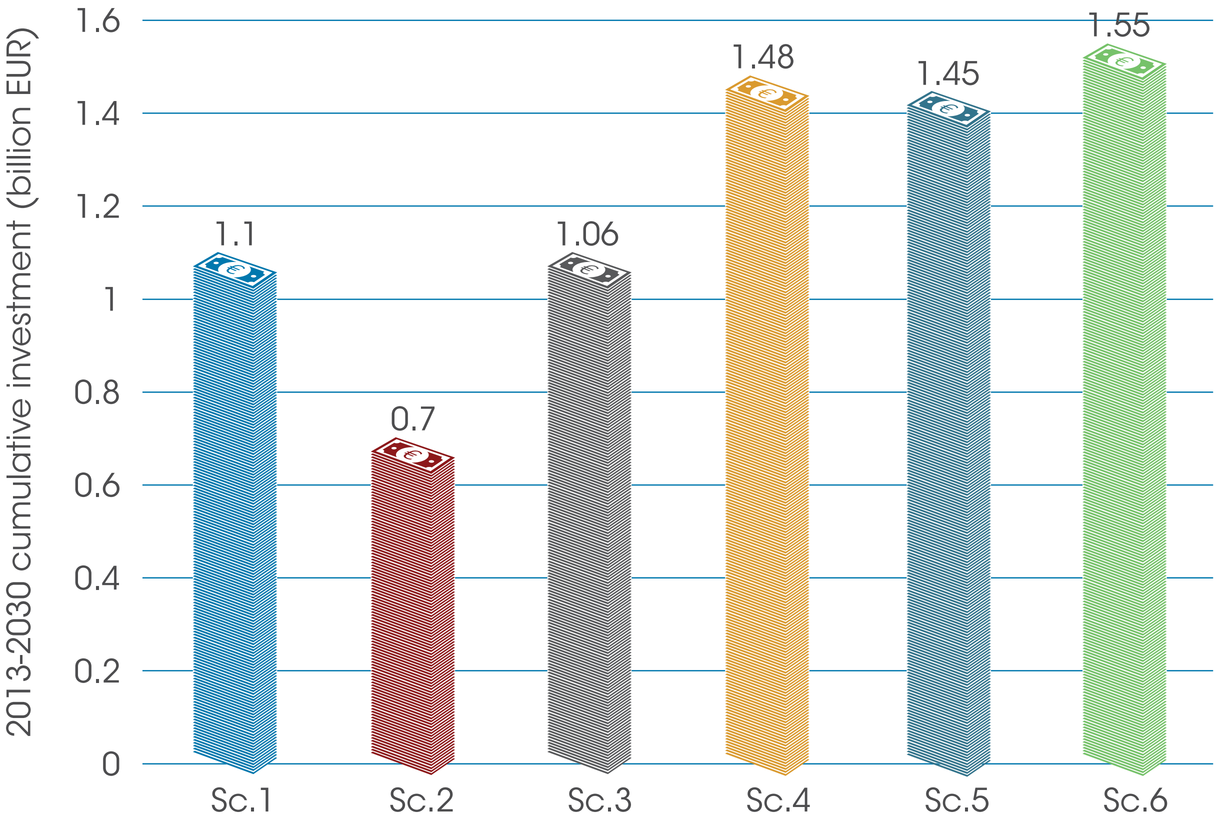
Infographic 6: Gas prices and renewable uptake



Infographic 7: Renewable energy job creation



Infographic 8: Investments in power generation



1 Introduction

1.1 Roadmap engagement background

In the Malta Communique on Accelerating Renewable Energy Uptake for Islands, ministers called on IRENA to establish a Global Renewable Energy Islands Network (GREIN) as a platform for pooling knowledge, sharing best practices and seeking innovative solutions for the accelerated uptake of clean and cost-effective renewable energy technologies on islands.

On 24 March 2013, during the Pacific Energy Summit in Auckland, New Zealand, IRENA launched the GREIN roadmap cluster. Through this co-operative effort IRENA stands ready to provide assistance to Member States in the development of local or national renewable energy deployment roadmaps for islands. On 10 November 2013, in the context of the GREIN roadmap cluster, IRENA solicited expressions of interest (EOI) from Member States for assistance in developing renewable energy roadmaps for islands.

1.1.1 Cyprus roadmap request

On 21 November 2013 the acting director of the Energy Service, Ministry of Energy, Commerce, Industry and Tourism, Republic of Cyprus, responded to the EOI solicitation, officially requesting assistance from IRENA in the development of a roadmap. The request from the Government of Cyprus indicated that the roadmap should:

- focus on solely on the power sector;
- determine options for economically optimal levels of renewable energy power generation;
- examine how to best integrate variable renewable energy into the Cyprus power grid;
- analyse impacts of the planned electrical interconnection to Greece and Israel; and
- investigate options under consideration for the planned production of domestic natural gas.

The policy driver for the roadmap is the EU renewable energy target for Cyprus in 2020, and the national aspirational target for 2030. The economic driver is the current high cost of electricity, based almost exclusively on imported oil products. The technical driver is minimising the effects that rapidly increasing shares of VRE sources can have on the reliability of the Cyprus power grid.

1.1.2 Roadmap scope of work

During early 2014 the Government of Cyprus and IRENA worked together to develop a scope of work detailing the specific analysis to be completed in support of the roadmap. In addition to the Ministry of Energy, Commerce, Industry and Tourism and IRENA the following key players contributed to defining the scope of work: the Cyprus TSO and DSO, the Cyprus Energy Regulatory Authority (CERA) and the incumbent utility, Electricity Authority of Cyprus (EAC).

The finalised statement of work was approved on 9 April 2014. It determined that roadmap would support the EOI goals outlined above through a detailed analysis covering the entire power sector. In order to provide the best insight into various areas covered by the roadmap, analysis was divided into three separate studies covering:

1. Energy balance and demand forecasts
2. Electricity supply model
3. Technical studies on integration of VRE

The findings and insights of the above studies have been thoroughly reviewed by the key stakeholders and are integrated together in this document. Taken together these three studies constitute the **Renewable Energy Roadmap for the Republic of Cyprus.**

1.2 Analysis background

Cyprus, a European Union member state since 2004, is at the crossroads of determining how its energy sector, and particularly the power sector, should develop in the coming decades. Cyprus is currently dependent on imported oil to meet most of its growing energy needs. At the same time, renewable energy technology cost reductions, coupled with abundant renewable energy resources, provide an opportunity to reduce Cyprus' dependency on fossil fuels while complying with EU renewable energy targets for 2020 and fulfilling the country's own targets for 2030. Developing a national energy plan that can effectively address these challenges is a difficult task that requires informed decision-making. As such, Cyprus has co-operated with IRENA to develop a Renewable Energy Roadmap based on detailed demand forecasts, long-term energy modelling and a review of relevant technologies that provides quantitative insights into the challenges Cyprus is facing and offers a clear path to accelerating the uptake of renewable energy.

As a result of the recent economic recession, final electricity demand in Cyprus has decreased during 2011-2013, and due to adopted efficiency measures is not expected to rise to 2010 levels before 2022 (Transmission System Operator - Cyprus 2013). However, it is not certain how demand will evolve. This uncertainty can complicate decisions regarding strategic energy planning. IRENA, with the support of CUT, developed several energy demand scenarios for Cyprus up to 2040. This analysis forms the first part of the Cyprus Renewable Energy Roadmap. The Energy Efficiency and Extra Efficiency scenarios taken from the energy demand study are used as key inputs in a long-term energy supply model developed by the KTH. This model has been used to analyse six scenarios covering major energy policy choices that Cyprus is facing in the near future. The outputs and key finding derived from an analysis of these six scenarios forms the core of the Renewable Energy Roadmap for the Republic of Cyprus.

The power system of Cyprus is completely isolated, as there are currently no interconnections to the electricity grids of neighbouring countries. Therefore, on-island generation must cover the full demand at all times and provide a sufficient margin to cover the potential loss of generation units. This roadmap includes analysis of scenarios examining the impact of international undersea electrical interconnections that would link Cyprus to Israel and Greece. In addition, Cyprus' electrical isolation increases the technical challenges of integrating a high share of VRE into the power grid. This roadmap includes two technical studies detailing how recent advances in VRE forecasting and advanced inverters can assist in overcoming the challenges of integrating high shares of VRE into isolated electricity grids.

Cyprus' power sector relies primarily on oil imports. This makes the price of electricity exceptionally vulnerable to fluctuations in international oil prices. Recent discoveries of offshore hydrocarbon reserves (natural gas reserves that have been proven) might change the picture in terms of energy imports, trade balance and the cost of power generation. It is estimated that production of natural gas for export will commence around 2022. The theoretically extensive volumes of gas available 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 currently seems to be a likely option, provided enough reserves are proven for building a financially viable project. However, extensive strategic planning and considerable investments in infrastructure are required to integrate indigenous energy sources in the power supply system of the island. It should be noted that while the generation assets at Vasilikos, Cyprus' main power station, are currently fired with diesel and heavy fuel oil, significant investment has already taken place to allow these assets to run on natural gas when it becomes available. This roadmap includes analysis of scenarios that provide key insights into the impacts of the major decisions regarding natural gas development.

As an EU member state, Cyprus must comply with a national renewable energy target currently set at 13% of gross final energy consumption from renewable energy by 2020. The renewable energy share for the power sector has been set at 16% by 2020 in the first National Renewable Energy Action Plan (NREAP) (Ministry of Energy, Commerce, Industry and Tourism, 2010). In addition, Cyprus has aspirational renewable energy targets that extend beyond 2020, aiming for 25.29% the renewable energy by 2030. The renewable energy share for the island was 7.5% in 2013 and has been following an increasing trend in recent years (Transmission System Operator - Cyprus 2014a). This roadmap shows that not only can Cyprus meet its EU and national renewable energy targets but that renewable energy generation provides a least-cost option that can greatly exceed the renewable energy targets while reducing generation cost. As a result it is likely that renewable energy targets can be revised upwards based on the recommendation of this roadmap, in the next review of the NREAP.

Cyprus currently faces very high electricity costs. The 2013 retail electricity price of EUR 248/MWh for medium-sized households in Cyprus was the third most expensive in the European Union (Eurostat 2014). This elevated cost is attributed partially to the extensive reliance on oil-fired electricity generation, which continues to supply more than 90% of the electricity demand (Transmission System Operator - Cyprus 2014a). It is also due to an incident in July 2011, in which the Vasilikos Power Station was damaged by an explosion, which resulted in substantial increased costs from 2011 through 2013. In turn, the high price of electricity negatively affects the competitiveness of the industrial and commercial sectors, thus hindering the ability of the island to tackle the economic recession. Thus, this roadmap shows that renewable energy provides a least-cost option for Cyprus to effectively reduce its oil imports and electricity costs.

At present, the Government of Cyprus is considering an interim solution as a measure to reduce the price of electricity until domestic hydrocarbon extraction starts. It is exploring importing gas in the medium-term, as gas is comparatively cheaper than oil and can be used in the existing highly efficient combined cycle gas turbines. This interim solution would require major investments in infrastructure i.e. a regasification terminal or gas pipelines from offshore gas reserves to the power plants. This roadmap includes analysis providing insight into the potential impacts of the interim gas solution.

2 Cyprus energy balance and demand forecasts study

In support of the Cyprus renewable energy roadmap, CUT completed a detailed analysis examining long-term forecasts of final energy demand in Cyprus. This energy demand study constitutes the first component of the Cyprus roadmap and the results of this study are given in full in section. The energy demand study has two main components:

i) development of a detailed national energy balance for the recent-most year based on available data, with additional emphasis on energy demand in buildings and the tourism sector; and

ii) forecasts of final energy demand up to the year 2040 for a number of scenarios reflecting different sets of assumptions in regards to the country's economic and energy system.

Regarding item i), Section 2.1 of the energy demand study describes the detailed energy balances developed by CUT with the aid of official data for the year 2012 as well as a provisional energy balance for 2013. These are used as a basis for the subsequent final energy demand forecasts presented in this report. Moreover, a more detailed look into energy consumption of residential buildings and the hotel sector is provided in Section 2.2, which also outlines the additional data collected for this purpose, the methodology followed and the assumptions made in order to arrive at reasonable energy estimates for hotels.

As far as item ii) is concerned, Section 2.3 outlines the mathematical model used for final energy demand forecasts; Section 2.4 reports the different scenarios designed for this study and their connection with national and international policy development; and Section 2.5 describes the main results, with the particular attention required by IRENA on the evolution of electricity demand by sector up to 2040. Finally, Section 2.6 contains the conclusion of the report. The report also ends with recommendations to the energy authorities of Cyprus for improving their energy balance development and the energy analysis of tourism.

2.1 Energy balance of Cyprus for years 2012 and 2013

Making use of available official information about energy consumption in the different sectors of the Cypriot economy, CUT developed a detailed energy balance for years 2012 and 2013. Apart from the possibility of errors, the 2012 balance has to be considered as the final one. Conversely, the energy balance for 2013 has to be treated as provisional – although most of its content is based on finalised statistical data – especially as the information on the breakdown of consumption of petroleum products by economic sector and subsector is not yet final.

Table 1 shows the data sources that were used for the construction of these balances. It was attempted to gather as much information as possible from the authorities who are responsible for collecting specific datasets and – wherever possible – to crosscheck the figures with those available from other authorities. In cases of discrepancies, we chose to use the data that we considered to be the most reliable or more easily reproducible (e.g. published figures as opposed to unpublished data). In cases of implausible data, and in the absence of any alternative information, we proceeded with our own estimates (e.g. allocating consumption of petroleum products in non-industrial sectors on the basis of changes in economic activity between 2012 and 2013).

The energy balances of 2012 and 2013 are presented in a somewhat concise form in Appendix II. They have also been provided to IRENA and the Ministry of Energy, Commerce, Industry and Tourism in electronic form, both in this format (which is similar to the one used by the ministry, although the latter is available in a more aggregated form) and in the energy balance template of the International Energy Agency.

Recommendations to national authorities on the development of energy balances

Based on the experience gained by CUT both during the process of preparing the energy balance in the frame of this study and in similar attempts in earlier years, the following recommendations are put forward for consideration.

» Authorities collecting and processing energy-related information – mainly the Statistical Service and the Ministry of Energy, Commerce, Industry and Tourism – have to collaborate closely in order to avoid discrepancies in the data they publish. For example, it is necessary for both authorities to agree on the quantities of imports, sales and stock changes of each petroleum product and publish consistent statistics.

» The accuracy and reliability of energy balance data can be considerably improved if the Cyprus Statistical Service carries out surveys on energy use at regular intervals, e.g. every 5-6 years, as is the case for Family Expenditure Surveys. In particular, it is important to conduct such surveys for two sectors with diverse energy uses: Households and Accommodation and Food Service Activities.

Moreover, the national energy balance needs to:

» become publicly available – e.g. to be published on the Ministry of Energy, Commerce, Industry and Tourism's website; and

» be extended in order to accommodate all relevant information that currently exists in Cyprus; a prominent example is energy consumption by fuel in industrial sub-sectors, for which information has been existing since some years thanks to surveys of the Statistical Service but has never been incorporated in official energy balances.

Table 1: List of data sources

Data	Provider
Total sales and stock changes of petroleum products for 2012 & 2013	Cystat
Electricity consumption by sector and sub-sector in 2012	Cystat
Fuel consumption by industrial sub-sector (2-digit sectors according to classification NACE rev. 2)	Cystat
Imports and sales of biofuels	MECIT
Final energy demand for biomass, solar thermal and geothermal energy in non-industrial sectors	MECIT
Fuel consumption of cement plant for production purposes and for power generation	DLI
Electricity consumption by main sector in 2013	EAC
Fuel consumption of thermal power plants	EAC
Power generation from thermal plants and from renewable sources connected to the electricity grid	CERA/TSO
Autonomous power generation from renewable sources	MECIT
Other power generation data (auto-consumption of thermal power plants, independent electricity generation and auto-consumption of cement plant, transmission and distribution losses)	CERA/TSO

Acronyms:

Cystat – Cyprus Statistical Service; MECIT – Ministry of Energy, Commerce, Industry and Tourism; DLI – Department of Labour Inspection of the Ministry of Labour and Social Insurance; EAC – Electricity Authority of Cyprus; CERA – Cyprus Energy Regulatory Authority; TSO – Cyprus Transmission System Operator

2.2 Estimates of final and useful energy demand in households and hotels

According to the Terms of Reference of this project, it is desirable to provide detailed estimates of energy demand in the tourism sector as well as in buildings in order to identify potential interventions to increase the penetration of renewable energy sources in these sectors. Therefore, in this study a more in-depth analysis of final and useful energy demand was carried out in those sub-sectors for which some information was available. This was possible i) for residential energy demand, thanks to a detailed survey that was conducted by the Statistical Service in 2009, and ii) for fuel consumption in hotels, thanks to a recent survey by CUT and additional information provided by the Cyprus Hotels Association and the Cyprus Tourism Organisation. Conversely, it was not possible to prepare such an assessment for the rest of the buildings sector (i.e. governmental or commercial buildings). Hence this section focuses on households and hotels.

2.2.1 Residential energy demand by end uses

The Cyprus Statistical Service conducted a unique survey in 2009 that was targeted on final energy consumption of households by end use (space heating, space cooling, water heating, cooking, lighting and appliances)[1] . We made use of this survey and applied its information on final household energy demand from the energy balance of year 2013 in order to disaggregate final residential energy consumption by end use and to enable a forecast of the future final energy needs of households. Table 2 describes the individual calculation steps for deriving useful energy demand in the base year 2013. According to the data, gas oil systems dominate space heating equipment, and liquid petroleum gas (LPG) is still more widespread for cooking than electricity[2], while solar water heaters are dominant in water heating systems. Electricity is the second most widely used energy form for space heating, water heating and cooking, and obviously the exclusive energy form used for space cooling, lighting and appliances – with the exception of a small amount of geothermal energy for space cooling[3].

On the basis of this information, a forecast of residential demand for useful energy was performed. Each one of the five main end uses mentioned above was assumed to follow a different dynamic path in the future. Therefore, different sets of income and price elasticities were assumed by end use, and the evolution of useful energy demand was computed up to 2040. Regarding fuel shares, different assumptions were made about their evolution until 2040 for each end use, depending also on the thermal efficiency of each fuel/technology and the turnover of old equipment and its replacement with new more efficient equipment. For this purpose, an average lifetime of equipment for each end use was assumed and a simple model of replacement of older equipment with new equipment (assuming constant annual scrappage rates) was included. The results of this forecast procedure were then used to calibrate parameters of the final energy demand model (see Equation 11 in Section 2.3) so that results of the latter would coincide, in terms of market shares by fuel, with those of the simple useful energy model described above.

In this forecast and model calibration procedure, a substantial electrification further to that which was already happening was assumed to gradually take place in Cypriot households, through the penetration of electric cooking devices and highly efficient heat pumps for space heating. Central heating systems based on petroleum products (oil, kerosene and LPG) are assumed to lose most of their market share in the coming decades, particularly in the medium- and long-term, to be replaced mainly be electric heat pumps and to a lesser extent by solar central heating systems. Some small use of geothermal systems (ground source heat pumps) for space heating and cooling is also assumed, along with

[1] 'Final energy consumption in households'. Published online at www.mof.gov.cy/cystat on 5/10/2011 (last accessed in July 2014).

[2] This information may be somewhat outdated and needs to be treated with caution.

[3] 'The number of existing GSHP systems is still limited in Cyprus. Around 160 systems were in operation in early 2014. There were 151 closed loop vertical systems, accounting for 123.5 km of vertical ground heat exchangers (GHEx), three closed loop horizontal systems of 3.7 km horizontal GHEx, two open loop systems and four gross systems combining vertical and horizontal loops or vertical GHEx and open loop system. Most systems have been installed in residential buildings, mainly in single-family houses, while there are three in hotels, four in office buildings, two in multi-space buildings, one in a private school and one in a clinic. Total installed thermal capacity of these systems is estimated at about 9.5 MWth. Although the oldest known install tion has been in operation since 2006, there is insufficient information concerning their energy efficiency and operating conditions. More information can be found in: Michopoulos A., Tsikaloudaki A., Voulgari V. and Zachariadis T., 'Analysis of ground source heat pump systems in residential buildings', submitted to the World Geothermal Congress 2015, Melbourne, Australia.

limited deployment of solar air conditioning systems for space cooling.

Regarding the future efficiency of residential energy devices, a significant improvement in the efficiency (co-efficient of performance) of heat pumps is assumed, in line with current and anticipated technological progress in this field, as well as a modestimprovement in the thermal efficiency of conventional systems for space and water heating.

As mentioned in Section 2.1, in order to be able to provide a more reliable breakdown of residential energy demand in the future, it is recommended that the Cyprus Statistical Service conducts surveys on household energy use at regular intervals in the future. This will enable the capturing of structural changes in the use of energy-consuming appliances in Cypriot households, analysis of the energy behaviour of consumers and improvements in the medium- and long-term forecasts.

Table 2: Step-by-step calculation of useful energy demand in households by fuel and end use in the year 2013

1. Breakdown of final energy consumption in households by end use in tonne of oil equivalent (toe) and percentage.

	toe	%
Space heating	89,166	31.2%
Water heating	69,871	24.5%
Space cooling	22,854	8.0%
Cooking	32,829	11.5%
Appliances & lighting	70,727	24.8%
Total final energy consumption	285,447	100.0%

2. Breakdown of final energy consumption in households by fuel & end use

	Electricity	Gas oil	Kerosene	LPG	Biomass	Solar	Geo-thermal
Space heating	10.2%	93.4%	94.6%	39.9%	68.0%	0.2%	20.0%
Water heating	6.1%	6.6%	5.4%	6.5%	0.8%	99.8%	0.0%
Space cooling	17.6%	0.0%	0.0%	0.0%	0.0%	0.0%	80.0%
Cooking	8.9%	0.0%	0.0%	53.6%	31.1%	0.0%	0.0%
Appliances & lighting	57.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

3. Fuel shares of final energy consumption in households by end use

	Electricity	Gas oil	Kerosene	LPG	Biomass	Solar	Geo-thermal	Total
Space heating	10.2%	93.4%	94.6%	39.9%	68.0%	0.2%	20.0%	100.0%
Water heating	6.1%	6.6%	5.4%	6.5%	0.8%	99.8%	0.0%	100.0%
Space cooling	17.6%	0.0%	0.0%	0.0%	0.0%	0.0%	80.0%	100.0%
Cooking	8.9%	0.0%	0.0%	53.6%	31.1%	0.0%	0.0%	100.0%
Appliances & lighting	57.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%

4. Final energy consumption in households by end use (tonnes oil equivalent)

	Electricity	Gas oil	Kerosene	LPG	Biomass	Solar	Geo-thermal	Total
Space heating	12,548	49,200	9,326	15,513	2,195	89	295	89,166
Water heating	7,529	3,465	533	2,539	26	55,779	0	69,871
Space cooling	21,675	0	0	0	0	0	1,180	22,854
Cooking	10,951	0	0	20,873	1,005	0	0	32,829
Appliances & lighting	70,727	0	0	0	0	0	0	70,727
Total final energy consumption	123,431	52,665	9,859	38,924	3,226	55,868	1,475	285,447

5. Useful energy conversion factors by end use for the current stock of equipment

	Electricity	Gas oil	Kerosene	LPG	Biomass	Solar	Geo-thermal
Space heating	0.99	0.75	0.75	0.75	0.50	1.00	3.00
Water heating	0.99	0.75	0.75	0.75	0.50	0.89	n.a.
Space cooling	2.60	n.a.	n.a.	n.a.	n.a.	n.a.	3.00
Cooking	0.70	n.a.	n.a.	0.50	0.20	n.a.	n.a.
Appliances & lighting	0.95	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

6. Useful energy consumption in households by end use (tonnes of oil equivalent)

	Electricity	Gas oil	Kerosene	LPG	Biomass	Solar	Geo-thermal	Total
Space heating	12,423	36,900	6,995	11,635	1,097	89	885	70,024
Water heating	7,454	2,599	400	1,904	13	49,643	0	62,012
Space cooling	56,354	0	0	0	0	0	3,540	59,894
Cooking	7,666	0	0	10,436	201	0	0	18303
Appliances & lighting	67,191	0	0	0	0	0	0	67,191
Total useful energy	151,088	39,499	7,394	23,975	1,312	49,732	4,425	277,424

7. Fuel shares of useful energy consumption in households by end use

	Electricity	Gas oil	Kerosene	LPG	Biomass	Solar	Geo-thermal	Total
Space heating	17.7%	52.7%	10.0%	16.6%	1.6%	0.1%	1.3%	100.0%
Water heating	12.0%	4.2%	0.6%	3.1%	0.0%	80.1%	0.0%	100.0%
Space cooling	94.1%	0.0%	0.0%	0.0%	0.0%	0.0%	5.9%	100.0%
Cooking	41.9%	0.0%	0.0%	57.0%	1.1%	0.0%	0.0%	100.0%
Appliances & lighting	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%

2.2.2 Breakdown of final and useful energy demand in hotels

Introduction

Despite its importance for the economy of Cyprus, and the considerable amounts of energy it consumes, the hotel sector has not been subject to an in-depth energy analysis so far. Therefore, in contrast to households, for which a significant amount of available information was utilised to arrive at estimates of end-use-specific fuel consumption as shown in Section 2.2.1, a substantial number of assumptions had to be made for the respective estimates for hotels. The analysis presented in this section has been facilitated by the experiences of CUT staff from energy audits and analyses of residential and industrial buildings in Greece and Cyprus as well as from personal communication with engineers in charge of the operation of energy systems in large buildings around Cyprus (including several hotels). Moreover, valuable information has been derived from a detailed survey and analysis that was finalised in May 2014 as part of a graduate thesis at CUT[4] , which cast significant light on the production of hot water in hotels.

Tables 3 to 6 at the end of this section present the calculations made in order to arrive at estimates of useful and final energy demand in hotels by fuel and end use. Table 3 presents the main data used for each class of hotels[5] ; Table 4 shows a summary of aggregate final energy demand calculations for the whole hotel sector; and Tables 5 and 6 show the step-by-step calculations for each end use. The remainder of this section provides explanations about the data sources used and the assumptions made for each parameter that appears in these tables, outlines the remaining important gaps, and proceeds with recommendations to national energy authorities.

In comparison with the total final energy consumption of the whole tertiary sector of Cyprus, according to the 2013 energy balance that appears in Appendix II, our estimates show that in the tertiary sector hotels seem to account for 13% of gas oil consumption, 2% of LPG consumption, 6% of electricity and 6% of solar thermal energy (see Table 4). According to the Statistical Service, electricity consumption in the Statistical Classification of Economic Activities in the European Community's (NACE) sector 'Accommodation and Food Service Activities' was 467 GWh in year 2012, out of which 'accommodation' accounted for about 65% (or 304 GWh) and 'food service activities' for the other 35%. Our estimate, shown in Table 4, is that hotels consume 102.4 GWh of electricity; amounting to one third of the figure provided by the Statistical Service. There are at least two reasons for this underestimation. The first is that the 'accommodation' sector includes other types of accommodation such as hotel apartments, which were not taken into consideration in our estimates. Secondly, our calculations do not include electricity consumption for cooking, electric appliances and central ventilation systems.

Methodology and assumptions

» Main Data (Table 3)

Number of hotels: The number of the existing hotel units was retrieved from statistical data provided by the Cyprus Hotel Association (CHA) and Cyprus Tourism Organisation (CTO). These numbers represent the hotel units on record in early 2014.

Rooms: Data on the existing room units in Cyprus' hotels on record in early 2014 was taken from CHA.

Beds: The number of beds in Cyprus' hotels is included in the statistical reports of CTO.

Mean winter/summer room occupancy: This information has been estimated from the Net Room Occupancy Reports of 2009-2013, which have been provided by CTO. The mean winter and summer room occupancy is used in order to estimate the useful energy consumption for space heating and space cooling respectively.

Mean annual room occupancy: This has also been estimated from the Net Room Occupancy Reports of 2009-2013 provided by CTO. It is used in order to estimate the useful energy consumption for lighting.

[4] *Kerimis M. (May 2014), Energy and Environmental Impacts from the Use of Hot Water in the Hotels of Cyprus. MSc Thesis, Dept. of Environmental Science and Technology, Cyprus University of Technology, Limassol (in Greek)..*

[5] *Hotel class is defined through a star system (i.e. 1-star to 5-star hotels).*

Mean annual bed occupancy: Estimated from the Net Bed Occupancy Reports of 2010-2013, provided by CTO, it is used to compute useful energy consumption for hot water production.

Mean room surface: The mean room surface has been estimated from *in-situ* inspections of existing hotel blocks (performed by CUT staff) as well as from the information provided by hotel owners, operators and technical managers. This value is used in order to estimate the total room surface for each hotel category.

Room to space ratio: This represents the ratio of the total room surface to the total surface of the hotel blocks. This value has been estimated from *in-situ* inspections of existing hotel blocks (performed by CUT staff) as well as from information provided by hotel owners, operators and technical managers, and is used to estimate the total common surface of each hotel category.

Estimated room surface: Total room surface of each hotel category is estimated based on the mean room surface and the room units.

Estimated common surface: This expresses the surface of the common areas of the hotel blocks, i.e. corridors, lounges, restaurants, conference and meeting rooms.

Winter/summer common area operating factor: These two factors have been estimated from *in-situ* inspections of existing hotel blocks (performed by CUT staff) as well as from information provided by hotel owners, operators and technical managers. It represents the surface of common areas that is heated during winter time and cooled during summer time, respectively. These factors are used in order to estimate the useful energy consumption for space heating and space cooling.

» Space Heating (Table 5)

Consumption: This value represents the annual heating energy demand per square metre of each hotel category and has been estimated from the information provided by hotel owners, operators and technical managers as well as from the survey conducted by CUT.

Share of use by equipment: This includes the shares of different heating technologies that are in operation in the Cypriot hotel sector. These values have been estimated from the information provided by hotel owners, operators and technical managers as well as from the survey conducted by CUT.

Production efficiency: This expresses the efficiency of heating equipment. These values were estimated from the survey and additional simulations conducted by CUT.

Distribution efficiency: This is the efficiency of the distribution network of each heating system. These values were estimated according to standard EN 15316-2-3 and take into account the typical layout of the distribution networks in Cypriot hotels.

Emission efficiency: This is the efficiency of the emission devices per heating system. Values were estimated according to standard EN 15316-2-1 and take into account the typical emission devices in Cypriot hotels.

Total thermal efficiency: This expresses the overall efficiency of each heating system and is the product of production, distribution and emission efficiency.

Useful thermal energy consumption: This is calculated for each hotel category and heating system, taking into account heating demand per square metre, the heating surface, and the share of use of each heating system.

Final heating energy consumption: This is calculated from useful thermal energy consumption and total thermal efficiency.

» Space Cooling (Table 5)

Consumption: This value represents the annual cooling energy demand per square metre of each hotel category and has been estimated from the information provided by hotel owners, operators and technical managers as well as from the survey conducted by CUT.

Share of use by equipment: This includes the shares of different cooling technologies that are in operation in the Cypriot hotel sector. It is estimated from the information provided by hotel owners, operators and technical managers as well as from the survey conducted by CUT.

Production efficiency: This expresses the efficiency of space cooling equipment. These values were estimated from our survey and from simulations conducted by CUT.

Distribution efficiency: This is the efficiency of the distribution network of each heating system. These values were estimated according to standard EN 15316-2-3 and take into account the typical layout of the distribution networks in Cypriot hotels.

Emission efficiency: This is the efficiency of the emission devices of each cooling system. Values were estimated according to standard EN 15316-2-1 and take into account the typical emission devices in Cypriot hotels.

Total cooling efficiency: The overall efficiency of each cooling system is the product of production, distribution and emission efficiency.

Useful cooling energy consumption: This is computed for each hotel category and cooling system, taking into account cooling demand per square metre, the cooling surface and the share of use of each cooling system.

Final cooling energy consumption: This is calculated by hotel category and cooling system with the aid of useful cooling energy consumption and total cooling efficiency.

» Hot water (Table 6)

Consumption: This value represents the hot water consumption per person per night of each hotel category and was estimated from the CUT survey.

Share of use by equipment: This is the share of different hot water production technologies that are in operation in Cypriot hotels and was estimated from the information provided by hotel owners, operators and technical managers as well as from the CUT survey.

Production efficiency: This expresses the efficiency of hot water producing equipment. These values were estimated from the survey and additional simulations conducted by CUT.

Distribution efficiency: These are efficiency figures for hot water distribution networks per heating system. These values were estimated according to standard EN 15316-2-3 and take into account the typical layout of the distribution networks in Cypriot hotels and the fact that these networks are in continuous operation throughout the day.

Storage efficiency: This expresses the efficiency of water storage tanks. These values were estimated according to the related literature and common practice taking into account that the majority of the storage tanks in Cypriot hotels are installed in the interior of hotels.

Total hot water system efficiency: The overall efficiency of each hot water production system is the product of each system's production, distribution and storage efficiency.

Useful hot water energy consumption: This is computed by hotel category and hot water production system, taking into account the hot water consumption per person per night, the mean annual room occupancy, the share of use of each production system, and the temperature difference between the desirable hot water temperature (50°C) and the mean annual water temperature in distribution networks (18°C).

Final hot water energy consumption: This is calculated on the basis of useful hot water energy consumption and total hot water system efficiency.

» Lighting (Table 6)

Consumption: This value represents the annual electricity consumption per square metre of each hotel category and has been estimated from the CUT survey as well as from the information provided by hotel owners, operators and technical managers.

Useful lighting energy consumption: This is calculated for each hotel category taking into account the electricity consumption per square metre, the estimated surface of each hotel category and the mean annual room occupancy.

Final lighting energy consumption: This is calculated for each hotel category from useful lighting energy consumption and total lighting efficiency (equal to 1).

Major gaps remaining

Due to the lack of available raw data, the above analysis does not include any estimate on the consumption of cooking and restaurant equipment as well as electrical appliances installed in hotels. In the absence of any relevant information, such an estimate would be too uncertain. This is an important gap in the energy analysis of the hotel sector and has to be corrected through a dedicated survey in hotels (which is particularly relevant for cooking equipment) and with the aid of data from international literature (which should be sufficient to estimate energy consumption of appliances).

Moreover, our calculations ignore the existence of central ventilation systems that are in operation in many hotels and consume non-negligible amounts of electricity. This electricity consumption has been excluded from this analysis due to the unavailability of primary information.

Recommendations for improving the energy analysis in the tourism sectors

The following recommendations are presented in order to improve the accuracy of the analysis and improve the understanding of the energy consumption in the tourism sector of Cyprus:

- An extensive survey needs to be conducted, which should focus not only on hotels but on all tourist establishments like hotel apartments, tourist apartments and houses etc. Within this survey primary data concerning the energy consumption for heating, cooling, hot water production and lighting as well as for equipment usage should be collected. It would also be interesting to include the main characteristics of the building envelopes, such as thermal transmittance of building elements and external openings.
- A second survey on cooking equipment and its energy consumption should be performed due to the fact that the cooking facilities in the majority of Cypriot hotels are characterised as 'industrial scale' facilities, as they have to prepare more than 2,000 meals per day.
- In collaboration with the Electricity Authority of Cyprus, gathering a complete record of the electricity consumption of each hotel category over the last four years would be useful in order to improve the reliability of the estimates of electricity demand.

Table 3: Main data and assumptions for calculation of energy demand in Cypriot hotels.

Class (no. of stars)	Number of hotels	Rooms	Beds	Mean winter room occupancy	Mean summer room occupancy	Mean annual bed occupancy	Mean annual bed occupancy	Mean room surface [m²]	Room to space ratio	Estimated room surface [m²]	Estimated common surface [m²]	Winter common area operating factor	Summer common area operating factor
5	25	5,853	11,464	35.5%	63.0%	57.8%	55.8%	34.0	65.0%	199,002	69,651	50%	100%
4	57	10,573	21,079	45.6%	70.7%	66.9%	66.2%	30.0	68.0%	317,190	101,501	50%	100%
3	77	8,163	15,679	37.5%	64.3%	61.6%	64.7%	26.0	70.0%	212,238	63,671	50%	100%
2	44	1,936	3,739	27.9%	42.2%	39.0%	33.2%	24.0	73.0%	46,464	12,545	40%	80%
1	21	522	1,030	13.3%	17.7%	16.9%	17.4%	22.0	75.0%	11,484	2,871	30%	60%

Table 4: Summary of estimated final energy consumption in Cypriot hotels

Final energy consumption in Cypriot hotels in year 2013						
(MWh)	Oil	LPG	Electricity	Solar	Geothermal	Total
Space heating	5,989	1,497	5,837	0	41	13,363
Space cooling	0	0	79,600	0	0	79,600
Hot water	31,855	1,622	2,670	7,138	0	43,285
Lighting	0	0	14,254	0	0	14,254
Total	37,844	3,119	102,360	7,138	41	150,502
(toe)	Oil	LPG	Electricity	Solar	Geothermal	Total
Space heating	515	129	502	0	4	1,149
Space cooling	0	0	6,844	0	0	6,844
Hot water	2,739	139	230	614	0	3,722
Lighting	0	0	1,226	0	0	1,226
Total	3,254	268	8,801	614	4	12,941

Table 5: Step-by-step calculation of useful and final energy demand from space heating and cooling in Cypriot hotels in the year 2013

Space heating

Share of use by equipment

Class (no. of stars)	Consumption [kWh/m²/a]	Oil boiler	LPG boiler	Air source HP	Geothermal HP
5	50	20.0%	5.0%	74.0%	1.0%
4	50	20.0%	5.0%	75.0%	0.0%
3	45	20.0%	5.0%	75.0%	0.0%
2	40	20.0%	5.0%	75.0%	0.0%
1	40	20.0%	5.0%	75.0%	0.0%

1 Production efficiency

Class (no. of stars)	Oil boiler	LPG boiler	Air source HP	Geothermal HP
5	0.88	0.88	3.00	5.00
4	0.88	0.88	3.00	5.00
3	0.88	0.88	3.00	5.00
2	0.88	0.88	3.00	5.00
1	0.88	0.88	3.00	5.00

2 Distribution efficiency

Class (no. of stars)	Oil boiler	LPG boiler	Air source HP	Geothermal HP
5	0.89	0.89	0.96	0.96
4	0.89	0.89	0.96	0.96
3	0.89	0.89	0.96	0.96
2	0.89	0.89	0.96	0.96
1	0.89	0.89	0.96	0.96

Space cooling

Share of use by equipment

Consumption [kWh/m²/a]	Air source HP	Geothermal HP
275	99.0%	1.0%
260	100.0%	0.0%
245	100.0%	0.0%
230	100.0%	0.0%
230	100.0%	0.0%

1 Production efficiency

Class	Air source HP	Geothermal HP
5	2.80	4.50
4	2.80	4.50
3	2.80	4.50
2	2.80	4.50
1	2.80	4.50

2 Distribution efficiency

Class	Air source HP	Geothermal HP
5	0.94	0.94
4	0.94	0.94
3	0.94	0.94
2	0.94	0.94
1	0.94	0.94

Space heating

3 Emission efficiency

Class (no. of stars)	Oil boiler	LPG boiler	Air source HP	Geothermal HP
5	0.89	0.89	0.93	0.93
4	0.89	0.89	0.93	0.93
3	0.89	0.89	0.93	0.93
2	0.89	0.89	0.93	0.93
1	0.89	0.89	0.93	0.93

Total thermal efficiency

Class (no. of stars)	Oil boiler	LPG boiler	Air source HP	Geothermal HP
5	0.70	0.70	2.68	4.46
4	0.70	0.70	2.68	4.46
3	0.70	0.70	2.68	4.46
2	0.70	0.70	2.68	4.46
1	0.70	0.70	2.68	4.46

Useful thermal energy consumption [kWh/a]

Class (no. of stars)	Oil boiler	LPG boiler	Air source HP	Geothermal HP
5	1,054,711	263,678	3,902,429	52 736
4	1,953,890	488,473	7,327,089	0
3	1,002,825	250,706	3,760,592	0
2	143,853	35,963	539,447	0
1	19,109	4,777	71,660	0

3 Emission efficiency

Class (no. of stars)	Air source HP	Geothermal HP
5	0.93	0.93
4	0.93	0.93
3	0.93	0.93
2	0.93	0.93
1	0.93	0.93

Total cooling efficiency

Class (no. of stars)	Air source HP	Geothermal HP
5	2.45	3.93
4	2.45	3.93
3	2.45	3.93
2	2.45	3.93
1	2.45	3.93

Useful cooling energy consumption [kWh/a]

Class (no. of stars)	Air source HP	Geothermal HP
5	53,094,729	536,310
4	84,696,074	0
3	49,034,406	0
2	6,818,127	0
1	863,712	0

Space heating					
	Final heating energy consumption [kWh/a]				
Class (no. of stars)	Oil boiler	LPG boiler	Electricity	Electricity geoth. HP	Geothermal
5	1,513,110	378,278	1,457,000	11,814	40,922
4	2,803,093	700,773	2,735,622	0	0
3	1,438,674	359,668	1,404,044	0	0
2	206,374	51,593	201,406	0	0
1	27,415	6,854	26,755	0	0
Total	5,988,666	1,497,166	5,824,827	11,814	40,922

Space cooling		
	Final cooling energy consumption [kWh/a]	
Class (no. of stars)	Electricity air HP	Electricity geoth. HP
5	21,691,150	136,330
4	34,601,462	0
3	20,032,359	0
2	2,785,456	0
1	352,858	0
Total	79,463,284	136,330

Table 6: Step-by-step calculation of useful and final energy demand from hot water production and lighting in Cypriot hotels in the year 2013

Hot water					
		Share of use by equipment			
Class (no. of stars)	Con-sumption [L/pn]	Oil boiler	LPG boiler	Air source HP	Solar thermal
5	120	50%	5%	20%	25%
4	85	50%	5%	20%	25%
3	65	50%	5%	20%	25%
2	55	50%	5%	20%	25%
1	55	50%	5%	20%	25%

1 Production efficiency				
Class (no. of stars)	Oil boiler	LPG boiler	Air source HP	Solar Thermal
5	0.88	0.88	4.20	1.00
4	0.88	0.88	4.20	1.00
3	0.88	0.88	4.20	1.00
2	0.88	0.88	4.20	1.00
1	0.88	0.88	4.20	1.00

Lighting	
Class (no. of stars)	Consumption [kWh/m²/a]
5	23.5
4	23.0
3	21.5
2	20.0
1	20.0

Hot water

2 Distribution efficiency

Class (no. of stars)	Oil boiler	LPG boiler	Air source HP	Solar thermal
5	0.70	0.70	0.70	0.70
4	0.70	0.70	0.70	0.70
3	0.70	0.70	0.70	0.70
2	0.70	0.70	0.70	0.70
1	0.70	0.70	0.70	0.70

3 Storage efficiency

Class (no. of stars)	Oil boiler	LPG boiler	Air source HP	Solar thermal
5	0.93	0.93	0.93	0.93
4	0.93	0.93	0.93	0.93
3	0.93	0.93	0.93	0.93
2	0.93	0.93	0.93	0.93
1	0.93	0.93	0.93	0.93

Total hot water system efficiency

Class (no. of stars)	Oil boiler	LPG boiler	Air source HP	Solar thermal
5	0.57	0.57	2.73	0.65
4	0.57	0.57	2.73	0.65
3	0.57	0.57	2.73	0.65
2	0.57	0.57	2.73	0.65
1	0.57	0.57	2.73	0.65

Useful hot water energy consumption [kWh/a]

Class (no. of stars)	Oil boiler	LPG boiler	Air source HP	Solar thermal
5	5,205,210	265,754	2,082,084	1,328,772
4	8,042,916	403,424	3,217,167	2,017,120
3	4,471,185	232,785	1,788,474	1163,923

Lighting

Useful lighting energy consumption [kWh/a]

Class (no. of stars)	Electricity
5	3,649,110
4	6,442,395
3	3,654,144

Hot water				
2	462,959	23,971	185,184	119,857
1	66,840	3,387	26,736	16,937

	Final hot water consumption [kWh/a]			
Class (no. of stars)	Oil boiler	LPG boiler	Electricity	Solar thermal
5	9,086,039	463,892	761,497	2 041,125
4	14,039,443	704,203	1,176,639	3 098,495
3	7,804,749	406,341	654,112	1 787,899
2	808,126	41,844	67,729	184,112
1	116,673	5,913	9,778	26,017
Total	31,855,031	1,622,193	2,669,755	7,137,648

Lighting	
2	119,857
1	16,937

	Final lighting energy consumption [kWh/a]
Class (no. of stars)	Electricity
5	3,649,110
4	6,442,395
3	3,654,144
2	460,272
1	48,520
Total	14,254,441

2.3 Methodology to forecast final energy demand

2.3.1 Introduction

This section presents the mathematical specification of the model developed and used by CUT to perform forecasts of final energy demand for the Republic of Cyprus. This methodology was first presented by Michael (2012)[6] and is based on a simplified energy model that was developed by the first author at the National Technical University of Athens in 2000-2002 and was used for energy forecasts of Central and Eastern European countries as part of energy modelling projects funded by the European Commission.

The model calculates future annual energy consumption in each major economic sector of Cyprus (agriculture, cement industry, other industry, households, services, road passenger transport, road freight transport and air transport) as a function of future macroeconomic variables and energy prices. It also calculates fuel shares in each sector, depending on technology costs (investment, operation, maintenance and fuel costs), the penetration potential of various technologies and technical constraints for the uptake of new technologies, and allows for computing of future final energy consumption by sector and fuel. Section 2.3.2 describes the mathematical formulation for calculating aggregate energy demand by sector, while Section 2.3.3 focuses on calculation of energy demand by sector and fuel. Section 2.3.4 provides some information on running the model and calibrating it to base year statistics.

2.3.2 Total final energy demand

Final energy demand, by economic sector and year, is the sum of demand for substitutable energy and demand of non-substitutable electricity. The former denotes all final energy forms that are used in various sectors and usages (including a fraction of electricity consumption), which may be substituted by other energy forms in the future. The latter denotes use of electricity in appliances and for lighting purposes, where electricity does not compete with other fuels and therefore all such uses will continue to be covered by electricity in the foreseeable future; non-substitutable electricity follows its own dynamic path in the model.

$$EN_{i,t} = E_{i,t} + ELCNS_{i,t} \qquad (1)$$

where

EN final energy demand (in ktoe) in sector *i* and year *t*,

E final substitutable energy demand (in ktoe)

ELCNS final demand for non-substitutable electricity (in ktoe)

Final demand for substitutable energy is calculated with the following formula:

$$E_{i,t} = E_{i,t-1} \cdot \left(1 - eff_{i,t}\right) \cdot \left(\frac{A_{i,t}}{A_{i,t-1}}\right)^{\alpha} \cdot \left(\frac{ap_{i,t}}{ap_{i,t-1}}\right)^{\beta_1} \cdot \left(\frac{ap_{i,t-1}}{ap_{i,t-2}}\right)^{\beta_2} \cdot \prod_{r=2}^{7} \left(\frac{ap_{i,t-r}}{ap_{i,t-r-1}}\right)^{\varphi\left(\frac{r}{n}\right) \cdot \gamma} \qquad (2)$$

where

eff exogenous energy efficiency improvement in sector *i* and year *t*

A economic activity variable that is relevant for sector *i;* Table 7 presents the different economic sectors included in the model and the corresponding activity variable of each sector

ap average energy price in sector *i;* this is the weighted average of fuel prices used in this sector; in order to avoid unnecessary simultaneity problems in solving the model, ap is calculated every year on the basis of the fuel shares of the previous year

φ(r/n) polynomial distributed lag with *n=5*. It is applied to the long-term elasticity of energy demand with respect to prices of years *t-3* to *t-7* in order to simulate a 'parabolic' price

[6] *Michael M. (2012), Development of a Mathematical Model for Long-Term Energy Planning in Cyprus. MSc Thesis, Dept. of Environmental Science and Technology, Cyprus University of Technology, Limassol (in Greek).*

effect: the long-term effect of energy prices is less pronounced for recent price developments (e.g. of years *t-3* and *t-4*), is stronger for prices of intermediate years and fades slowly in later years, so that the price developments of years *t*-8 and before do not affect today's energy demand at all.

It is calculated as follows:

$$\varphi\left(\frac{r}{n}\right) = \frac{6(n+1-r)r}{n(n+1)(n+2)} \qquad (3)$$

As regards the exponents of equation (2), α is the assumed income elasticity, β_1 and β_2 are short-term price elasticities, and γ is the long-term price elasticity. These elasticities vary by sector and year but indices i and t are omitted here for brevity. Table 8 shows these elasticities for the base year; to what extent their value changes over the forecast period depends on each scenario's assumptions and will be described in Section 2.4.

Turning back to the average energy price *ap* of equation (2), this is calculated as follows:

$$ap_{i,t} = \sum_j \left(W_{i,j,t-1} \cdot p_{j,t}\right) \qquad (4)$$

where

W the share of consumption of fuel *j* in sector *i* in year t-1 over total fuel consumption of that sector and year

p end-user price of fuel *j* in year *t* (in constant euros per toe). For future years, this is calculated with the following formula:

$$p_{j,t} = p_{j,t-1} + ppa_j \cdot \left(p_{oil,t} - p_{oil,t-1}\right) + r_{j,t} \qquad (5)$$

where

p_{oil} the international crude oil price in a given year (in constant euros per toe), according to an exogenous oil price forecast – usually adopted from a forecast of an international organisation such as the International Energy Agency or the US Department of Energy's Energy Information Administration; since up to now all fuels used in Cyprus are petroleum products, the crude oil price is decisive for the evolution of their end-user prices [7]

ppa coefficient (derived through a simple statistical estimation) expressing the pass-through of a change in international crude oil prices to retail fuel prices in Cyprus

r adjustment coefficient that may be used to account for e.g. changes in fuel taxation from a year onwards as a result of a policy change, imposition of carbon taxes etc.

The fuels/energy forms j considered in the model are: gasoline, automotive diesel, aviation kerosene, gas oil, light fuel oil, heavy fuel oil, liquefied petroleum gas (LPG), coal, biomass, biofuels, electricity, solar energy, geothermal energy and hydrogen. Obviously, not all fuels are relevant for all economic sectors – for example, coal has historically been used only in the cement industry in Cyprus. In the road transport sector (passenger and freight) there is a further breakdown to hybrid technologies – hybrid gasoline vehicles and hybrid diesel vehicles.

Turning to Equation 1, final demand for non-substitutable electricity is calculated with the following formula:

$$ELCNS_{i,t} = ELCNS_{i,t-1} \cdot \left(1 - ef_{i,t}f_{i,t}\right) \cdot \left(\frac{A_{i,t}}{A_{i,t-1}}\right)^{\alpha_e}$$

$$\cdot \left(\frac{pelc_{i,t}}{pelc_{i,t-1}}\right)^{\beta e_1} \cdot \left(\frac{pelc_{i,t-1}}{pelc_{i,t-2}}\right)^{\beta e_2} \cdot \prod_{r=2}^{7} \qquad (6)$$

where *pelc* is the retail price of electricity in sector *i* and year *t.*

The exponents of Equation 6 denote elasticities in the same manner with the corresponding ones of Equation 2.

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[7] *There is a small amount of coal used in the cement industry; a simple separate forecast is made for the evolution of coal prices.*

Table 7: List of economic sectors covered in the energy demand model and the corresponding economic activity variable A of Equation 2

Sector	*Activity variable*
Agriculture	Value-added of agriculture, forestry and fishing
Cement industry	Value-added of cement industry
Other industry	Value-added of all industry except cement industry
Households	Private consumption
Services	Value-added of tertiary sector
Road passenger transport	Private consumption
Road freight transport	Gross domestic product
Aviation	Gross domestic product

Table 8: Elasticities currently used in the model in line with Equations 2 and 6

Sector	*Income elasticity (α)*	*Short-term price elasticity (β_1, β_2)*	*Long-term price elasticity (γ)*
Substitutable energy forms in:			
Agriculture	0.7	-0.15	-0.60
Cement industry	0.7	-0.20	-0.80
Other industry	0.7	-0.20	-0.80
Households	0.7	-0.15	-0.60
Services	0.7	-0.20	-0.80
Road passenger transport	0.9	-0.15	-0.60
Road freight transport	1.1	-0.15	-0.60
Aviation	1.2	-0.20	-0.80
Non-substitutable electricity in:			
Agriculture	0.8	-0.15	-0.60
Cement industry	0.9	-0.10	-0.40
Other industry	0.9	-0.10	-0.40
Households	1.1	-0.10	-0.40
Services	1.1	-0.05	-0.20

2.3.3 Calculation of fuel shares and future final energy demand by fuel

Focusing now on the consumption of substitutable energy, it is necessary to compute for each future year the fuel/technology shares in final energy demand by sector. For equipment that survives from the previous year, final energy demand by sector and fuel is calculated as follows:

$$\overline{E_{i,j,t}} = E_{i,j,t-1} \cdot (1 - eff_t) \cdot \left(\frac{A_{i,t}}{A_{i,t-1}}\right)^{\alpha} \cdot \left(\frac{ap_{i,t}}{ap_{i,t-1}}\right)^{\beta_1} \cdot \left(\frac{ap_{i,t-1}}{ap_{i,t-2}}\right)^{\beta 2} \quad (7)$$

$$\cdot \prod_{r=2}^{7} \left(\frac{ap_{i,t-r}}{ap_{i,t-r-1}}\right)^{\varphi\left(\frac{r}{n}\right)\cdot\gamma} \cdot \frac{LF_{i,j} - 1}{LF_{i,j}}$$

with notations similar to those of Equation 2, and LF the lifetime of typical energy-using equipment in sector *i* using fuel *j*.

Summing up over all fuels *j* in a given sector *i*, one can obtain total final energy consumption in this sector from equipment that has survived in year *t* from previous years. In most cases, this sum will not be equal to the sector's total substitutable energy use $E_{i,t}$ as computed by Equation 2. The difference between the two is:

$$NEW_{i,t} = E_{i,t} - \sum_{j} \overline{E_{i,j,t}} \quad (8)$$

If *NEW* is positive, which is the normal case in times of economic growth and rising energy use, this means that total demand for substitutable energy in this sector cannot be satisfied by surviving equipment alone, hence new equipment has to be installed to fill this gap:

$$\text{If } NEW_{i,t} > 0 \text{ then } \mathrm{E}_{i,j,t} = \overline{\mathrm{E}_{i,j,t}} + s_{i,j,t} \cdot NEW_{i,t} \quad (9)$$

where s denotes the share of fuel/technology *j* in that sector's new energy-using equipment.

On the other hand, if *NEW* is negative, which may occur in case of an economic recession or a strong reduction in energy use for other reasons, an adjustment of the calculated fuel-specific energy consumption is necessary in order to equate it with the sector's total substitutable energy use $E_{i,t}$.

$$\text{If } NEW_{i,t} \le 0 \text{ then } \mathrm{E}_{i,j,t} = \mathrm{E}_{i,j,t-1} \frac{\mathrm{E}_{i,t}}{\mathrm{E}_{i,t-1}} \quad (10)$$

The fuel/technology share s of equation (9) is calculated with the aid of the following formula, which involves an implicit cost minimisation:

$$s_{i,j,t} = w_{i,j,t} \frac{\left(\frac{d_i . e^{d_i LF_{i,t}}}{e^{d_i LF_{i,t}} - 1} . CC_{i,j,t} + FC_{i,j,t} + \frac{\left(VC_{i,j,t} + \frac{p_j}{eff_{j,t}} \right)}{CONV_{i,j,t}} \right)^{\eta}}{SUM_{i,t}} \quad (11)$$

with

$$SUM_{i,t} = \sum_{j} w_{i,j,t} \cdot \left(\frac{d_i . e^{d_i LF_{i,j}}}{e^{d_i LF_{i,j}} - 1} . CC_{i,j,t} + FC_{i,j,t} + \frac{\left(VC_{i,j,t} + \frac{p_j}{eff_{j,t}} \right)}{CONV_{i,j,t}} \right)^{\eta} \quad (12)$$

where

CC capital costs of technology *j* (in constant euros per installation)

FC fixed operation & maintenance costs of technology *j* (in constant euros per year)

VC variable operation & maintenance costs of technology *j* (in constant euros per appropriate unit depending on the sector)

d real discount rate used for energy investment decisions in sector i; in line with values assumed in European Commission's energy forecasts[8] , discount rates of 12% for firms and 17% for private individuals are used in the model; in other words, *d=17%* for households and road passenger transport and *d=12%* for all other sectors.

eff 'efficiency' factor depending on sector (e.g. fuel consumption in litres per 100 kilometres for cars and trucks or in kilograms per hour for boilers etc.)

CONV appropriate conversion factor, depending on sector, in order to convert variable and fuel costs to the same unit with annualised capital and fixed maintenance costs – e.g. kilometres travelled per year for vehicles, hours of operation of boilers per year etc.

[8] *European Commission (2014), EU Energy, Transport and GHG Emissions – Trends to 2050 – Reference Scenario 2013. Publications Office of the European Union, Luxembourg; ISBN 978-92-79-33728-4. Also at http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2050_u date_2013.pd*

w technology 'maturity factor' – a figure taking any non-negative value, expressing the potential of a given fuel/technology *j* to penetrate the market in that sector; e.g. *w = 0* for coal in industries other than cement industry because historically there has been no coal use in these sectors in Cyprus; or *w = 1* (a relatively high figure) for hybrid vehicle technologies that may be promoted in the near future.

Equation 9 implies that the fuel/technology with the lowest annualised costs (comprising investment, operation & maintenance and fuel costs) will gain the highest share in new energy-using equipment. The relative advantage of the cheapest technology is largely determined by the substitution elasticity η of Equations 11 and 12. The higher η is (in absolute terms) the higher the shares of the cheapest technologies – and correspondingly the lower the shares of the most costly technologies. For →-∞, the computed shares correspond to those of an optimisation algorithm, i.e. the cheapest technology gets the full share of the market. We currently use η = -1 across all sectors, in order to allow for many technologies to have a share in the market since real-world market shares are not determined by annualised costs alone but by a number of other factors that are not accounted for in the model's equations.

Calculating $\overline{E_{i,j,t}}$ from equation (7), $NEW_{i,t}$ from equation (8) and (if applicable) $s_{i,j,t}$ from equation (11), it is possible to compute annual energy demand by sector and fuel $E_{i,j,t}$ from equation (9) or equation (10). By definition, due to the adjustments made before, total sectoral non-substitutable energy consumption computed in equation (2) is equal to the sum of fuel-specific sectoral consumption – i.e. $E_{i,t} = \sum_j E_{i,j,t}$ If non-substitutable electricity consumption from equation (6) is added to it in line with Equation 1, this leads to the calculated total annual energy consumption by sector $EN_{i,t}$ for each future year.

2.3.4 Implementation of the energy forecast

Due to the recursive form of the model's equations, a forecast can start from any year *t* – the base year – using energy, macroeconomic and price data from official sources, and proceed year by year until 2040 with the use of the formulae described above. When data for a more recent year *t'* becomes available, the new year can become the base year, and the forecast can then start from year *t'+1* onwards. This makes it easy to update national energy forecasts when new base year data are available.

The fraction of electricity consumption that is considered to be non-substitutable is assumed for the base year. Thus base year $ELCNS_{i,t}$ is determined and then follows its own dynamic evolution over the forecast horizon through the use of equation 6. For obvious reasons, ELCNS is zero for all transport sectors, while it is equal to different percentages of total electricity use in the other sectors. Thanks to the information collected and analysed regarding end uses in households (see Section 3), the percentage of ELCNS for households is assumed to be 60%, roughly equal to the fraction of electricity used for lighting and appliances as shown in Table 2. In the absence of any information on end uses in the other sectors, we assumed that this ELCNS share is also 60% for services and 50% for industry and agriculture (representing electricity uses for stationary machinery and lighting).

2.4 Assumptions for the energy demand forecasts

2.4.1 Macroeconomic and oil price assumptions

As is evident from the description of Section 2.3, our model – like many energy forecast models applied worldwide – relies on the evolution of several exogenous variables, such as the economic activity variables listed in Table 7, the international oil price variable used in equation 5, and variables expressing policy-induced energy efficiency improvements. This section documents the assumptions made for the evolution of exogenous variables and describes four different scenarios that have been designed for the purpose of this report. At the current stage of the study, the evolution of major macroeconomic and oil price variables is assumed to follow one specific path for all scenarios considered. This may change in future model runs; it has to be noted, however, that there is currently no alternative macroeconomic scenario under consideration by any one of the competent national and international authorities, hence it is difficult for non-experts such as the study team of this project to design alternative long-term macroeconomic paths that will follow a consistent macroeconomic 'storyline' that is different from those of established international organisations.

More specifically, the macroeconomic outlook for Cyprus has changed considerably in 2013-2014 in comparison to the recent past. After some dramatic events in spring 2013 and requirements for fiscal adjustment as well as downsizing and restructuring of the domestic banking sector in order to attain sustainable levels of public debt in the medium term, an economic and financial adjustment programme for Cyprus was agreed between the national authorities and the Troika (European Commission, European Central Bank and International Monetary Fund). This adjustment programme has led to a strong contraction of the national economy in 2013-2014, while a slow rebound of economic growth is expected from 2015 onwards. The forecasts presented in this study adopt the official short-term forecasts of the Cyprus Ministry of Finance and international organisations regarding the evolution of macroeconomic variables such as gross domestic product (GDP) and private consumption. According to these, GDP is expected to reach pre-crisis levels (i.e. those of the period 2008-2011) by the year 2021. As for the evolution in the longer term, it was assumed that economic growth will continue albeit at gradually lower rates. This is in line with official demographic projections for Cyprus, which foresee that total population will start declining around 2030, so that moderate total GDP growth combined with a decreasing population will lead to a stable growth rate in the per capita GDP of the order of 2.1% per year after 2030. Table 9 shows these assumptions.

Regarding the contribution of each economic sector to total GDP, although the adjustment programme is generally expected to affect services more strongly than other sectors of the economy, there are still vague indications about a potential change in the structure of the GDP. In fact, some subsectors of the tertiary sector have turned out to be less vulnerable to the adjustment than initially expected. As the published macroeconomic forecasts do not include projections for the evolution of sectoral GDP shares, we assumed modest changes in sectoral contributions to GDP. More specifically, three assumptions were made – that the share of industry and agriculture will slightly fall in the future, that the share of the

Table 9: Assumptions on the evolution of GDP, private consumption and sectoral GDP shares in Cyprus

	Actual values in 2013	**Forecast of real growth rates (average over each period)**		
	(million euros)	***2014-2020***	***2020-2030***	***2030-2040***
GDP	16,504	1.9%	2.2%	2.0%
Private consumption	11,447	2.6%	2.6%	2.1%
Sectoral GDP shares	*Actual in 2013*	*2020*	*2030*	*2040*
Agriculture	2.4%	2.2%	1.9%	1.8%
Industry	8.6%	8.5%	8.4%	8.1%
Construction	4.8%	6.3%	8.5%	8.8%
Services	84.3%	83.0%	81.2%	81.3%

Source: Authors' assumptions based on: national accounts; forecast provided through personal communication with the Ministry of Finance of Cyprus in May 2014; short-term economic forecasts of the European Commission for Cyprus as of May 2014[9] ; and projections from the IMF World Economic Outlook Database as of April 2014[10]

[9] *European Commission (2014), European Economic Forecasts – Spring 2014. Report 'European Economy' No 3/2014, KC-AR-14-003-EN-N; Brussels; May 2014. Also at http://ec.europa.eu/economy_finance/eu/forecasts/2014_spring_forecast_en.htm (last accessed 7 July 2014)*
[10] *IMF (2014), IMF World Economic Outlook Database. International Monetary Fund, Washington D.C., last updated 8 April 2014. Available at www.imf org/external/pubs/ft/weo/data/assump.htm (last accessed 7 July 2014).*

construction sector will gradually rebound but will not return to pre-crisis levels, and that the share of the tertiary sector will increase further. The evolution of sectoral GDP shares is included in Table 9 and illustrated in Figure 1, which also shows their historical development since 1995.

As regards the evolution of crude oil prices, this study has adopted the latest oil price forecasts published by the International Energy Agency in November 2013[11]. According to the IEA's medium forecast ('New Policies Scenario'), crude oil price is expected to increase slightly and reach USD 113 per barrel in 2020 (at constant prices of year 2012) with a further increasing trend in later years, up to USD 128 in 2035. For the purpose of this study we extrapolated IEA's trend of the period 2030-2035 up to 2040, which leads to a crude oil price of USD 135 per barrel (at 2012 prices).

2.4.2 Scenarios considered

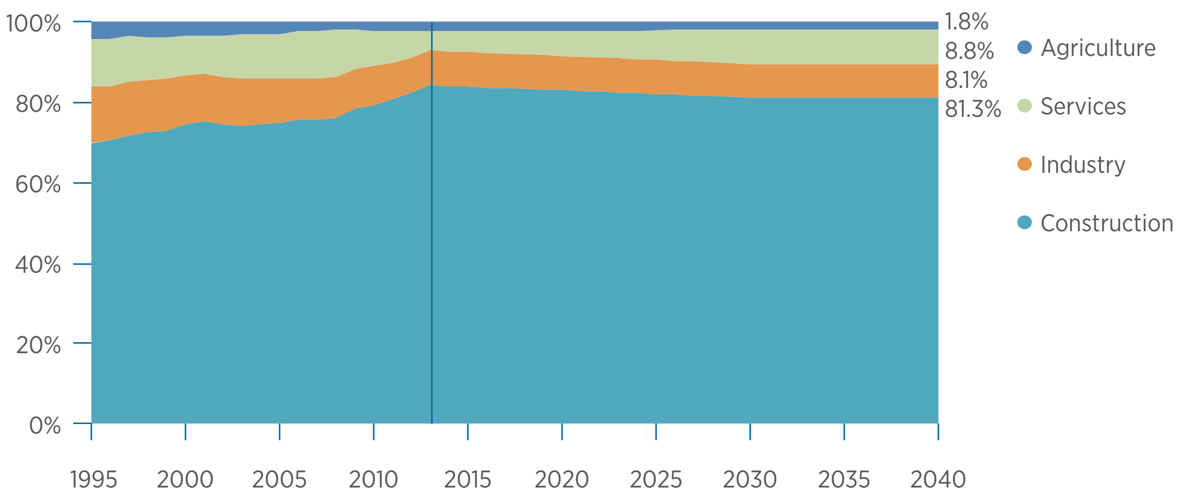
Four distinct scenarios were designed in the context of this study, featuring alternative assumptions about i) the implementation of more stringent economy-wide energy saving measures and ii) the existence or not of saturation effects in the use of energy-consuming appliances and equipment.

In order to ensure consistency with previous modelling work that was carried out by CUT for the Ministry of Energy, Commerce, Industry and Tourism, the first two scenarios are updated versions of the corresponding two scenarios that were used in the 3rd National Energy Efficiency Action Plan (NEEAP 2014) which was submitted to the European Commission in April 2014[12]. These are:

1. The Reference Scenario, which assumes that no additional measures – at EU and national levels – are implemented after 2010. In other words, directives adopted in 2010 and national subsidies up to 2010 are assumed to take effect, but no post-2010 actions are included. Although this scenario as such is not realistic anymore because additional measures have been adopted at the EU and national levels, it is still useful as a benchmark for other scenarios and as a reflection of the possible evolution of the Cypriot energy system if a substantial shift towards more energy-intensive sectors happens in the economy in the future; it can be considered as a high-end energy forecast.

2. The Energy Efficiency Scenario, which assumes that further energy efficiency measures are adopted in the post-2010 period, such as a continuation of national subsidies for investments in energy saving technologies by

FIGURE 1: HISTORICAL EVOLUTION (1995-2013) AND ASSUMED FUTURE DEVELOPMENT OF SECTORAL GDP SHARES IN CYPRUS



[11] *International Energy Agency, World Energy Outlook 2013. Paris, ISBN: 978-92-64-20130-9*

[12] *Ministry of Energy, Commerce, Industry and Tourism of the Republic of Cyprus (2014), 3rd National Energy Efficiency Action Plan of Cyprus in Compliance with Directive 2012/27/EU, April 2014, Nicosia..*

households and firms, the implementation of the Recast Buildings Directive (2010/31/EC) and the Energy Efficiency Directive (2012/27/EU) at EU level, and some modest adoption of further legislation on 'near-zero energy buildings' later in this decade. A new feature of the energy efficiency scenario used in this study is that – as far as final electricity demand is concerned – it has been calibrated so as to reproduce the latest official electricity forecast for the period 2014-2023 that was prepared by the Transmission System Operator and approved by the Cyprus Regulatory Authority for Energy in June 2014[13] .

Apart from these two scenarios, two additional ones have been designed:

3. A scenario assuming that the use of energy-consuming equipment in most sectors of the Cypriot economy is approaching a saturation level and a substantial decoupling of energy use from economic activity will occur, so that further economic growth will be possible in the coming decades without the need for much additional energy. This is called the Decoupling Scenario in this report, and is implemented by assuming that income elasticities in equations 2, 6 and 7 of Section 2.3 will decline gradually in the post-2020 period[14]. Conversely, these elasticities are assumed to change very little in the first two scenarios mentioned above.

4. A scenario that incorporates the decoupling assumption of Scenario 3 and additionally assumes a more aggressive adoption of 'near-zero energy building' regulations, the implementation of strong regional and local energy saving initiatives from municipalities and the implementation of measures to achieve (or even exceed) full compliance with the Energy Efficiency Directive (2012/27/EU). It therefore leads to higher energy savings and lower energy demand overall, and can be considered to be consistent with an eventual binding target of a 30% EU-wide energy efficiency improvement that is currently under discussion between the European Commission and EU member states. This is called the Extra Efficiency + Decoupling Scenario in this report and intends to serve as a low-end projection of energy needs in Cyprus up to 2040.

In summary, the four scenarios examined here address the modelling needs that were laid out by IRENA. More specifically, they reflect:

- The latest energy policy assumptions from the government of Cyprus, as discussed in the first workshop of the project that was held on 2-3 June 2014 in Nicosia;
- Current policies of the government of Cyprus and their planned future modifications, as discussed with officers of the Ministry of Energy, Commerce, Industry and Tourism in June-July 2014;
- The most recent data on energy demand and supply that were incorporated in the energy balance of the base year 2013 (see Table 1 in Section 2.1);
- The effect of current and already planned EU policies as regards renewable energy and energy efficiency improvements;
- Earlier energy-related studies for Cyprus, to the extent that they were up-to-date and relevant for the purpose of this study, and its focus on final energy demand projections.

2.5 Scenario results

This section presents the results of the four scenarios described above. Section 2.5.1 describes aggregate energy demand forecasts, while Section 2.5.2 focuses on electricity demand. Further details of these projections, by sector,

[13] See webpage of the Transmission System Operator of Cyprus: http://www.dsm.org.cy; latest projection was published in July 2014 and was accessed in August 2014. As this forecast is about electricity generation, and transmission & distribution losses and auto-consumption of power plants consistently account for about 9% of total power generation in Cyprus according to official data of recent years, our final electricity demand forecasts reproduce 91% of the annual figures of the official projection.

[14] For example, as Table 8 shows, pre-2020 elasticities used for freight transport, car transport, households and non-substitutable hous hold electricity are 1.1, 0.9, 0.7 and 1.1 respectively, and are assumed to gradually drop to 0.7, 0.45, 0.4 and 0.6 respectively in year 2040.

fuel and scenario, are provided in the electronic files accompanying this report.

2.5.1 Aggregate final energy demand

Figure 2 illustrates the evolution of total final energy demand up to 2040 for each scenario. Energy use is expected to start growing again from 2015 onwards, albeit at a slower pace than economic activity, and may reach pre-crisis levels around the year 2025 – with the exception of the reference case that projects a faster rebound of energy demand. This growth is projected to decelerate in the longer term, as a combined result of relatively slow economic growth, rising energy prices and energy efficiency improvements, thanks to the implementation of national and EU policies. Especially in the fourth scenario (Extra Efficiency and Decoupling), aggregate final energy needs are expected to stabilise after 2030 and may even decline slightly by the end of the forecast horizon.

The evolution of two main indicators – final energy intensity of the economy and final energy use per capita – is displayed in Figure 3. Energy use per capita is expected to follow an increasing trend – though slower than the growth rate of total energy demand – with signs of stabilisation in the late 2030s. Conversely, energy intensity is forecast to follow a declining trend after the mid-2020s; by 2040 it is projected to be lower than 2025 by a percentage ranging between 10% (in the Reference and Efficiency Scenarios) and about 20% (in the other two scenarios). Obviously, the combination of energy efficiency improvements (of varying stringency by scenario) and energy-economy decoupling effects (in the latter two scenarios) is responsible for this development. However, this is projected to happen only after the first part of the forecast period (2014-2025), in which energy intensity is forecast to increase. Energy consumption has dropped more than economic activity in the crisis years 2011-2013 and – somewhat symmetrically – is expected to rise more than economic activity in the post-crisis period.

This intensity increase up to the mid-2020s is largely driven by the official forecasts of total electricity demand in the 2014-2023 period (see footnote 12 in Section 2.4.2), which have been replicated in the Efficiency Scenario and hence affect the assumptions of Scenarios 3 and 4 as well. One explanation for such an evolution is

Figure 2: Forecast of aggregate final energy demand

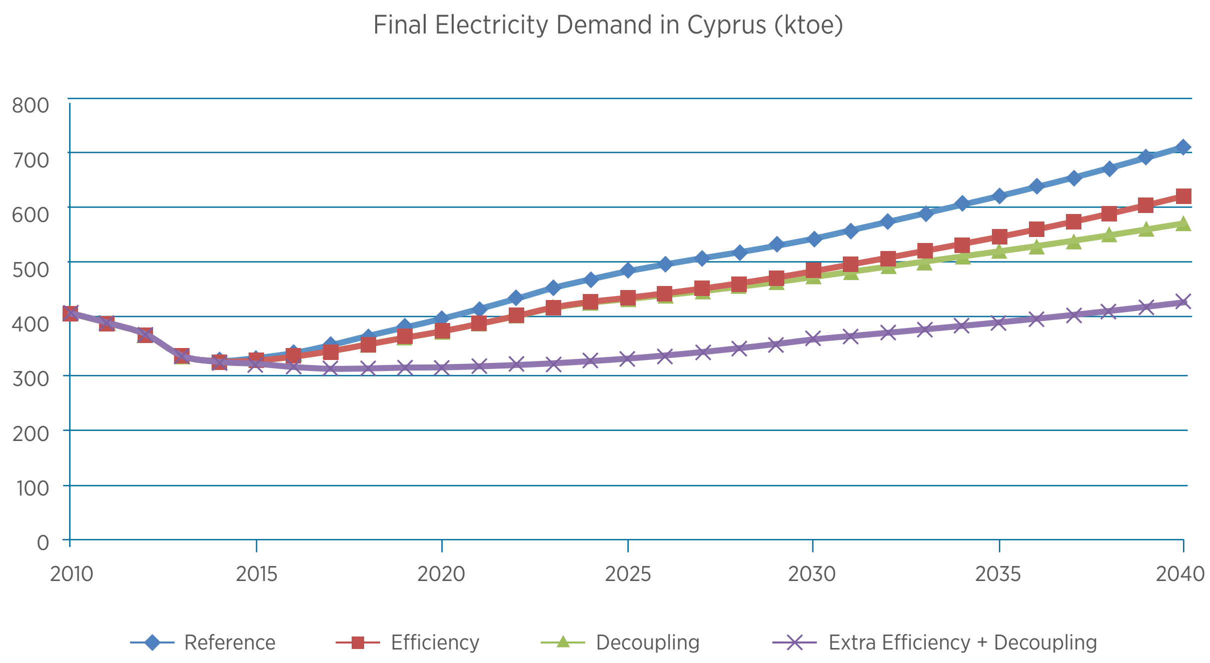
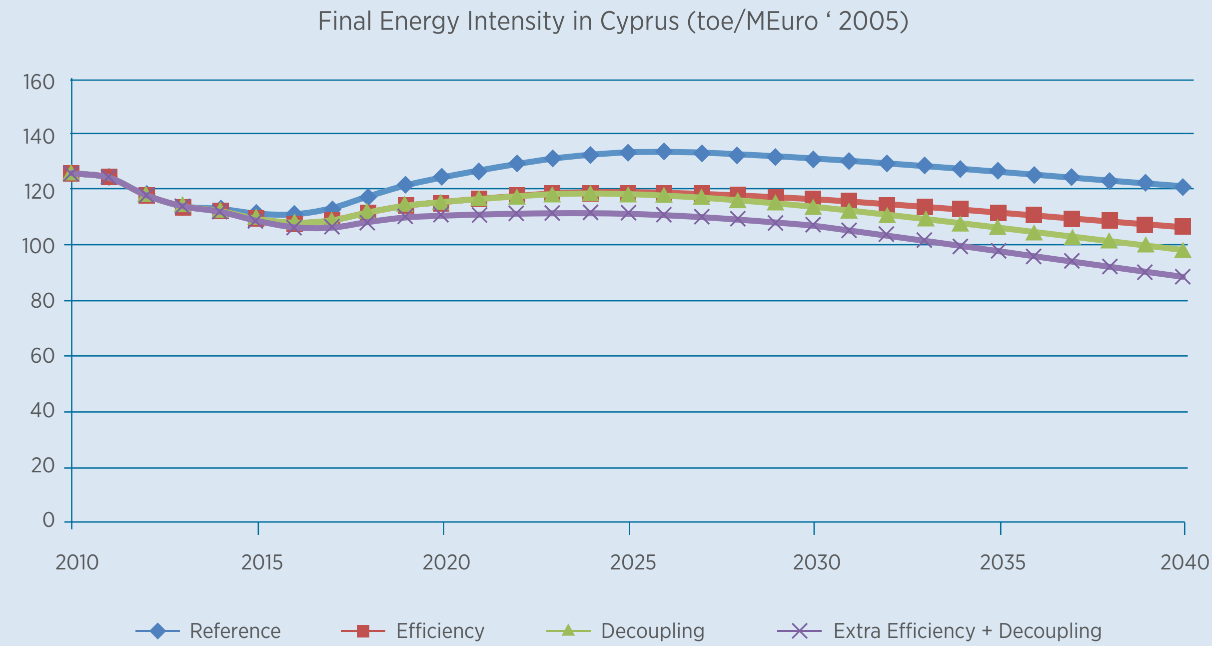
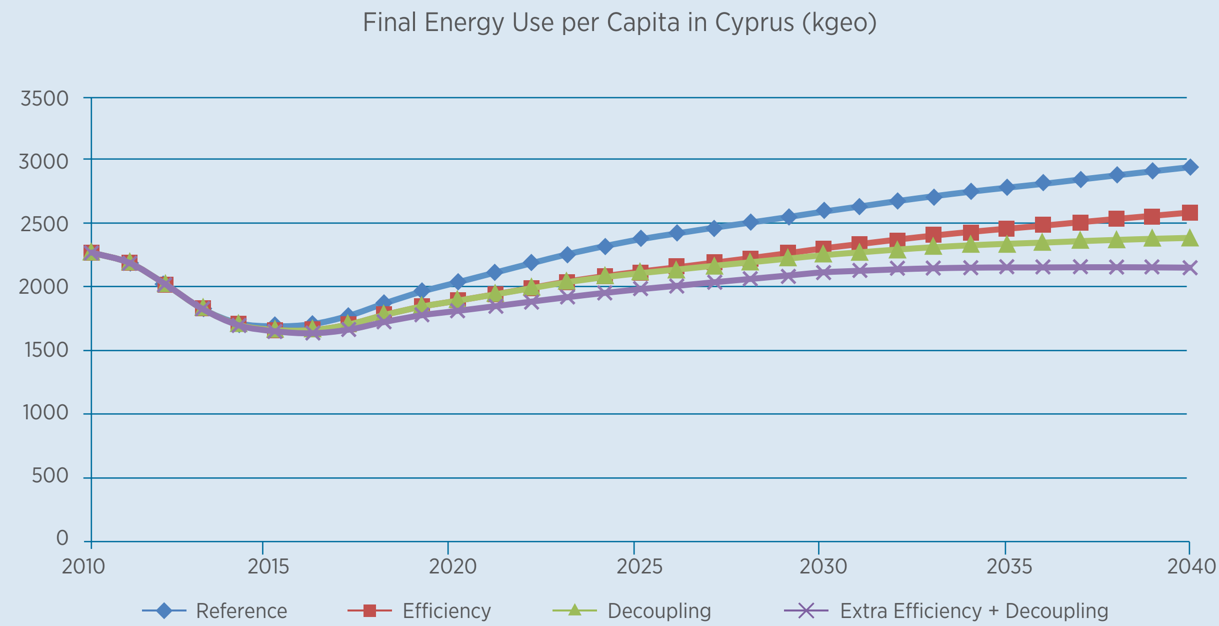


Figure 3: Projected evolution of major energy indicators in Cyprus up to 2040





that the economic recession, reinforced by limited capital investment expenditure and lack of adequate public funds, can lead to delays in the expansion of new activities utilising modern energy technologies and slower adoption of energy efficient technologies in both the existing and new stock of buildings and equipment. However, to what extent this delay in the modernisation of energy-consuming capital stock will indeed lead to a 10% growth in energy intensity between 2015 and 2025 in a period of implementation of energy efficiency regulations, as projected in the second and third scenarios, remains an open question. On the other hand, the fourth scenario foresees essentially stable energy intensity between 2013 and 2025 and a considerable decline thereafter – which under some circumstances may be a more plausible evolution.

As explained in Section 2.4, the four scenarios currently considered in this study mainly differ regarding the effect of economic activity on energy use and the extent of adoption of energy saving measures across economic sectors. Both these aspects give rise to future energy savings, which are different by scenario. Tables 10 and 11 show the projected energy savings between Scenarios 1 and 2, and Scenarios 2 and 4 respectively. The former comparison is equivalent and identical to the energy savings that have been agreed with the Ministry of Energy, Commerce, Industry and Tourism and are reported in the Cyprus NEEAP 2014, which was submitted to the European Commission in April 2014[15]. The major portion of energy savings come from the buildings sector (i.e. households and services) as a result of the implementation of EU directives and national initiatives targeted to buildings as explained in the previous section.

The latter comparison (Table 11) illustrates the additional energy saving potential that seems to exist in Cyprus and may be realised if the national government and local authorities engage in a more proactive approach and/or if a binding energy efficiency target for 2030 is decided

Table 10: Projected savings in final energy consumption between the Reference and Energy Efficiency Scenarios

	2020		2030		2040	
	(ktoe)	(%)	(ktoe)	(%)	(ktoe)	(%)
Total savings across sectors and fuels	132	7.1%	270	11.2%	333	12.2%
of which in:						
air transport	9	3.2%	18	4.7%	23	5.7%
freight transport	11	3.3%	20	4.9%	26	5.8%
road passenger transport	29	7.1%	64	11.5%	77	12.3%
cement industry	4	4.7%	4	4.1%	4	3.8%
other industries	3	4.5%	7	6.9%	8	7.8%
households	52	14.7%	104	21.4%	126	21.8%
services	22	8.2%	52	14.6%	66	15.5%
agriculture	1	3.1%	2	4.6%	2	5.4%
Economy-wide savings in final electricity	***23***	***5.7%***	***60***	***10.8%***	***90***	***12.5%***

[15] According to NEEAP 2014, attainable energy savings by 2020 are 14.5% of national energy consumption of the reference scenario. Note, however, that most of these savings are assumed to come, not from final energy savings, but from the introduction of natural gas in power generation. Therefore, the 7.1% total savings reported in Table 6.1 are consistent with the corresponding projections of NEEAP 2014.

at the EU level. It has to be emphasised that these extra energy savings are based on assumptions and calculations of the study team and the authors believe that these are valid assumptions and offer a broad and realistic outlook of the energy saving potential in the medium- to long-term.

Regarding the composition of final energy demand, Figure 4 displays the projected evolution of the sectoral and fuel shares of the final energy demand in the Energy Efficiency Scenario. Because of the assumed small changes in GDP shares of each economic sector up to 2040 as displayed in Table 9 and Figure 1, there are no spectacular changes in sectoral energy shares; the most noteworthy development is the further decline in the share of industrial sectors and agriculture. As far as fuel shares are concerned, the main projected developments are:

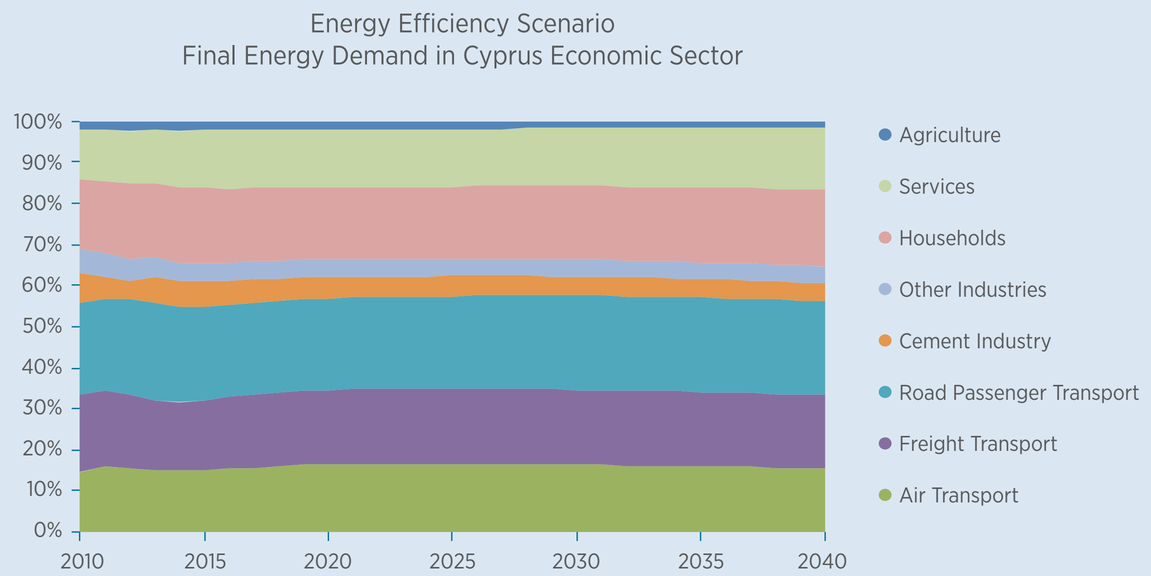
- the further electrification of the energy system – especially of road transport;
- the drop in consumption of industrial fuels – particularly light and heavy fuel oil and to a lesser extent gas oil; and
- the increased use of biomass and particularly transport biofuels; the latter are projected to account for around 8% and 16% of final energy demand in road passenger transport and road freight transport respectively, and up to 7.4% of total final energy consumption by 2040.

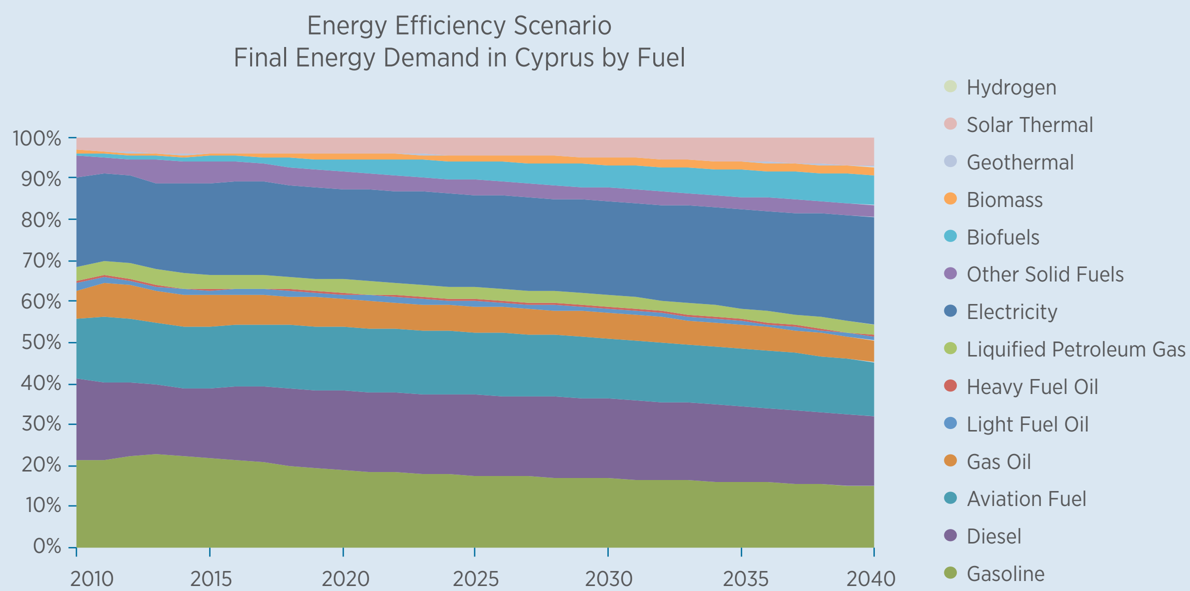
As none of the current scenarios assumes substantially different evolution in economic activity or efficiency of one sector over the others, the sectoral and fuel shares shown in Figure 4 are generally representative of those in other scenarios as well. (Electricity is a special case that deserves more attention, which will be explained in Section 2.5.2).

TABLE 11: PROJECTED SAVINGS IN FINAL ENERGY CONSUMPTION BETWEEN THE ENERGY EFFICIENCY' AND EXTRA EFFICIENCY + DECOUPLING SCENARIOS

	2020		2030		2040	
	(ktoe)	(%)	(ktoe)	(%)	(ktoe)	(%)
Total savings across sectors and fuels	73	4.3%	177	8.2%	404	16.8%
of which in:						
air transport	0	0.0%	8	2.4%	44	11.8%
freight transport	0	0.0%	9	2.4%	50	11.8%
road passenger transport	0	0.0%	16	3.2%	73	13.4%
cement industry	1	1.2%	0	0.3%	2	1.5%
other industries	7	9.3%	13	14.1%	19	19.2%
households	26	8.7%	58	15.1%	105	23.2%
services	37	15.5%	69	22.9%	106	29.5%
agriculture	2	5.0%	3	7.4%	5	11.3%
Economy-wide savings in final electricity	***66***	***17.3%***	***125***	***25.4%***	***195***	***31.0%***

Figure 4: Evolution of final energy use by economic sector and energy form in the Energy Efficiency Scenario.

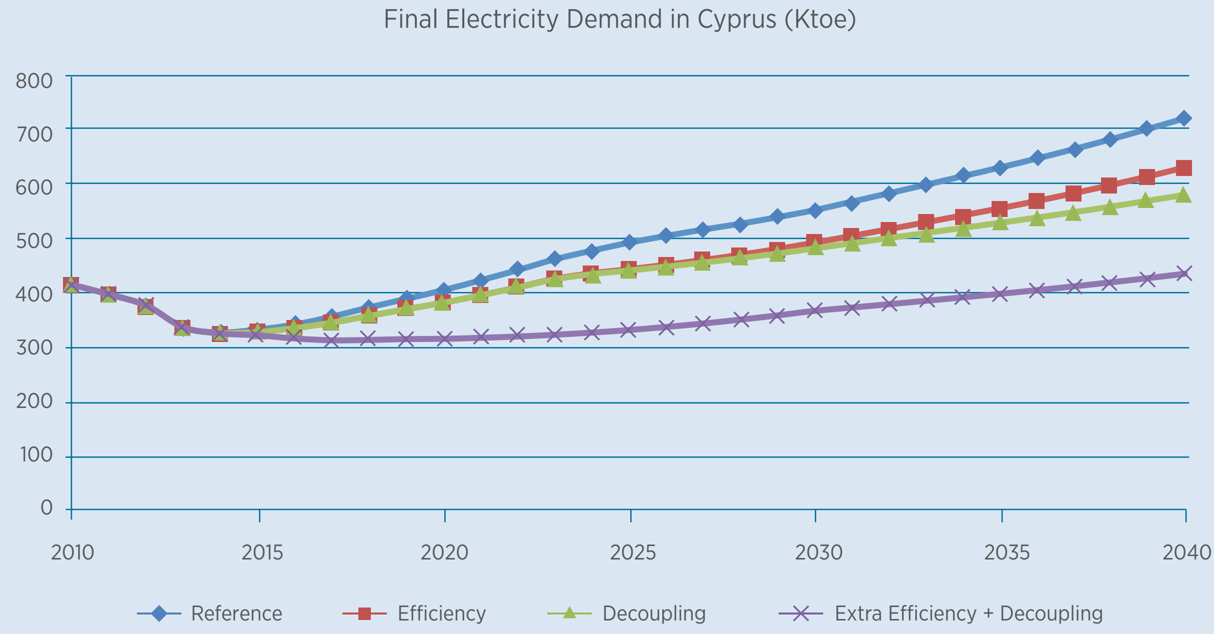


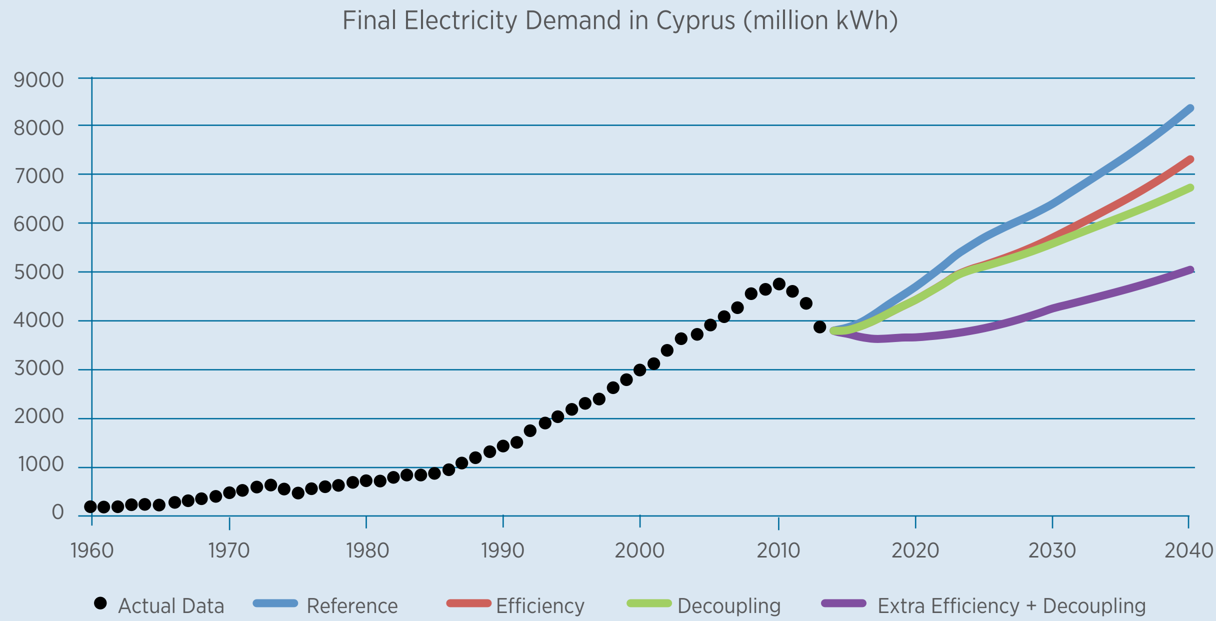


2.5.2 Final electricity demand

Figure 5 presents the evolution of final electricity demand by scenario up to 2040. To put this forcast in perspective, the bottom part of Figure 5 shows the historical evolution of electricity use in the Republic of Cyprus since 1960. As in total final energy demand, electricity use is expected to start growing again from 2015 onwards and may reach pre-crisis levels shortly after 2020. This growth is projected to continue over the longer-term despite energy efficiency improvements caused by the adoption of national and EU policies. The main reason for this effect is the further electrification of the energy system, in particular because of the projected penetration of electric vehicles in road transport. As a result, depending on the scenario, electricity consumption in 2040 may be from 5% to 74% higher than the corresponding figure of 2010.

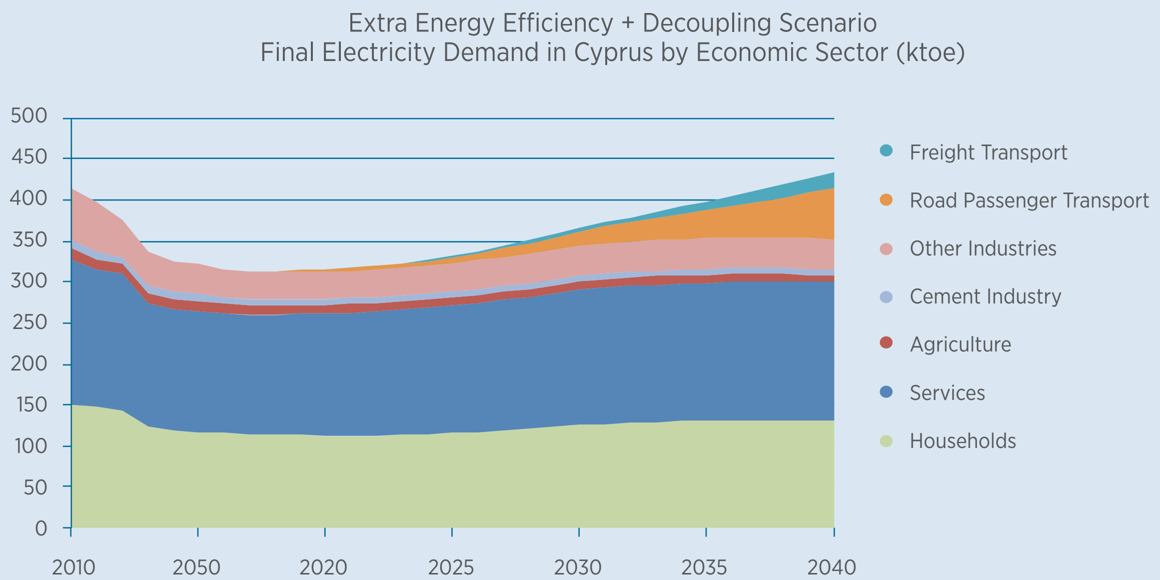
Figure 5: Forecast of aggregate final electricity demand





The evolution of electricity use by economic sector is shown in Figure 6, both in absolute terms and as sectoral shares. The fraction of households and the tertiary sector, which dominate electricity consumption with a 79% share in 2010, is projected to continue increasing and reach 83% in the mid-2020s. In later years, the use of more efficient appliances and electric space heating and cooling equipment as well as the penetration of electric vehicles will lead to a gradual decline in this share, so that passenger and freight transport are expected to account for 15% of total electricity demand by 2040. Although Figure 6 displays the evolution according to the Energy Efficiency Scenario, the relative picture does not change in the other scenarios; the only difference is that the share of electricity consumed by the transport sector in 2040 reaches 19% in the Extra Efficiency + Decoupling Scenario due to the further efficiency improvements in electric appliances and equipment assumed in that scenario.

Figure 6: Forecast of final electricity demand by economic sector, in absolute and relative terms



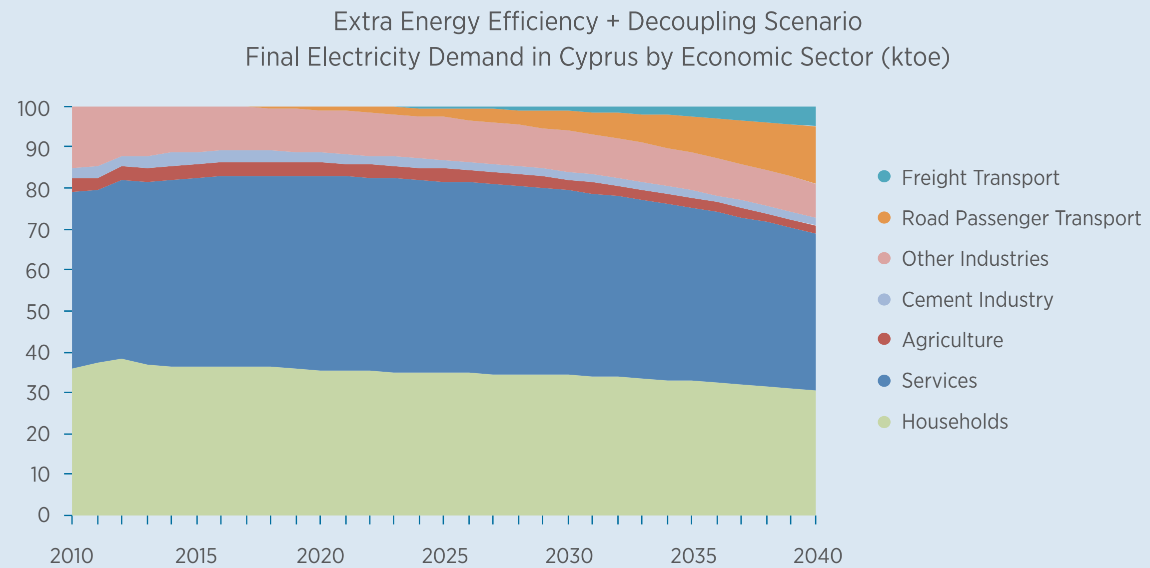
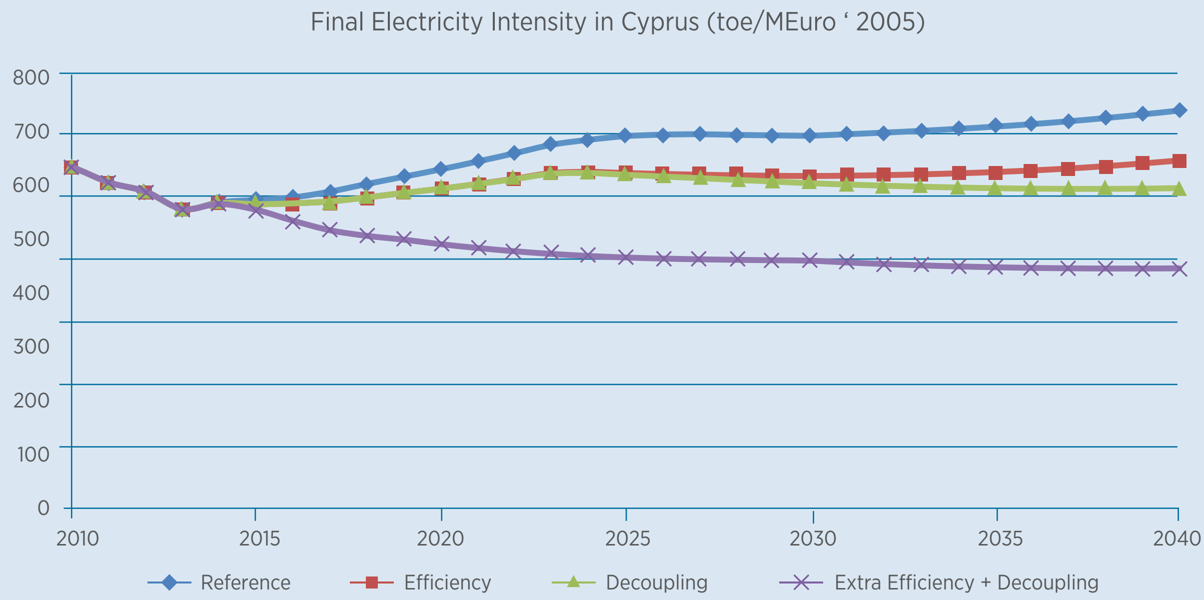
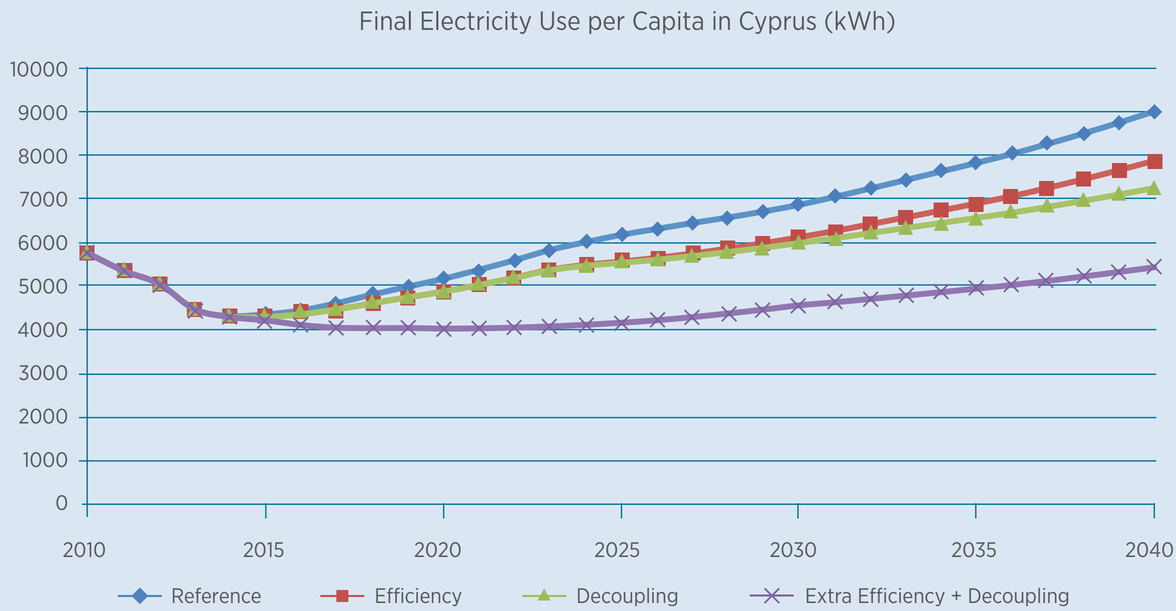


Figure 7 illustrates the forecast evolution of final electricity intensity and electricity use per capita. The latter is expected to follow a continuously increasing trend without any clear signs of stabilisation. Electricity intensity follows different paths depending on the scenario. The Extra Efficiency + Decoupling Scenario foresees a constant decrease in intensity of final electricity demand, as a result of both decoupling of energy use from economic activity and strong energy efficiency policies. Conversely, the other scenarios display an increasing intensity up to the mid-2020s, mainly as a result of adopting TSO's official electricity forecast, and a stabilisation afterwards, with the Efficiency Scenario showing a further rise in intensity post-2030 as a result of electrification of transport and modest efficiency improvements in other electricity-intensive sectors. It has to be noted that the projections of the two middle scenarios (Efficiency and Decoupling Scenarios) are in reasonable agreement with the historical evolution of electricity intensity in Cyprus, as will be explained in Section 2.5.3 below.

Figure 7: Projected evolution of major electricity demand indicators in Cyprus up to 2040

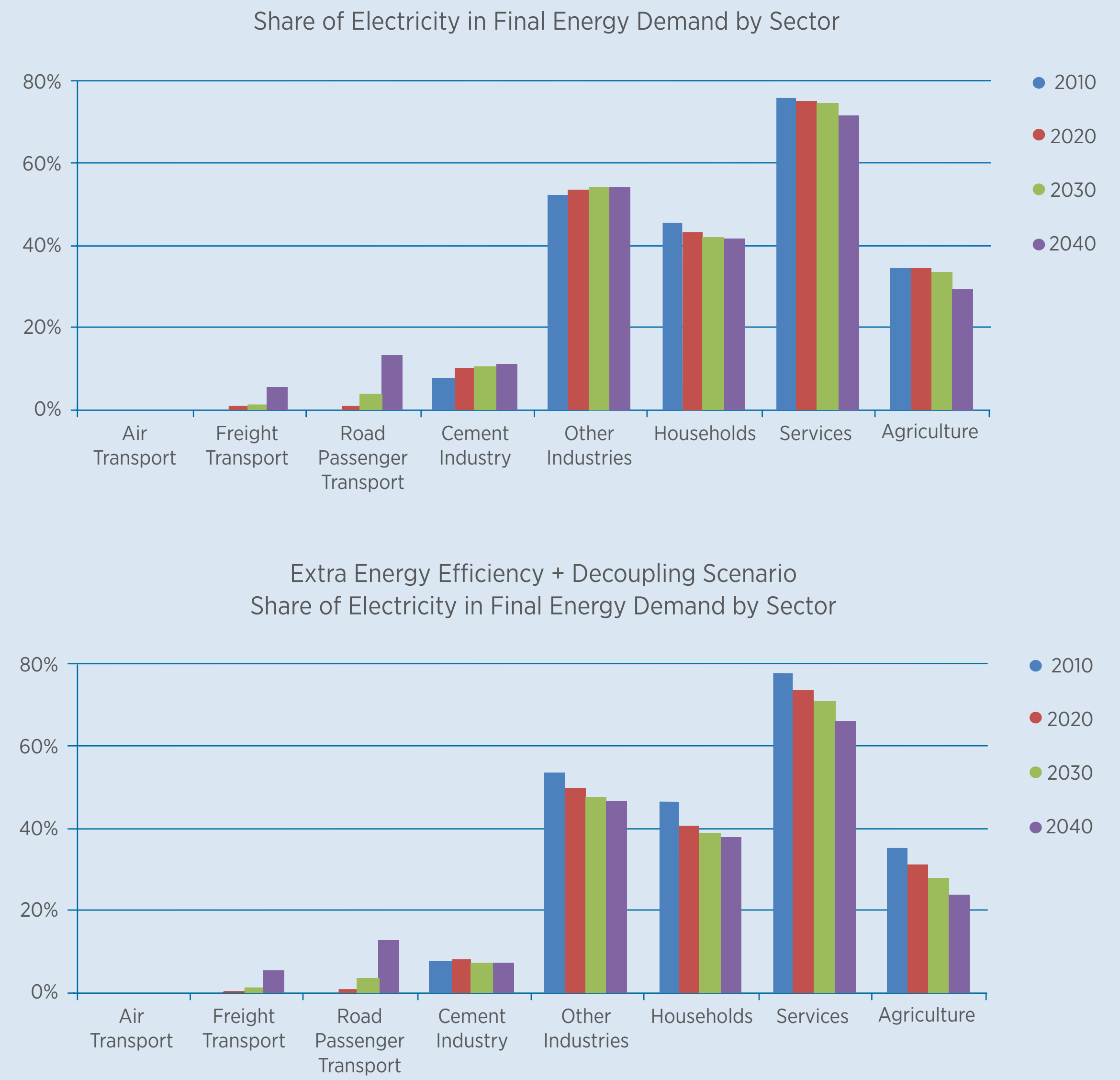




Focusing on the two main scenarios considered here – the Energy Efficiency and the Extra Efficiency + Decoupling Scenario – Figure 8 shows the projected evolution of the shares of electricity in final energy demand of each sector. Especially for households, these shares have been determined on the basis of the analysis of useful energy demand that was described in Section 2.2.1; a similar approach was followed in modelling electricity shares in other non-transport sectors, although demand for useful energy was not explicitly modelled in those cases.

Two things stand out in this comparison. The first is the clear increase in the share of electricity in road transport[16] , enabled both by technological progress and declining capital costs of electric vehicles, which are assumed to converge with those of conventional cars by 2040, and by the gradual removal of barriers related to infrastructure. In both scenarios, electricity accounts for 6% and 13% of the final energy demand in road freight and road passenger transport respectively in 2040. In the case of passenger transport, this corresponds to 72 ktoe in the Energy Efficiency Scenario

Figure 8: Evolution of sector-specific shares of electricity in total energy demand for the two main scenarios



[16] *Hybrid cars (both gasoline- and diesel-powered) are also projected to penetrate the market in significant nu bers, but energy consumption from such vehicles is included in gasoline and diesel consumption of the transport sector.*

which, at an average energy consumption of 0.2 kWh/km[17] , corresponds to about 209,000 electric cars in 2040. The corresponding figure for 2030 is 18 ktoe, which corresponds to about 53,000 electric cars in the market of Cyprus in that year. Assuming that motorisation rates – that are already high in Cyprus at around 550 cars per 1,000 inhabitants – will slightly increase and reach 600 cars per 1,000 inhabitants in 2040, and assuming that new registrations will account for 10% of the existing car stock[18], i.e. about 55,000 cars per year in the 2030-2040 period, this forecast means that the share of electric cars in annual new registrations will be around 15% in 2030 and reach 40% in 2040. Taking into account that used cars have historically accounted for a substantial fraction of new registrations in Cyprus, and that new registrations of electric cars will probably involve sales of brand new and not used cars, this 40% means that most of the new cars sold in Cyprus in 2040 will be electric, according to this projection. It is evident that such an outlook will only be possible if significant investments in relevant infrastructure start in the near future. It is also important to note that these car numbers represent an upper range of estimates, as our model currently does not distinguish between different modes in road passenger transport and thus a part of the projected energy consumption in road passenger transport may be due to the operation of electric buses.

A second interesting observation on Figure 8 is the lower share of final electricity demand in the Extra Efficiency + Decoupling Scenario. Although the shares of electricity in the year 2040 in the latter scenario are lower in some cases compared to the Energy Efficiency Scenario, this is not due to a de-electrification of the energy system but due to the continuously improving thermal efficiency of electric appliances and equipment (mainly heat pumps for space heating and cooling). In the future, their efficiency is assumed to improve faster than the efficiency of non-electric systems, hence the increasing demand for useful energy from electricity will be satisfied by appliances and equipment requiring less final electricity demand for their operation.

2.5.3 Comparison with historical trends

To put these forecasts in a historical perspective, final energy demand was estimated for years 1990-2010 with the aid of official statistical data and a few necessary assumptions in order to fill some gaps in the officially available information. Appendix I presents this historical evolution and several diagrams that are identical with many of those shown in Sections 2.5.1 and 2.5.2 above, but scaled back to the year 1990. It is evident that the period of economic crisis (2010-2014) has considerably changed the evolution of total energy and electricity demand in comparison to the recent past.

A general remark one can make when comparing past trends with those of future scenarios is that the two middle scenarios (Energy Efficiency and Decoupling) seem to essentially continue the pre-crisis trends; energy intensity seems to stabilise and then follow a declining path after 2025, while electricity intensity continues its pre-crisis increasing trend before it stabilises by 2025 and then starts slightly rising or dropping (depending on the scenario). Aggregate demand of energy and electricity as well as per capita demand follow the path of energy intensity in combination with the exogenously assumed evolution of national income and population.

In contrast, the low-end Extra Efficiency + Decoupling Scenario seems to reflect an economy that will undergo substantial structural changes up to 2040 – perhaps an optimistic path to a low-energy economy of Cyprus that will adopt energy efficiency measures at a scale that has not been experienced up to now. The fact that this will be an unprecedented development does not render this scenario entirely unlikely since the overall EU decarbonisation strategy (and the pertinent EU legislation that is currently under discussion) is indeed aimed at creating a low-energy and low-carbon European economy by the mid-21st century.

At the other extreme, the high-end Reference Scenario leads to an evolution of energy and

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[17] This is the average of the energy consumption of a plug-in hybrid vehicle (0.225 kWh/km) and a batery electric vehicle (0.175 kWh/km). Source: Poullikkas A., Sustainable options for electric vehicle technologies, Renewable & Sustainable Energy Review (forthcoming), Digital Object Identifier: 10.1016/j.rser.2014.09.016.

[18] According to Cystat data, new registrations (i.e. sales of new and used imported cars) accounted for over 10% of the car stock in the recent pre-crisis period (i.e. 2000-2008). Used cars accounted for a significant part of these new registrations.

electricity intensity that may only be justified in case of a considerable delay in the modernisation of energy-using equipment, or if an opposite structural change happens in the Cypriot economy – i.e. if a shift towards energy-intensive sectors occurs. Under some conditions, such an evolution of energy demand may happen due to the operation of industrial facilities associated with the exploitation of natural gas reserves post-2020 (liquefaction plant, chemical industry development etc.). It should be emphasised, however, that such a structural change (with the accompanying macroeconomic implications) has not been explicitly accounted for in this modelling study due to the uncertainty of many crucial technical and economic parameters. For this reason, although the Reference Scenario should not be viewed as entirely unrealistic, it should also not be considered the energy outlook of a more industrialised and energy-intensive Cyprus.

2.5.4 Comparison with other recent studies

As already mentioned in Section 2.4.2, regarding electricity demand, the Efficiency Scenario is consistent with the latest official electricity forecast for the period 2014-2023 that was prepared by the TSO and approved by the Cyprus Regulatory Authority for Energy in June 2014. Moreover, the Reference and Efficiency Scenarios are in line with those reported by the government of Cyprus in its 3rd National Energy Efficiency Action Plan that was submitted to the European Commission in April 2014. Therefore, the projections presented in this report are in agreement with both recent official forecasts performed by governmental authorities of Cyprus.

It is also useful to compare the above scenario forecasts with those of two recent independent studies: i) a purely econometric one co-authored by the CUT group leader[19] and ii) European commission's official energy projection for Cyprus published in early 2014[20] .

The former study aimed at assessing additional electricity requirements (and the associated costs) in Cyprus due to climate change up to 2050, and employed an autoregressive distributed lag (ARDL) model of electricity demand as a function of economic activity, electricity prices and a climate variable, which was estimated on the basis of time series data of the period 1960-2013. For the case without climate change, two projections were carried out – one assuming that econometrically estimated elasticities will not change in the future, and one assuming a gradual decline in income elasticities, in line with empirical evidence from the recent past in Cyprus. For 2040, these two forecasts are 8,478 GWh and 6,432 GWh respectively. Compared with the scenarios of this report, the former projection slightly exceeds our Reference Scenario, whereas the latter projection lies between the Decoupling and the Extra Efficiency + Decoupling Scenarios – although much closer to the Decoupling Scenario.

The European Commission's Reference Scenario projected that final electricity demand in Cyprus will reach 614 ktoe, or 7,141 GWh, in the year 2040. This figure lies between our two medium forecasts, i.e. the Energy Efficiency and Decoupling Scenarios (7,326 and 6,744 GWh respectively). It should be noted that the Commission's estimates assume that electricity use would continue to increase even in years 2013-2015, although in reality electricity demand has declined by almost 20% between 2010-2013 and is not expected to rebound to 2010 levels before the end of this decade. The estimated growth in total electricity consumption in the Commission's study is given at 46% in 2040 compared to 2010, and again lies between our Energy Efficiency and Decoupling Scenarios. However, if one examines the evolution of electricity intensity, the Commission's projections lie closer to those of our fourth Extra Efficiency + Decoupling Scenario – they foresee a 17% reduction in intensity between 2010 and 2040, whereas our forecasts are for a 6% reduction in the third and 30% reduction in the fourth scenario.

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[19] *Zachariadis, T. and P. Hadjinicolaou (2014), The Effect of Climate Change on Electricity Needs – A Case Study from Mediterranean Europe. Energy 76, pp. 899–910.*

[20] *European Commission (2012), EU Energy, Transport and GHG Emissions – Trends to 2050 – Reference Scenario 2013. Publications Office of the European Union, Luxembourg; ISBN 978-92-79-33728-4. Also at http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2050_update_2013.pdf (last accessed July 2014)*

In summary, this comparison demonstrates that the approach of the current study to design four scenarios with divergent assumptions seems to be reasonable, as these scenarios offer a broad spectrum of possible outcomes up to 2040, such that it seems unlikely to foresee an evolution of final energy demand in Cyprus that lies outside of this range.

2.6 Demand study conclusions and outlook

The following key components have been presented in the demand study:

- a detailed energy balance for Cyprus with documentation of the data sources used for its preparation;
- the methodology and data sources for estimating energy consumption by end uses in households and hotels;
- a mathematical description of the energy demand forecast methodology;
- a description of the assumptions made in four different projection scenarios; and
- a description and interpretation of the results of each scenario, with special emphasis on electricity demand.

Moreover, in Sections 2.1 and 2.2 the report contains policy recommendations to national energy authorities for improving the quality and reliability of national energy balances in the future and improving the knowledge base as regards the energy consumption of the tourism sector. Two major recommendations are below.

- Authorities should publicly publish the annual energy balance of Cyprus and extend it in order to accommodate all available statistical information, e.g. for industrial sub-sectors.
- Surveys on energy use should be conducted at regular intervals, e.g. every few years, particularly for inhomogeneous sectors with diverse energy-using activities such as Households and Accommodation and Food Service Activities.

2.6.1 Key messages for the tourism sector

Apart from the above mentioned suggestions for improving the knowledge base on energy information, data collection and modelling work carried out during this study has highlighted that there is a substantial potential for energy savings, energy efficiency improvement and further penetration of renewables in the tourism sector, provided that appropriate policies are implemented to enable the uptake of advanced technologies. More specifically, it should be possible to retrofit the existing cooling systems of hotels with the following:

- high efficiency chillers in combination with heat recovery systems for hot water production;
- thermal energy storage systems and in particularly latent storage systems (e.g. ice storage); and
- solar air conditioning systems.

These systems can bring about serious energy savings but would require financial support for the significant upfront investment costs required. Moreover, as there is little experience by local engineers and technicians in the design, installation and maintenance, especially in thermal storage and solar air conditioning systems, appropriate training of professionals is necessary in order to enable the diffusion of these technologies.

2.6.2 Key messages of energy demand forecasts

With regard to final energy demand forecasts, four scenarios with quite diverging assumptions were defined in this study, offering a wide range of possible outcomes up to 2040. According to these, aggregate final energy demand in 2040 may be 5% to 44% higher than that observed in 2010, whereas final electricity demand is projected to reach from 5% to 74% higher levels than the corresponding figure of 2010. Although the two middle scenarios can be regarded as those continuing the trends of the recent past in Cyprus (prior to the economic and financial crisis), the high-end and low-end scenarios are also worth examining as they reflect structural shifts of the Cypriot economy towards more energy-intensive sectors or a very efficient economy, respectively. Comparisons of these forecasts with those of other recent studies for Cyprus also confirm that the wide range of projections produced by these four scenarios offer a useful spectrum of the potential evolution of the Cypriot energy system in the coming decades.

Focusing on the two scenarios of this study that were further used for electricity supply modelling in the same IRENA-supported energy roadmap, it is important to note the difference in their results. As shown in Table 11, the Extra Efficiency + Decoupling Scenario projects 125 ktoe (or 25.4%) lower electricity demand and 177 ktoe (or 8.2%) lower final energy demand compared to the Energy Efficiency Scenario by 2030. The major part of these savings – 127 out of the 177 ktoe – is foreseen to come from the implementation of stronger energy saving measures in buildings (i.e. in the residential and service sector), with the remaining 50 ktoe coming from increased efficiency of industrial and transport sectors. It has not been possible in the course of this study to quantify the additional costs that would be necessary for the implementation of the additional measures that lead to these savings in the Extra Efficiency + Decoupling Scenario. It is clear that these costs would not be negligible and would have to be compared with the cost savings that may be attained due to the reduced needs for investments in power generation in such a scenario. The improvements in the final energy demand modelling framework that are outlined in the following page would enable more accurate assessments of the above mentioned costs.

A View to the future

Taking into account the future needs of national policy makers, the authors believe that it is essential for energy, environmental and economic authorities of Cyprus to consider making a long-term commitment to energy modelling work, as regards both final energy demand and electricity supply. Especially as far as final energy demand is concerned, it is important for the country to be able to assess the potential and cost-effectiveness of energy savings and renewable energy use across all economic sectors. This is possible if the useful energy demand modelling that has been demonstrated for households and hotels in Section 2.2 of this report:

- is carried out in more detail (e.g. proceeding with disaggregated projections of useful energy demand for each end use since each end use has its own dynamics and depends differently on economic conditions, energy prices and climatic conditions);

- is extended to the other sectors of the economy (other services, industry and transport);

- is complemented with further engineering knowledge of processes and technologies used or expected to be used in Cyprus; and

- exploits cost data of each technology with appropriate data collection from the national and international market.

It would thus be possible for authorities to prioritise policy interventions and determin national incentives for energy efficiency and renewable energy in final demand in a rational and cost-effective manner. Annual updates of the energy forecasts – which are always necessary in view of changing conditions in the economy, the international energy markets and the regulatory environment – would also become simpler to obtain; this would considerably assist authorities in their reporting obligations to the European Commission and international bodies.

The existence of such a modelling platform would also enable the government of Cyprus to be prepared for future energy, air pollution and climate negotiations at EU and international level. For this purpose, it is essential to ensure that governmental departments involved with environmental policy (the Environment Department and the Department of Labour Inspection) provide feedback, are kept up-to-date with such model projections and exploit them for their own assessments and reporting needs.

The above is possible with a modest investment in human and financial resources over a period of several years that would be devoted to:

» improving the final energy demand model along the lines mentioned above;

» updating its scenarios and projections on a regular basis; and

» preparing special reports and providing additional assistance at the request of national authorities.

3 Electricity supply scenarios for the Republic of Cyprus

This section gives the full results of a future energy system optimisation study conducted by KTH to give insight into renewable energy deployment options and related energy policy decision in Cyprus. This study and the associated findings constitute the core of the Cyprus renewable energy roadmap. The primary aim of the energy supply study is to provide insights on the future role of renewable energy technologies in the electricity mix, ensuring a cost-optimal power supply mix, taking into account the policy targets.

The necessity for this analysis is threefold. The **policy driver** is the EU renewable energy target for Cyprus in 2020, and the country's own aspirational targets for 2030. The **economic driver** is the need to reduce the current high power generation cost. The **technical driver** is the minimisation of any technical challenges in terms of high dependence of the power system on rapidly increasing shares of variable renewable energy sources. As such, the present analysis aims at identifying the optimal energy mix under particular scenarios and the associated technology deployment necessary.

It should be clearly noted that the energy supply study cannot assess all the technical aspects of the grid nor the power generation system, which means that the outputs and insights offered here should be evaluated in a separate grid analysis for a comprehensive overview of the effects on the system. As of October 2014 such analysis is being carried out by the JRC of the European Commission. This grid study will be able to validate the proposed electricity generation mix scenarios developed in the energy supply study or suggest any necessary electricity storage, grid strengthening or smart grids options required to support renewable energy deployment.

Section 3.1 of the report briefly introduces the methodology followed and the tools used to conduct the analysis. A short overview of the current status of the Cyprus power system is provided in Section 3.2, along with a description of the aspirations of the different stakeholders that provided input to this study through the Ministry of Energy, Commerce, Industry and Tourism. Section 3.3 gives the assumptions provided by the government of Cyprus. These assumptions helped to define the scope and constraints for the analysis. Section 3.4 provides a detailed breakdown of the assumptions used in the analysis. Since the output of such an assessment is directly linked to the inputs used, this section is particularly critical for potential modifications made to the model in the future, and any further analysis. In Section 3.5, indicative results of the optimum power generation mix are provided as well as a comparison among the different scenarios is provided.

3.1 Methodology

The Electricity Supply Model for Cyprus (ESMC) has been developed using the long-term energy modelling platform called Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) (IIASA 2012). This is a dynamic, bottom-up, multi-year energy system model allowing the use of linear and mixed-integer optimisation techniques. MESSAGE was originally developed by the International Institute of Applied System Analysis (IIASA), and more recently it has been expanded by the International Atomic Energy Agency (IAEA).

MESSAGE can be utilised to model and optimise national and regional energy systems. This is achieved by minimising the discounted, system-wide costs for each of a variety of scenarios provided by the analyst. Energy sources, energy supply and demand-side technologies can be linked along 'energy chains', thus enabling the user to construct a model from resource extraction to final energy use (Figure 9).

MESSAGE requires a range of data input. This involves populating the model with a set of demand projections and a database of power supply technologies characterised by economic, technical and environmental parameters, as well as information regarding existing resource stocks.

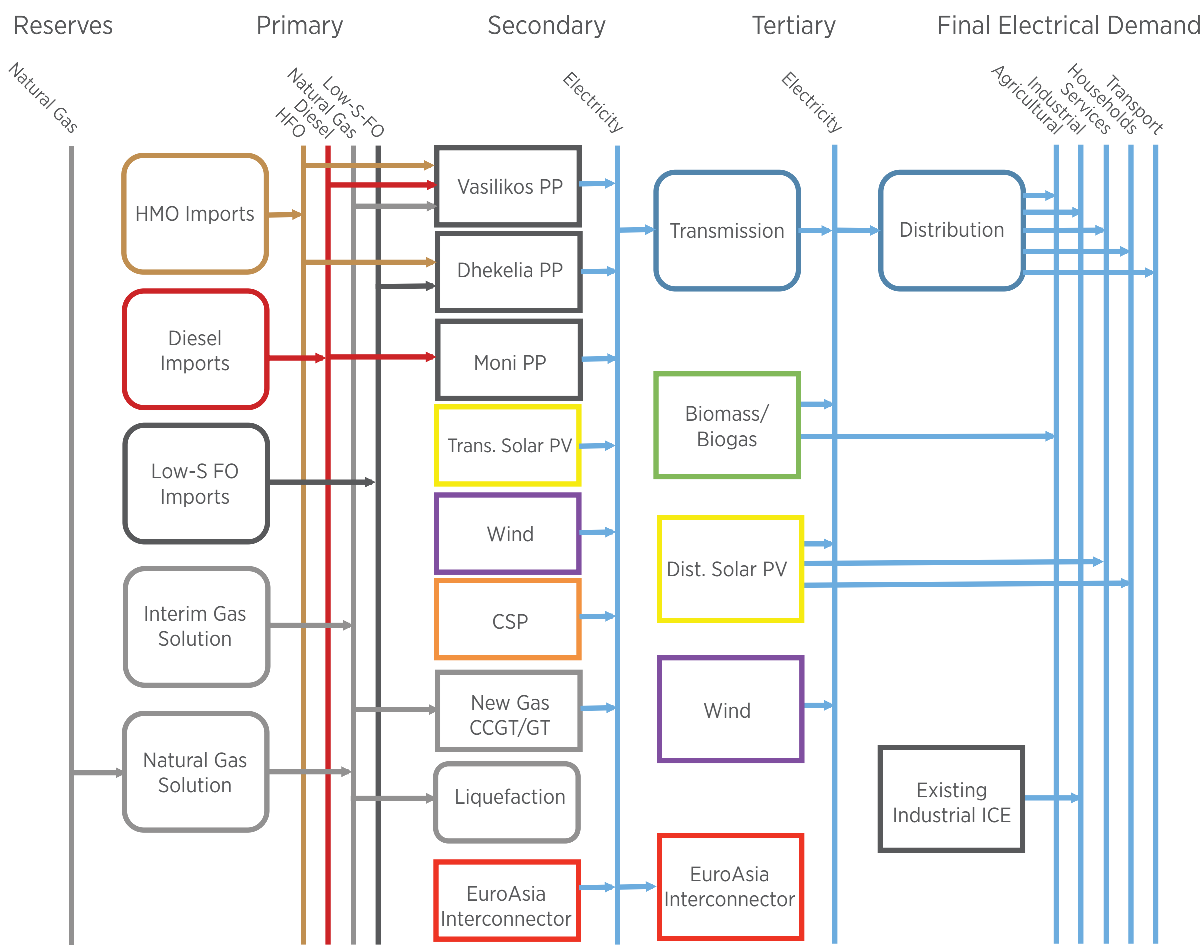
The ESCM model is developed by formulating a representative baseline that simulates the existing energy system of Cyprus in 2012. Furthermore, generation that is supported by firm plans to be developed with the relevant policy, decisions or otherwise have been considered as committed as per the latest information available (October 2014). Additionally, "constraints" have been implemented to reflect policies, resource availabilities and scenario assumptions. The model calculates an evolution of a technology mix that achieves the least-cost objective (i.e. minimal total system costs), while meeting several predefined constraints and sets of demands in each scenario. Outputs of the model provide insights related to investment potential in new technologies, trade, fuel production and use. Economic and environmental implications associated with the identified energy systems can also be calculated with the model.

The ESMC model includes three types of power generation options: existing power plants, power plants to be commissioned, and non-site-specific, generic power plants. In terms of energy inputs into the system, imports as well as domestic production of oil products and gas are included. Additionally, the potential for gas exports is taken into consideration in some scenarios, in particular via an onshore liquefaction terminal. The EuroAsia Interconnector that may link Israel's grid to Cyprus and then Greece is also considered in some scenarios.

Once the demand is specified, a cost-optimal combination of energy supply technologies that meets the given demand, while satisfying all the constraints, is computed by the model for each year of the specified modelling period. For the purposes of this analysis, the model horizon for which annual results are reported has been set for 2013-2030.

Final demand for electricity is split into five customer categories; industrial, residential, commercial, agricultural and transport. This is done for the following reasons:

Figure 9: Simplified reference energy system of the Cyprus power sector



- to allow a better representation of decentralised power supply (e.g. residential solar PV or industrial diesel generators);
- to improve the representation of the load variability in each customer category; and
- as a result of the previous two points, to identify the potential of power "trading" between customer categories taking into account variability in demand and distribution losses. For instance a residential solar PV panel could be providing power to nearby commercial facilities during early afternoon, when residents are away at work.

Furthermore, the year is divided into seven seasons of variable length. The seasons are broken down into two types of days; workday and weekend/holiday. In turn, workdays are characterised by six, and weekends by three day slices. As such, the year is broken down into 63 blocks of varying demand. This allows the model to represent periods of high and low demand and control the dispatch of technologies during specific times; for example, solar PV without storage is not able to supply power during night hours.

A wide range of different types of generation technologies are considered in the ESMC model. These include thermal and renewable energy technologies that can be categorised as centralised (i.e. connected to the electricity transmission system[21]) and decentralised (i.e. connected to the electricity distribution system). Additional centralised and decentralised forms of electricity storage are considered to facilitate the integration of renewable energy sources in the system. All of these technology options are summarised in Table 12.

A breakdown of potential renewable technologies considered in this analysis is provided in Appendix IV. In order to introduce as much detail to the model as possible, centralised and decentralised options have been added. Large wind generators, biomass-fired plants, utility-scale PV and CSP all feed power directly to the transmission network, whereas small wind, biomass facilities and rooftop PV can provide electricity directly to demand points or supply the distribution network. Even though Cyprus currently has not yet developed the option of electricity storage, this aspect is taken into consideration, both as a centralised (e.g. pumped storage or

Table 12: Technologies represented in the ESMC

Fossil fuel-fired generation	Renewable energy sources	Storage options
Diesel - combined cycle gas turbines	Wind (connected to transmission or distribution)	Pumped storage
Diesel - gas Turbines	Utility-scale PV (>8 MW connected to transmission)	Flow batteries (centralised)
Diesel – ICE (centralised or decentralised)	Decentralised PV (connected to distribution)	Li-ion batteries (decentralised)
Heavy fuel oil - steam turbines	Concentrating solar power (CSP) with thermal storage	
Heavy fuel oil – ICE (centralised or decentralised)	Decentralised biomass (connected to distribution)	
Natural gas - combined cycle gas turbines		
Natural gas - gas turbines		
Natural Gas - Steam Turbines		

[21] *RET with installed capacity >8 MW (indicative value) are installed on transmission system network, with the rest in the distribution system network*

large scale battery systems) and decentralised option (small-scale batteries). These options can potentially be particularly useful to allow for an increasing level of variable renewable energy technologies deployed within the system. The exact amount of storage, if considered at all necessary given the scenarios developed in this analysis, will be assessed by the dedicated grid study. A more detailed description of the assumptions used in the model is given in Section 3.4.

3.2 Current energy system status and plans

As mentioned above, Cyprus relies heavily on fossil fuel imports, which makes the domestic economy particularly vulnerable to international oil price fluctuations. At the same time, the lack of grid interconnections to neighbouring countries prevents the purchase of cheaper electricity to meet peak demand, or the sale of excess generation from variable renewables in periods of high generation and low demand as an alternative to curtailment.

With the latest installations of combined cycle gas turbines, the total installed power generation capacity is approximately 1,685 MW, of which 1,478 MW are operated by the Electricity Authority of Cyprus at the sites of Vasilikos, Dhekelia and Moni (Table 13). This provides a large reserve margin; recorded fifteen-minute peak demand transmission system generation was just below

Table 13: Total installed capacity at the end of 2013 (EAC 2013; Transmission System Operator - Cyprus 2014a)

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
Vasilikos Cement	Internal combustion engine	Heavy fuel oil	6
Skouriotissa Mine	Internal combustion engine	Diesel	6.72
Larnaca Airport	Internal combustion engine	Diesel	6.4
Wind	connected to transmission	—	144.3
Wind	connected to distribution	—	2.4
Biomass/biomass	connected to distribution	—	9.7
PV	connected to distribution	—	31.36[6]
		Total	1,684.82

[1] Consists of 4 gas turbine units (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.

[6] Does not include the net metering systems; this value as of September 2014 is greater than 45 MW with an increasing trend

1,000 MW in 2012 and 815 MW in 2013 (total load approximated as 839 MW - Transmission System Operator - Cyprus 2014b, 2014c). It should be noted that the units at the Vasilikos site can burn natural gas, once this becomes available, instead of diesel and heavy fuel oil.

The government of Cyprus is currently considering the introduction of natural gas in the power sector. The main reason for changing fuel is to reduce the costs in power generation, as price hikes and fluctuations in international oil prices have increased electricity costs in Cyprus. Currently, there are two alternatives for this. A first option, referred to as the Interim Gas Solution, involves the purchase of imported natural gas and the development of related infrastructure until indigenous natural gas is available. For the Interim Gas Solution there are different scenarios under consideration and these involve, but are not limited to, Floating Storage Re-Gasification units to be used by the supplier in order to supply the Vasilikos Power Station with natural gas and the possibility of a pipeline interconnection with Israel. The second alternative is to continue to rely on oil imports for power generation and only shift to indigenous natural gas once it is available. This would require the development of gas pipelines that would transport extracted natural gas from the offshore reserves to the island.

At the same time, another major project is under consideration, which aims to deploy an electric cable connection from Israel to Cyprus and then to Greece. The EuroAsia Interconnector would have a capacity of 2 GW (interconnection to Cyprus: 1 GW) and an expected length of approximately 1,500 km (CERA 2013). This would allow trade and could contribute in enhancing energy security for the involved countries.

Since the government of Cyprus must comply with the environmental regulations presented later in Section 3.4.8 regarding atmospheric pollutants and energy production from renewable sources, a restructuring of the power system is necessary. Renewable energy technologies had a total installed capacity of 188 MW at the end of 2013 and contributed to 7.5% of the total electricity generation (Transmission System Operator - Cyprus 2014a). Consequently, taking into account that demand is expected to increase as the island recovers from the recent financial recession, installed capacity of renewable energy sources will need to increase in the coming years to allow achievement of set targets. A National Renewable Energy Action Plan (NREAP) has been developed in the past to set a pathway for the island to reach its 2020 targets (Ministry of Commerce, Industry and Tourism 2010), but this will be revised in the near future. The revision of the NREAP is expected to commence in January 2015, which makes this report very timely.

In order to give a sense of the required capacity additions based on an assumption that all new renewable energy capacity will be solar PV (with a capacity factor of 20%) due to its low cost, in order to achieve the compulsory EU renewable energy target, which corresponds to roughly 16% from renewables in the power sector by 2020, investments in approximately 300 MW of solar PV would be required. This assumes a final electricity demand corresponding to an Energy Efficiency Scenario in which the government proceeds with committed obligations regarding efficiency measures (Zachariadis et al. 2014). Similarly, in the same scenario, in order to achieve the aspirational target of 25% by 2030, an additional 350 MW of solar PV would have to be installed in the system, beyond existing and new installations.

3.3 Key assumptions for electricity supply analysis

The following key assumptions were provided by the government of Cyprus in consultation with other key stakeholders. These assumptions helped to define the scope and constraints for the required analysis and the resulting electricity supply model.

- This analysis provides a **comparative economic assessment** of different pathways in terms of investment requirements and power generation costs, and does not have the capacity nor attempts to provide projections of future prices of electricity. As such, the values presented here are cost projections and not price forecasts.
- The present analysis aims at identifying the **optimal energy mix under particular scenarios** and the associated technology deployment necessary. However, it is important to highlight that the assessment of all the technical and operational aspects of the power system of Cyprus is beyond the scope of this

analysis, and is subject to further studies. The optimal generation mix derived in each scenario should be evaluated in a separate grid analysis for a comprehensive overview of the effects on the system and identification of any additional cost necessary to provide stable operation of the grid. It is key to keep in mind that the model used for this analysis has been handed over to the Government of Cyprus, and a specific training on its use and update has been provided. Changing assumptions, policy decisions, technologies and market developments will affect the accuracy of the results presented, therefore the model needs to be kept up to date to be able to provide support to policy decisions. Results from other studies will also have to be reflected in the model. In particular, it will be important to update the model to reflect: results from the grid study under development by the JRC, real project cost and location information, optimised dispatching plan, cost benefit analysis, future policies and regulations, and the upcoming market design.

» The cost effectiveness of RETs and the optimal level of penetration in the system are dependent on the evolution of their capital cost, their performance, the price of electricity storage as well as the price of alternative energy sources. As these are dynamic, it is **important that future market design is flexible and competitive enough** to reflect these changes, and ensures efficient pricing of energy and services. This in turn will help ensure that an economically optimal system receives investment, and that all necessary services (e.g. grid support services) are provided at minimum cost.

» The **price and timing for indigenous gas to be used for power generation will be a key driver** for the evolution of Cyprus' electricity system. The use of indigenous gas at a low price will shift all generation towards gas (apart from those generation options that do not require fuel, like wind and solar, already installed prior to 2023, which will continue to operate). Similarly, if indigenous gas is not developed or dedicated exclusively to export, renewables can have an even more important role. The scenarios are all very sensitive to price and the introduction date of indigenous gas. It is important to note that due to the absence of fuel cost, renewables like solar PV, CSP and wind, once installed, will continue to supply an important share of the electricity demand of Cyprus for the time horizon of this analysis, regardless the price of gas.

» An electrical interconnection like the **EuroAsia Interconnector** can provide **supply diversification,** allow for more renewable energy to be deployed and thus reduce the need for curtailment, create a more dynamic electricity market and, below a certain import price, reduce the average cost of electricity in Cyprus. Results suggest that imports will occur at prices of electricity delivered to Cyprus of up to EUR 90/MWh, becoming substantial at about EUR 68/MWh and below. Provided this investment will materialise, this will be a key component of the solution to reduce the cost of wholesale electricity (indigenous and imported) for the customers in Cyprus, while maximising the share of renewables deployed.

» The share of renewable energy in the **power generation mix** of Cyprus, in most years, **exceeds EU targets** and Cyprus' aspirational targets in all scenarios. A comparative analysis has been conducted assessing the impact of having the renewable energy aspirational targets not made compulsory after 2020; minimal additional investment will be required to achieve the aspirational renewable energy targets, with no noticeable change in system cost (additional investments compensated by savings on fuel and CO_2 allowances). The possibility of exceeding renewable energy targets may present an opportunity for the government of Cyprus to obtain additional income through statistical transfers. These possible outcomes have not been included in the analysis.

» Deployment of **variable RETs** is mostly limited by **concerns on grid stability.** The cap has been set based on the preliminary study developed for the Cyprus Energy Regulatory Authority (CERA), which assumes that a maximum installed capacity of 40% of PV and 20% of wind as a fraction of yearly peak power demand can be allowed in the current grid (CERA 2014). This constraint will be used in the model until the grid assessment study is completed by the JRC, which will include a dynamic grid stability analysis. If these constraints are removed, as in Scenario 5 (in the presence of an electrical interconnection with Israel and Greece), the share of renewable energy grows even further, to exceed 40% on yearly electricity demand in 2030, with over 900 MW of solar PV installed (higher than average demand). A sensitivity analysis has been run for scenario SC3 by removing all constraints on deployment of variable renewables. In such a case, capacity of solar PV reaches 415 and 1,135 MW by 2020 and 2030 respectively; this is roughly double the respective values of 200 and 559 MW in SC3 with constraints (Table 25). Actual maximum allowable levels for variable renewable energy penetration (e.g. solar PV and wind without storage) will be assessed by the grid analysis developed by the JRC of the European Commission, and can be incorporated in the model once available. The key message is that constraints on variable RET should be carefully evaluated in further studies, with a focus on technical and market measures to integrate large shares of variable RET whenever economical, rather than on imposing limits on deployment. When the cost of RET plus integration measures exceeds the cost of alternative generation options (e.g. natural gas-fired combined cycle gas turbines), that is when no further deployment should be considered to be beneficial. Determining this threshold requires careful assessment of integration cost, to ensure that they are minimised.

» In SC 2, 3, 4, 5 and 6, there is an assumption that **imported natural gas (Interim Gas Solution)** will become available in 2016. Based on assumptions provided, the natural gas will be imported with a take-or-pay clause, which has been translated into a cap on RET capacity allowed to be installed. This constraint has been reflected in the model for all scenarios except SC1. In the absence of imported natural gas and the subsequent cap on RET, the optimal RET capacity in 2020 would be over 700 MW, of which 640 MW would come from variable RET (427 MW PV and 213 MW wind). This would require a conducive environment for investments in RET, and a careful assessment of the cost of integrating such a large capacity of variable RET in proportion to average demand.

» **High penetration levels of RET are feasible.** While some technical constraints have been imposed in the analysis, operational and technical issues need to be examined in greater detail in the JRC study. In this analysis different penetration levels were considered. Technical constraints have been considered as a general rule based on a draft study commissioned by CERA, and need to be revised by the JRC study. These constraints are a function of the realities associated with operating a secure electricity system. The constraints will change as technology and control systems change. It is therefore important to ensure that changes in constraints are reflected while designing the future electricity market for Cyprus. This study does not assess the technical feasibility or the integration cost of the unconstrained shares of variable RET, which will be covered by the JRC grid analysis.

» The ancillary services needed in the electricity system to ensure control, stability and security of electricity supply are represented in a simplified manner in this analysis. The costs and benefits of those ancillary services need further analysis. In order to find an optimal cost-benefit allocation, **future market simulations** should consider explicitly pricing and allowing trade of the necessary **ancillary services.** It is important to strike a balance between services required in the grid code and services to be traded in the electricity market, to minimise the cost of maintaining the grid stability with high penetration of variable renewables. Only those services that must be provided by all installations should be a requirement in the grid code, while most of the services can be provided by a few, large-scale installations. For those services, trading through a dedicated market is a more cost-effective solution.

» **Storage** only makes economic sense once the **maximum allowable share of variable renewable energy** is reached, although the need for storage may be dictated by technical constraints. Renewables have the potential to be deployed together with storage, but currently in the majority of the scenarios only small additions beyond committed options are installed, as renewables paired with storage are less cost-competitive, in particular compared to indigenous gas. However, the upcoming grid study will help define the necessary quantity of electricity storage under different scenarios, and their cost impact on the energy system of Cyprus. This can also be incorporated in a later revision of the model, once available. When a market for ancillary services is developed in Cyprus, storage may have an important role to play, as storage can provide valuable grid support services regardless of renewable deployment, becoming a key enabler in the presence of high shares of variable renewables.

- If the plan **to export indigenous gas through a liquefaction plant** is implemented (as in SC4 and SC6), it will be crucial to define whether its **self-production and consumption of electricity** will be considered part of the endogenous generation mix of the island. If it is, this will rapidly increase investment in renewable energy to meet the aspirational targets, as the plant will provide a substantial escalation in the electricity demand of Cyprus. An annual addition of 1,490 GWh is currently estimated, which represents a sudden 30% increase in electricity demand in 2023 (as per the Efficiency Demand Scenario). As the indigenous gas liquefaction plan is not expected to be developed before 2022, this will have no impact on the EU 2020 targets. Current analysis includes self-consumption of the liquefaction plant to calculate the aspirational targets of the renewable energy share in SC4 and SC6.

- Limits on emissions of SOx and NOx have been incorporated in the model, but only for the whole energy sector. The Ministry of Labour will have to define specific limits for the electricity sector. Depending on the new **SOx and NOx emission limits** and the availability of gas before 2020, there is a possibility of **major impacts on generation cost due to the possible need to retrofit some plants and reduce the operating hours of others,** in order to comply with stricter emission limits from 2020 onwards. This would have to be carefully assessed in the definition of sectoral limits, assessing where the least-cost abatement options exist.

- Further analysis is recommended on the **interaction of demand-side measures** with generation investment. In particular, the cost of moving from the demand in the Efficiency Scenario (used in all scenarios, except SC2) to the demand in the Extra Efficiency Scenario (as in SC2) should be assessed in comparison to the savings in generation investments (EUR 400 million for 2013-2030 when comparing SC2 to SC3) and fuel cost that this demand reduction will lead to. Additionally, detailed decomposition of demand profiles can help in costing efficiency measures in relation to the cost of generation of the electricity they will displace, in the context of a future market with hourly electricity prices (e.g. more cost-effective to reduce demand when electricity has the highest price).

- The government of Cyprus is currently **considering the introduction of natural gas** in the power sector. Currently, there are two sources expected to supply gas to the power sector in Cyprus:

  - A first option, referred to as the Interim Gas Solution, involves the purchase of imported natural gas and the development of related infrastructure, until indigenous natural gas eventually becomes available. This option is assumed to commence in 2016 and has been included in Scenarios 2 through 6. In order to estimate a price of gas for the Interim Gas Solution, the assumption recommended by the government was to set the gas price such as the cost of electricity generated by the most efficient unit producing electricity from gas is equal to the cost of electricity generated from the cheapest renewable energy technology (solar PV at the transmission level). This is not reflective of the ongoing tendering process, but just to provide insights to the policy making process. In line with this, a sensitivity analysis was carried out on price, to determine impacts of different prices for the Interim Gas Solution on the generation mix.

  - A second option is the use of natural gas from indigenous production, which is assumed to commence around 2022 and be available to all power plants in 2023. An international market price is assumed for indigenous natural gas, which enhances the cost-competitiveness of renewable energy technologies compared to e.g. using a netback price (opportunity cost). It was requested by the government to assume that indigenous gas will be available for power generation as of 2023 in all scenarios.

» **Export of natural gas beginning in 2022** using an **onshore gas liquefaction terminal** is currently considered a likely option, provided enough reserves are proven to build a financially viable project. This option has been included in scenarios 4 and 6.

» Another major project under consideration is an **electric cable connection from Israel to Cyprus** and then to Greece, which is known as the EuroAsia Interconnector. The EuroAsia Interconnector would have a capacity of 2 GW (interconnection to Cyprus: 1 GW). This option was included in Scenarios 5 and 6, however the model only considered electricity imports. It is assumed that majority of imports will originate from Israel, which has a generation mix dominated by hydrocarbons. As such, it is assumed that these imports cannot contribute to achieving Cyprus' renewable energy targets.

» The availability of indigenous natural gas or electrical interconnection, along with the end period of the derogation on SOx emissions, will force a **switch to more expensive low sulphur fuel** for generating units that will not use natural gas. All scenarios with indigenous natural gas or electrical interconnection replace heavy fuel oil with low-sulphur content fuel oil (<0.23% sulphur)

» The share of renewable energy for the electricity power sector has been set at a **minimum of 16% by 2020 to meet the EU 2020 target** for Cyprus to provide 13% of its final energy consumption using renewable energy. The 16% minimum renewable energy target is included in all scenarios. Beyond 2020 all scenarios contain aspirational minimum renewable energy targets for the electricity sector (see Table 20) that increase each year and reach 25.29% in 2030.

» EU regulations for the **maximum CO_2, NOx and SOx emissions** (see Table 21) have been included in all scenarios.

  » Although no scenarios exceeded these emission limits for NOx and SOx it should be noted that the limits for NOx and SOx cover all sectors in Cyprus, not just the electricity sector, as sector-specific limits have not been set yet by the government. Sector-specific limits should take into account the cost of emission reductions in different sectors, to define a minimum-cost emission reduction strategy based on ranking of emission reduction measures by increasing cost. Once these limits are set, they might impact the electricity sector and require additional investments in abatement technologies or a switch to more expensive generators with lower emissions.

  » The use of abatement technologies to reduce emissions of atmospheric pollutants is not considered in the current setup of the model.

» **A discount rate of 6%, as recommended by the Ministry of Finance of Cyprus, is used for all scenarios.** No risk premium has been included. However the suggested value of 1% would not have changed the results significantly.

» Due to lack of data, **variations in electricity load** are assumed to be the same for all customer categories throughout the model period.

» **Electric vehicles** are explicitly considered in the demand forecast, and **represented in MESSAGE** as a separate component of the electricity demand (i.e., electricity for transport). The forecast considers ca. 50 000 electric vehicles in Cyprus by 2030, representing 10% of the national fleet and a 15% of new vehicle sales.

» There is a government commitment to commission a **CSP project with capacity of 50 MW** in the fourth quarter of 2017. The required investment of EUR 115 million takes place in 2017 and the unit is to be operational at the start of 2018. This generation asset has been included in all scenarios.

» **The Net Metering Scheme** encourages the **annual installation of up to 10 MW**

distributed solar PV each year in households and public buildings and an **additional 5 MW** for **self-generation** with optional **storage in enterprises.** As a result, the model deployed 15 MW of distribution-connected solar PV each year in all scenarios until 2020.

- A **maximum annual investment of 80 MW** has been imposed on **utility-scale solar PV** in all scenarios in the attempt to simulate a realistic deployment rate.

- No constraint was imposed on the capacity reserve margin required by the system. It is assumed that the RETs, the EuroAsia Interconnector, and/or energy storage, will provide sufficient power generation for security and to cover the needs of the system with respect to available capacity. Hence, no additional thermal (dispatchable) capacity is installed to satisfy such a constraint. The above assumptions need to be re-examined in future analyses.

- In order to avoid unrealistic deployment of large shares of variable renewable technologies, and in the absence of an interconnector, **a few key limitations were placed on the amount of solar PV and wind that can enter the system without associated storage,** based on an unreleased study developed for the government of Cyprus to assess possible grid stability issues. The maximum capacity for solar PV without storage has been set at 400 MW by 2018 while the corresponding limit for wind has been set at 200 MW by 2018. These figures will be updated by the ongoing study from the JRC.

- Once the thresholds for solar PV without storage and wind are reached, no new solar PV without storage or wind can enter the generation mix. Instead, the system can either invest in storage options of 1 kWh for solar PV or deploy transmission connected storage (e.g. pumped hydro storage or flow batteries). It should be noted that in the case of CSP, only plants with thermal storage are allowed in the system. This is based on the assumption that it is preferable to develop solar PV facilities without storage instead of CSP without storage.

- In all scenarios the last generation units at the **Moni Power Station** will be fully **decommissioned in 2024,** while 360 MW of generation capacity at the **Dhekelia Power Station** will be decommissioned by 2027. However, this may not comply with the plans of the Electricity Authority of Cyprus and the policies of CERA. For instance, given the Moni facility's currently limited operating hours, it might be more cost-effective to extend its lifetime to provide capacity reserve, rather than investing in new facilities solely for this purpose.

3.4 Incorporating key assumptions into MESSAGE model

In this section, the main analytical assumptions are presented, so as to provide an understanding of the structure of the model. In order to assess the total cost of the least-cost system, the sum of discounted costs of investment, operation and maintenance, and fuel costs are taken into account. For these costs **a discount rate of 6% is assumed, as recommended by the Ministry of Finance of Cyprus,** but no risk premium is included in this value. Since the model assumes that the discount rate directly affects the cost of capital, if a risk premium is used this will proportionally increase the overall cost of electricity. As renewables that use no fuel have their generation cost defined almost exclusively by the upfront investment, they are more adversely affected by an increase in cost of capital compared to fossil fuel-based thermal power plants. The base year of the model has been set as 2012 and the model horizon extends to 2030, which means that results are produced by the model starting from 2013. It should be mentioned that whenever prices were available in US dollars, the exchange rate of EUR 1 to USD 1.3285 was assumed. All figures are accounted for and reported in real terms.

3.4.1 Demand projections

Analysis regarding demand projections in terms of final energy demand has been conducted in parallel to this assessment for IRENA by the CUT (Zachariadis et al. 2014). Final electricity demand scenarios from the dedicated study are used as input to this model. Projections are provided for eight different categories of consumers, which have been aggregated to five (transport, industrial, residential, service and agricultural demands) in the case of the ESMC for the sake of simplicity. CUT's methodology is based on an econometric model to forecast final energy demand. The study presents four scenarios.

1. **The Reference Scenario,** which assumes that all parameters such as legislation and energy efficiency measures remain at current levels, is in line with the requirements of the EU Renewables Directive (2009/28/EC). It was included in the National Renewables Action Plan that was submitted to the Commission in June 2010

2. **The Energy Efficiency Scenario** expects that additional, already planned measures of energy efficiency and 'near-zero energy buildings' will be adopted, which is in line with TSO's electricity demand forecast for 2014-2023. This scenario reflects the impact of the new directives (Directive 2010/31/EU) on energy efficiency.

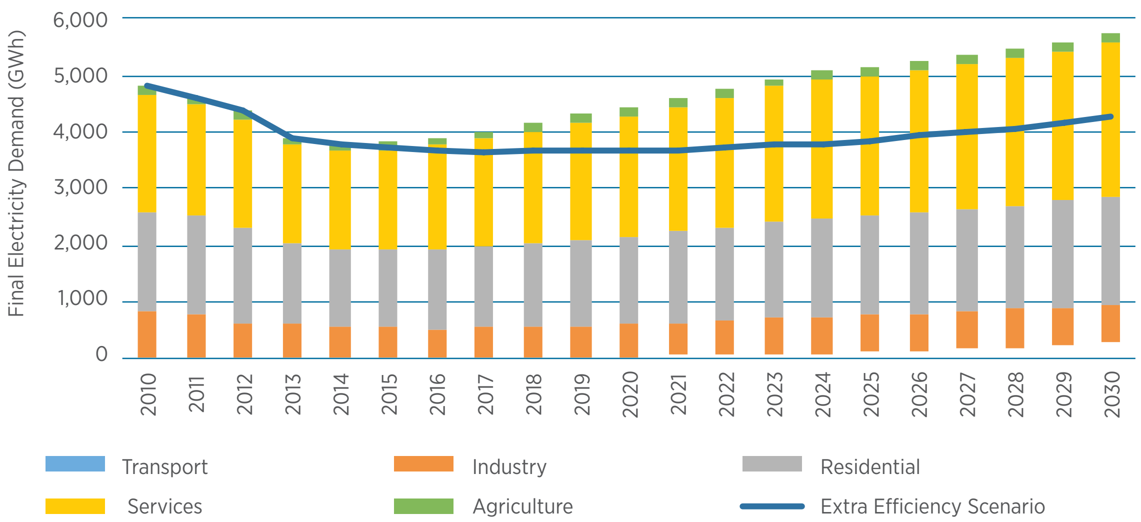
3. **The Decoupling Scenario** assumes that the use of energy-consuming equipment in most sectors of the Cypriot economy is approaching a saturation level and a substantial decoupling of energy use from economic activity will occur, so that further economic growth will be possible in the coming decades without the need of much additional energy.

4. **The Extra Efficiency Scenario** assumes the decoupling scenario as well as the adoption of aggressive policies on energy efficiency and 'near-zero energy buildings' legislation (Directive 2010/31/EU).

For the purposes of this study, demands from scenarios 2 and 4 are used. This is based on the assumption that the Reference Scenario is very unlikely to occur, as there are indications that additional energy efficiency measures will be implemented. As such, the Energy Efficiency Scenario forms the basis for analysis; final electricity demand in this scenario is comparable to the official TSO forecast. Additionally, in order to investigate potential benefits from the adoption of aggressive efficiency measures, the Extra Efficiency Scenario is included in the assessment. Figure 10 illustrates how electricity demand in each of the customer categories is expected to evolve up to 2030 in the Energy Efficiency Scenario as compared to the total demand in the Extra Efficiency Scenario; detailed demand breakdown is provided for both cases in Appendix III.

Electricity demand varies greatly between seasons in Cyprus, with peak demand occurring usually in mid-July, when the temperature on the island is high and hence electricity demand for space cooling rises considerably. Beyond this, demand varies throughout each day, mainly affected by activities in industry, residential and service sectors.

Figure 10: Final electricity demand projections by customer category in the Energy Efficiency Scenario and total demand in the Extra Efficiency Scenario (Zachariadis et al. 2014)



In order to capture the load variability in as much detail as possible, the year has been broken down into a number of time-steps, based on recorded generation in 2012 (Transmission System Operator - Cyprus 2014b). As shown in Figure 11, seven seasons, numbered 1-7, have been identified. These have varying durations, as the primary purpose is to capture periods of low and peak demand. For instance, Season 5 lasts from 16 July to 11 August (a total of 27 days) and 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 22 March, ends on 5 June (a total of 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).

Further to this, two types of days have been identified; workday and weekend. Once again, this is done to capture load variation during these times as a result of different socioeconomic activities taking place. More importantly though, each day is divided into a number of time-slices. Due to a greater variation observed, workdays are divided into six time-steps (Figure 12), whereas weekends are split into three time-steps.

At the moment, due to lack of data, load variation is assumed to be the same for all customer categories throughout the model period. Representation of this aspect can be improved if load curves for each category are provided, along with projected efficiency improvements in each category. In such a case, the model will be able to calculate how the load variation in each customer category, and hence the gross load, will evolve over time.

Since seasonal and daily demand variability differs between each consumer category (Transmission System Operator - Cyprus 2014d), the model prioritises the required capacity that should be online in order to meet the demand, by taking into consideration the demand level in each customer category at each particular time-step.

It is worth mentioning that electric vehicles are explicitly considered in the demand forecast, and are represented in MESSAGE as a separate component of the electricity demand (i.e. electricity for transport). At the moment the forecast considers ca. 50,000 electric cars on the road in Cyprus by 2030, with a total share of 10% of the car stock and 15% market share on new sales. These 50,000 vehicles represent ca. 5% of the total electricity demand in Cyprus in 2030. When future studies will provide a different forecast, this can be

incorporated easily in a revision of the model as electricity for transport is modelled separately.

3.4.2 Scenario definitions

This assessment includes the analysis of a number of scenarios (Table 14).

- **Energy Efficiency Demand Scenario without Interim Gas Solution Scenario (SC1)** - Demands for this scenario are taken from an energy efficiency scenario developed in a separate study examining energy demand projections (Zachariadis et al. 2014). None of the major projects under consideration are implemented, except the production of domestic natural gas for the internal market in 2022; a transition period is assumed where indigenous gas for power generation becomes available in 2023. Specifically, the Interim Gas Solution, the EuroAsia Interconnector and the LNG export terminal are excluded from this scenario.

- **Extra Efficiency Demand Scenario with Interim Gas Solution Scenario (SC2)** - This scenario follows the same logic as SC1, with the exception of different final electricity demand assumptions and the success of the Interim Gas Solution negotiations. Demands are taken from the Extra Efficiency Scenario (Zachariadis et al. 2014), which also assumes a decoupling between economic growth and electricity demand. Thus, demand in this scenario is lower than in SC1. Also, the Interim Gas Solution is allowed to make gas available for the power sector, which means that a limit is imposed on the maximum contribution of renewables in the generation mix, so as to ensure consumption of a minimum volume of gas based on the likely minimum quantity requirements to be purchased for the Interim Gas Solution to happen.

- **Energy Efficiency Scenario Demand with Interim Gas Solution Scenario (SC3)** - This scenario follows the same assumptions and final electricity demand as SC1. However, the Interim Gas Solution negotiations are assumed to be successful, as in the case of SC2. By comparing SC1 with SC3, outputs from

Figure 11: Seasonal variability in demand in 2012 and indication of the chosen seven seasons

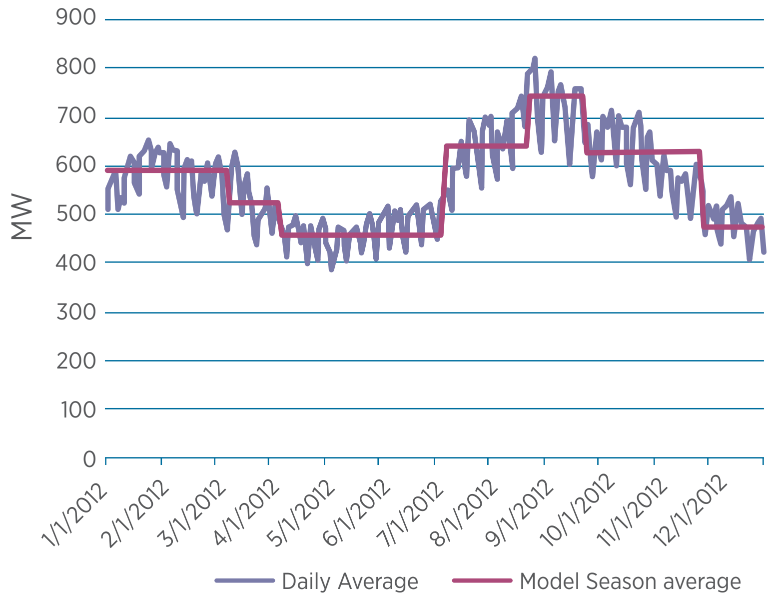
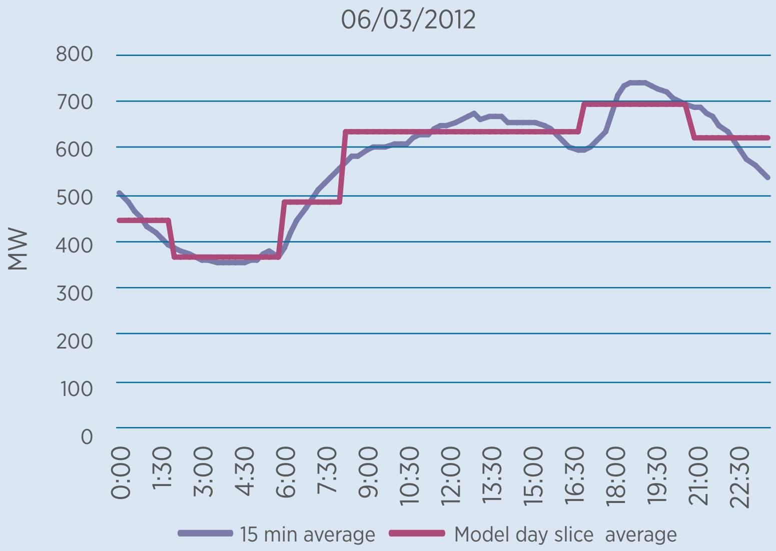
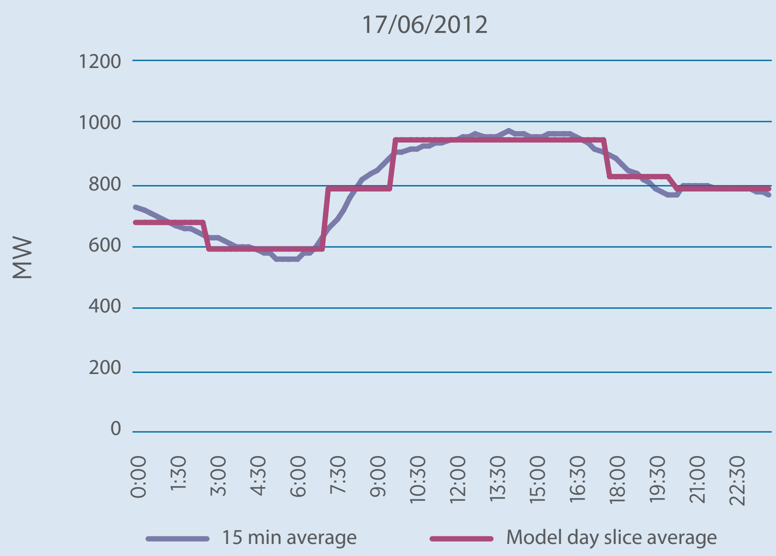


Figure 12: Typical daily variability in electricity demand and indication of the chosen six day slices in March and June





this scenario can provide insights regarding the effects of the Interim Gas Solution.

» **LNG Export Terminal Scenario (SC4)** - In this scenario, assumptions are the same as in the previous scenario (SC3), but investment in a liquefaction facility for export purposes is allowed. Since the interconnector is not deployed in this scenario, storage is again deemed necessary beyond certain pre-defined limits.

» **EuroAsia Interconnector Scenario (SC5)** - This scenario assumes that the EuroAsia Interconnector will be implemented as planned, but no liquefaction facility will be developed. Unless a separate grid analysis indicates otherwise, the assumption here is that storage is not a prerequisite in the case of high renewable energy penetration. The Interim Gas Solution is assumed to be successful as in SC3. Final electricity demands are the same as in SC1 and SC3. The aim of this scenario is to identify the price at which imported electricity becomes cost-competitive enough to be part of the Cyprus power generation mix. Since investment cost for development of the cable connection has not been considered in the analysis, the economic and other benefits from the deployment of the interconnector should outweigh the cost of the associated infrastructure for the interconnector to add value to the electrical system. In the presence of an interconnector, the impact on renewable energy deployment would be twofold: no storage would be required and more variable renewable energy can enter the power generation mix without the need for storage, which would reduce its competitiveness.

» **LNG Export Terminal and EuroAsia Interconnector Scenario (SC6)** - A combination of scenarios SC4 and SC5 has been conducted, with both the liquefaction facility and the interconnector considered. Assumptions regarding the interim gas solution are the same as in SC4, while the assumptions regarding the necessity of storage are the same as in SC5.

As a parallel activity, a sensitivity analysis has been carried out to assess the impact of various key parameters (Section 3.5.4). These include the price of imported electricity via the interconnector and cost for the use of indigenous gas in the power sector.

3.4.3 Fuel availability and cost assumptions

At present, heavy fuel oil, diesel and very limited quantities of biomass are the only fuels used in the Cyprus power sector (solar and wind do not use fuel). However, it is expected that natural gas will be the main fuel for power generation in the coming years; either through the Interim Gas Solution,

Table 14: Main scenario assumptions

Scenario	Energy Efficiency Demand	Extra Efficiency Demand	Interim Gas Solution	Storage	Liquefaction terminal	Interconnector	Indigenous gas for power
SC1	√			√			2023
SC2		√	√	√			2023
SC3	√		√	√			2023
SC4	√		√	√	√		2023
SC5	√		√			√	2023
SC6	√		√		√	√	2023

subject to its economic feasibility, or through domestic production within the next few years.

However, once natural gas becomes available to the Cyprus power sector or once the island becomes connected to the Israeli and Greek grids via the EuroAsia Interconnector, further analysis is needed regarding the existing derogations on SOx emissions limits, since the installation and use of emission abatement technologies or the replacement of heavy fuel oil with low-sulphur content fuel oil (<0.23% sulphur) might be required before 2020.

In order to project fuel prices relevant to the Cyprus system, available historical values from the island or from Europe are taken and related to international crude oil prices (IEA, 2014). Consequently, available price projections for crude oil (IEA, 2013) are used to establish price projections for heavy fuel oil, low-sulphur fuel oil and diesel (Table 15). In order to calculate a price of gas for the Interim Gas Solution, the assumption recommended by the government was to use the levelised cost of electricity (LCOE) from the cheapest renewable energy technology (solar PV at the transmission level) is first derived for current prices[22]. The price of imported natural gas in the Interim Gas Solution has been set at a level so that the variable cost of generation from the most efficient gas-firing power plants matches the previously calculated figure (EUR 78/MWh). This calculation only includes fuel, operation and maintenance costs. Since the Vasilikos combined cycle gas turbines are already installed, investment cost and depreciation of the infrastructure are ignored. By treating existing fossil fuel-fired plants in this manner, the analysis adopts a rather conservative approach on the cost-competitiveness of renewables.

The price of domestic natural gas is derived from international price projections at the European level (IEA 2013), while a sensitivity analysis is also carried out to investigate the potential effect of a range of prices on the generation mix.

3.4.4 Electricity supply system

The current status of Cyprus' power supply system has been discussed in Section 3.2 of the report. In this part, the key assumptions regarding technical characteristics of the power supply options are provided.

Table 15: Projected fuel prices used in the model

		2013	2015	2020	2025	2030	2035
Oil	USD/barrel	110	111	113	116	121	128
	EUR/Mbtu	14.1	14.7	15.1	15.7	16.6	14.1
Heavy fuel oil	EUR/Mbtu	11.7	11.8	12.1	12.4	12.9	13.6
Diesel	EUR/Mbtu	16.8	16.9	17.3	17.8	18.5	19.6
Low-sulphur fuel oil	EUR/Mbtu	14.5	16.1	16.5	16.9	17.6	18.6
Natural gas (international market price)*	EUR/Mbtu	8.8	8.9	9.0	9.0	9.3	9.6

*Market price is aligned with the projected European market price and is the assumed price for domestic use in the power sector (IEA 2013)

[22] *In the case of PV this includes investment, operation and maintenance costs, and takes into account the lifetime, capacity factor and associated discount rate.*

Power generating technologies

As shown in Table 13, the existing power system relies on thermal generating units, which are burning diesel and heavy fuel oil for the generation of electricity. However, in recent years the share of renewable energy has been increasing, with contributions from wind, solar PV and biomass-fired facilities (Transmission System Operator - Cyprus 2014a). Existing RETs are included in the model's baseline setup. Future investments in these technologies are allowed to occur so as to expand the generating capacity of the system, if required, to meet growing demand.

Furthermore, CSP with thermal storage, which does not currently exist in the system, is considered, as this technology is assumed will be introduced in the generation mix. A committed CSP project with capacity of 50 MW may be commissioned in the fourth quarter of 2017. The model is allowed to invest in further capacity additions of the same technology in the subsequent years, if it is deemed economical. Additionally, a second CSP plant without storage with a capacity of 50 MW is planned to be constructed and commissioned by 2017, but this is not included in the analysis. In case this plant materialises, assuming a capacity factor of about 27%, it will displace 72 MW of solar PV.

The current Net Metering Scheme encourages the annual installation of up to 10 MW distributed solar PV each year in households and public buildings and an additional 5 MW for self-generation with optional storage in enterprises. The scheme, which is taken into consideration in the analysis, is set to last until 2020, but this can be revised depending on new developments. Even though a comprehensive assessment of the results of this policy has not been carried out yet, given the large difference between generation cost from PV and retail tariff in Cyprus, it is assumed that at a minimum 15 MW of distributed solar PV will be installed annually until 2020 due to the large savings that customers can achieve through net metering.

It is important to note that the amount of distribution-connected PV to be installed under net metering has been assumed as committed (at least 15 MW per year will be deployed for sure), in compliance with a CERA decision and ministerial guideline. However, TSO set a limit of 60 MW of non-controllable PV that can be connected to the grid in Cyprus (as of October 2014 more than 40 MW is already installed). This translates into a requirement for future small-scale PV systems in net metering to invest in additional controls as of 2015. TSO is already asking for ripple-control on all new systems, including small-scale domestic installations. As a comparison, in Germany this is required only in systems above 100 kWp, with retrofitting cost paid by the system operator and curtailment being compensated (according to Section 66 of the German Renewable Energy Sources Act). Having the possibility of reducing active power on all installed systems, coupled with no compensation for curtailment of RET because of system security reasons, increases the risk for investors and increases investment cost. Additional research on different electricity demand profiles for different categories of customers can also help the government in targeting the net metering policy towards those for which self-consumption can be maximised, minimising grid integration cost. For instance, users with large mid-day cooling loads or with the possibility of installing centralised ice storage for space cooling given some small incentive can be a focus (e.g. hotels, office buildings). Any installations beyond the above levels (50 MW CSP with storage, 15 MW distribution-connected PV under net-metering yearly up to 2020, 175 MW wind) levels are simply part of the model's minimum cost pathway to satisfy electricity demand. It should be noted that a maximum annual investment of 80 MW has been imposed on utility-scale solar PV in the attempt to simulate a realistic deployment rate, which would otherwise be faster due to the large generation cost difference between PV and power plants fuelled by oil products (i.e. heavy fuel oil and diesel).

Other renewable energy technologies, such as hydropower, geothermal, ocean and wave energy, are under assessment, including in some pilot projects. Since it is unlikely that these options will have a sizeable contribution to the energy system of Cyprus by 2020, and due to the fact that there are no estimates as to their potential in Cyprus, these options are excluded from the analysis. In a future update of this work, the scope of the analysis can be expanded to include these technologies, in case their potential and cost in Cyprus is identified as attractive.

Generic cost assumptions have been adopted in the analysis, whenever specific data for

Cyprus was not available (Figure 13). However, the data is aligned with the situation in Cyprus. For instance, the IEA projects investment costs for rooftop PV in 2014 at EUR 2,900/kW (IEA 2012), while at the moment installations in Cyprus cost EUR 1,400-2,000/kW. Previous IRENA assessments report values that are within this range (IRENA 2013a, 2013b), so IRENA values are adopted for PV (investment cost of EUR 1,665/kW for 2013). Detailed cost and performance parameters for existing and future generation technologies are provided in Appendix IV.

Storage options

Storage is considered a facilitator of high penetration of renewable energy technologies for two reasons: it provides the additional reserves required to effectively regulate load and frequency and it allows time-shifting of RET generation from times of low residual dispatchable generation to times of high residual dispatchable generation (peak shaving).

As a result of the variability of the output of some RETs (i.e. solar PV and wind), further to thermal storage for CSP mentioned above, additional options of electrical storage have been considered in the model. These include storage at the centralised and decentralised levels, imposed as a prerequisite beyond certain renewable energy shares if the interconnector with Israel and Greece is not implemented. If such an electrical interconnection exists, from an energy planning perspective, it is assumed that there is no reason to enforce storage in an interconnected system with interconnection capacity that is comparable to the system's peak demand and maximum variable renewable energy generation. Nonetheless, storage is allowed to come in if deemed economical in all scenarios of this assessment. The grid study to be carried out by JRC will verify any bottlenecks in the transmission and distribution system and any need for grid support services that might still make storage necessary. Storage can serve other valuable purposes (e.g. increased self-consumption at the customer level, provision of ancillary services, peak shaving, etc.), and this can be evaluated using this model, once it has been updated based on the results of the grid study from JRC.

Assessments have been made in the past to investigate the possibility of introducing pumped-hydro storage at the centralised level (Poullikkas 2013). In such a system, water would be pumped from a lower to an upper reservoir when demand is low or generation from variable RET is particularly high, and released through a turbine to generate power, when that additional power is required by the system. Cyprus has the advantage that dams are already in place in all its major freshwater streams, due to freshwater supply purposes, so a part of the required infrastructure exists.

Figure 13: Renewable energy technology investment cost projections

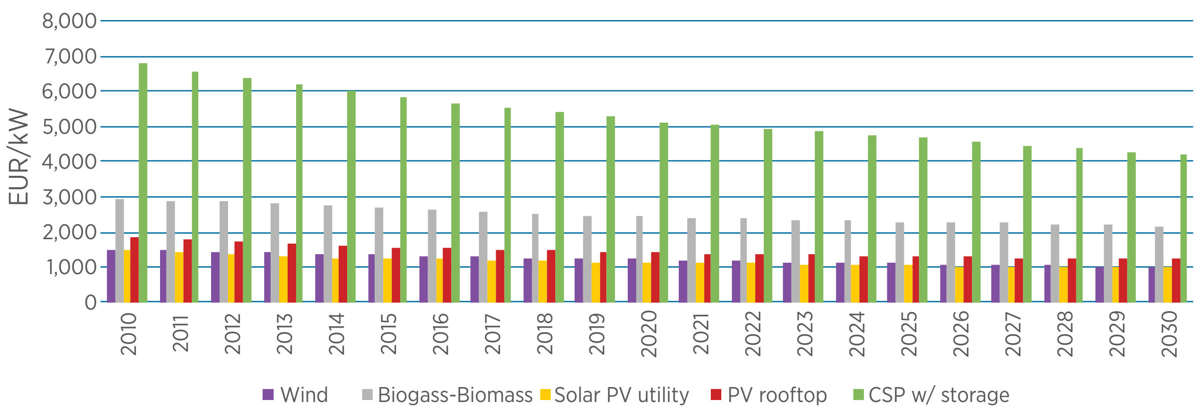


Table 16 provides the main details of the proposed pumped hydro storage as provided by the aforementioned assessment. It should be noted that as a first step only one pumped-hydro storage facility is included in the ESMC.

Another centralised electricity storage option considered in the analysis is flow batteries (Table 17). These are applicable for grid sizes between 25 kW and 10 MW (IRENA 2012d), so they are suitable in case renewable facilities within this size get connected to the transmission network.

Similarly, the option of decentralised storage is also included as an option to investigate the potential for "time-shifting" of power generation. For instance, peak power generation by household photovoltaics occurs around noon, at a time when the demand of households is low due to absence of inhabitants. It is quite interesting to examine whether the electricity generated at this time can be stored with batteries to reduce peak demand, which during most of the year occurs in the evening. As such, Li-Ion batteries are considered for storage in the residential and services sectors, for which the main assumptions are presented in Table 17.

Table 16: Pumped-hydro storage specifications (Poullikkas 2013)

Location of facility	Kourris Dam
Year of operation	2021
Nominal capacity (MW)	130
Overall efficiency	77%
Storage capacity	11.44 GWh
(88 h at full load)	EUR/Mbtu
Capital cost (EUR/kW)	1,185
O&M cost (EUR/kW-yr)	11

Table 17: Storage options for decentralised solar PV (IRENA 2012d)

	Flow batteries	Li-Ion batteries
Level	Centralised	Decentralised
First year of operation	2016	2016
Capital cost EUR/kW	828	527
Capital cost EUR/kWhcap	433	753
Fixed OM costEUR/kW-yr	22.6	18.8
Efficiency	77.5%	90%
Lifetime (yrs)	10	12.5
Lifetime (charge cycles)	1,500-15,000	2,000-3,000

As a follow up to this work, further options can be incorporated for storage. An alternative that can be assessed in more detail is that of electric vehicles, as use of this mode of transport is expected to increase in the years leading to 2030. Additionally, with the potential introduction of smart grids, the role of storage will gain significance. These are part of the grid analysis that has started in October 2014.

A weakness in the modelling approach is that not all key technical characteristics of storage technologies can be represented in MESSAGE. For instance, response time characteristics, lifecycle charges and Ampere hour storage cannot be defined directly in the model, while retention time can be included. As such, the decision on whether to invest in storage options is primarily based on their economic characteristics. Storage technologies in MESSAGE are used to store or discharge electricity according to the marginal cost of electricity at each particular time-slice. For instance, it may be deemed economical to store electricity from a PV system during early afternoon and discharge this electricity during peak demand in the evening, so as to substitute generation from costlier options (e.g. diesel gas turbines).

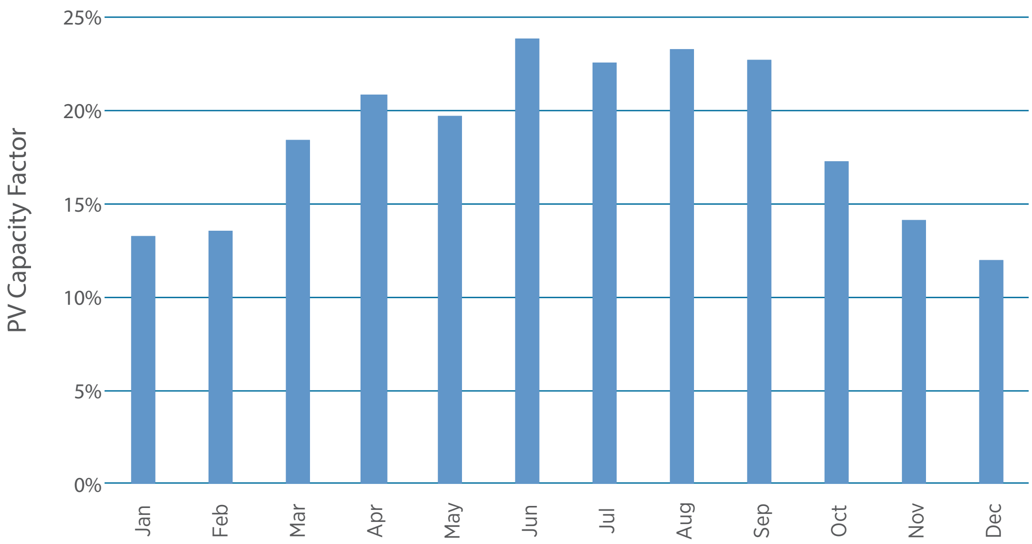
3.4.5 Seasonal and daily generation variability of RETs

Biomass-fired, wind and solar PV generators are currently the only sources of renewable energy-based power generation in Cyprus. The latter two, however, are variable energy sources, which means that their electricity production changes with the solar radiation and wind speed. The role of predictability is highly significant and must be taken into consideration when the aim is to integrate renewable energy sources in the system. Forecasting of wind speed and solar radiation can greatly help in the dispatching of thermal power plants, as variable renewable energy (VRE) output can be predicted with reasonable accuracy. The results of a technical study detailing the benefits of VRE production forecasting for the integration of high shares of VRE is included in this roadmap.

With regards to solar PV, the meteorological conditions in Cyprus are favourable, as there is an abundance of sunny days. As such, the generation potential from this technology is predictable for the majority of the year. Figure 14 illustrates the average monthly capacity factor of solar PV; June has the highest (23.8%), whereas December (12%) has the lowest capacity factor. Figure 15 shows the daily variability in the PV generation potential for the months of March, June and September. As expected, peak generation occurs around noon throughout the year.

Contrary to solar insolation, wind availability in Cyprus is not as predictable. Even though average wind availability in each month seems to follow a particular daily pattern (Figure 16), this is not always the case when generation is examined for each separate day. Therefore, the variability of

Figure 14: Seasonal variability in generation potential of solar PV (based on values provided by the TSO)



wind speed coupled with the lack of grid interconnections to other countries, poses a challenge in ensuring a constant uninterruptible supply of electricity. Therefore, in case the Cyprus system relies heavily on wind generation in the future, this would potentially be a challenge that requires a combination of improved forecasting techniques and technological solutions (e.g. highly controllable turbines, improved power system controls).

The capacity factors for wind and solar PV technologies provided by the TSO are used to calculate potential shares in generation for each time-step. In the case of solar PV this is a good approximation, as the greater geographical distribution of solar PV systems evens out variation in total PV generation, while hour-to-hour or day-to-day variability of PV generation is less than that of wind generation. However, in the case of wind, this approach has the disadvantage of assuming that wind availability follows the same daily pattern in all years. Nonetheless, despite its generic nature, the addition of this fluctuation introduces an element of variability of this technology option.

In the case of CSP, the System Advisor Model (SAM – version 2014.1.14) (NREL 2014) is used to

Figure 15: Daily variability in solar PV generation potential for selected months (based on values provided by the TSO)

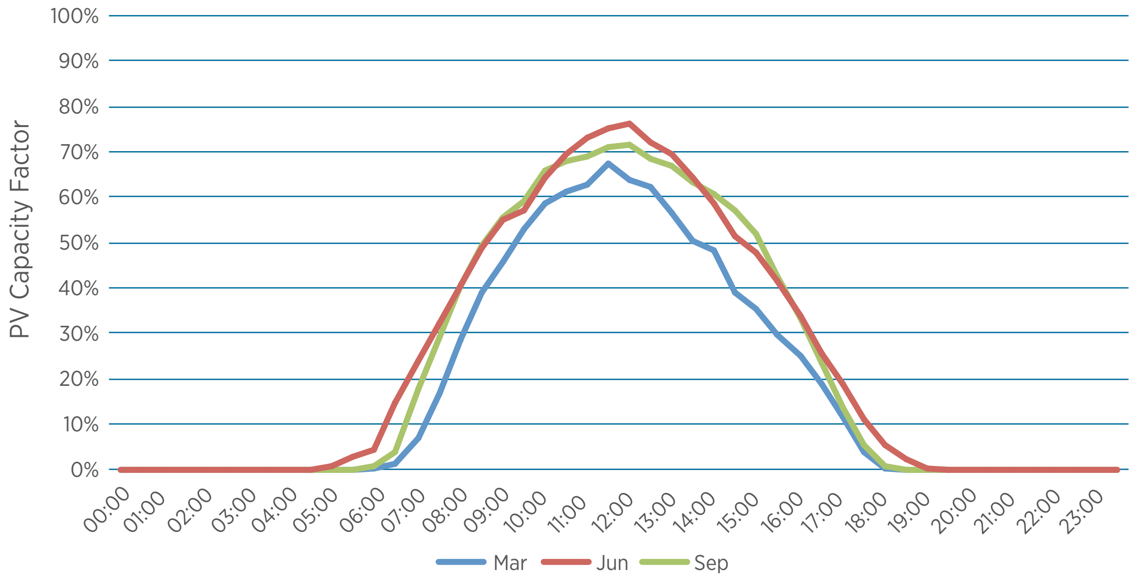
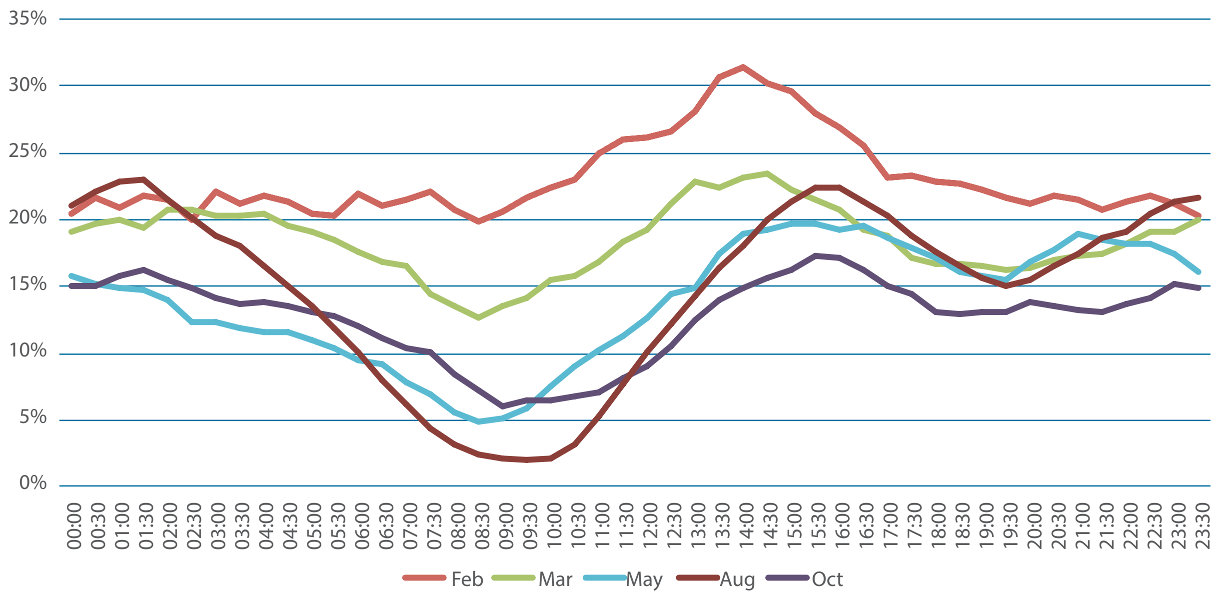


Figure 16: Daily variability in wind generation potential for selected months (based on values provided by the TSO)



extract information regarding seasonal and daily generation variability. A technology corresponding to a CSP facility with thermal storage (solar tower with 12 hours thermal storage) is simulated and information regarding electricity production for each hour of the year is extracted. The capacity factor (39.25%) of the committed CSP facility is taken from project-specific documents provided by the Ministry of Energy, Commerce, Industry and Tourism, while only the shape of seasonal and daily generation is estimated through SAM and inserted in MESSAGE.

One important aspect currently not considered directly by the model is that of curtailment. This is particularly significant, especially as the share of renewable energy generation is expected to increase. At the moment, the model chooses to provide electricity from renewables based on their availability and their economic characteristics. Constraints could potentially be imposed so that the share from particular renewables cannot exceed a particular level at each time-slice, but these would be based on rough estimations. It is more practical at this stage to leave this to be discussed and quantitatively defined in the upcoming grid study, which will provide the appropriate constraints to be added to the ESMC in a future update.

3.4.6 Transmission, distribution and electricity trade

Developing a detailed plan of the transmission and distribution network of Cyprus is a complex task that falls outside the scope of this analysis. Long-term cost optimisation tools like MESSAGE are not appropriate for this task. A detailed load-flow analysis and dynamic stability analysis should be used for more detailed investigations of the grid, which is outside the scope of this assessment, and should instead be covered as part of the grid study from JRC.

Nonetheless, in order to include an estimate of the operation and maintenance costs of the grid in Cyprus, historic figures are used. Table 18 shows these approximations.

A more accurate estimate of the transmission and distribution investment needs related to deployment of higher shares of variable RET can be developed based on the upcoming methodology being developed by IRENA, which will be available in the second quarter of 2015.

An assessment developed under the PV Parity Project (Pudjanto *et al.* 2013) shows how, in some cases, distribution-connected PV reduced the need for investment in distribution network upgrades (see Figure 9). When designing policies

Table 18: Estimated transmission and distribution operation and maintenance costs

	Transmission	Distribution
Fixed O&M (EUR/kW-yr)	0.72	1.12
Variable O&M (EUR/MWh)	0.22	0.35
Losses (%)	1.52	3.24

to promote distributed PV versus utility-scale PV, these costs and savings need to be carefully assessed. In some instances, demand response and storage can reduce grid integration cost.

EuroAsia Interconnector

Beyond the domestic transmission and distribution system, considerations are taken regarding cross-border transmission links. The EuroAsia Interconnector is a privately funded project under proposal to deploy an underwater electric cable that will connect Israel to Cyprus and then Greece. The 400 kV direct current (DC) connection is planned to have a capacity of 2,000 MW and a total length of approximately 1,518 km (CERA 2013) with the capacity of the interconnection to Cyprus of 1,000 MW. If such a connection becomes available, Cyprus will benefit in terms of security of supply and management of reserves for generation. For the purposes of this assessment, the total cost of the project is out of the scope of this analysis since the cost will be recovered by the differential in prices between the connected electricity markets. Key project information is shown in Table 19.

The addition of the interconnector in the model suggests that there is potential for imports and exports of electricity by the Cyprus power system. However, while the development of an interconnector suggests that the island will be able export electricity, the model currently does not allow this; although it is implicitly assumed that excess renewable energy technology generation may be exported, thus relaxing system technical constraints. Due to the difficulty in projecting at what prices exports can occur, this aspect is excluded from the model. If information becomes available on potential market development for exchange of power between the associated countries, the treatment of exports in the

Figure 17: Additional distribution network cost of PV (EUR/MWh) in Greece (Pudjanto et al. 2013)

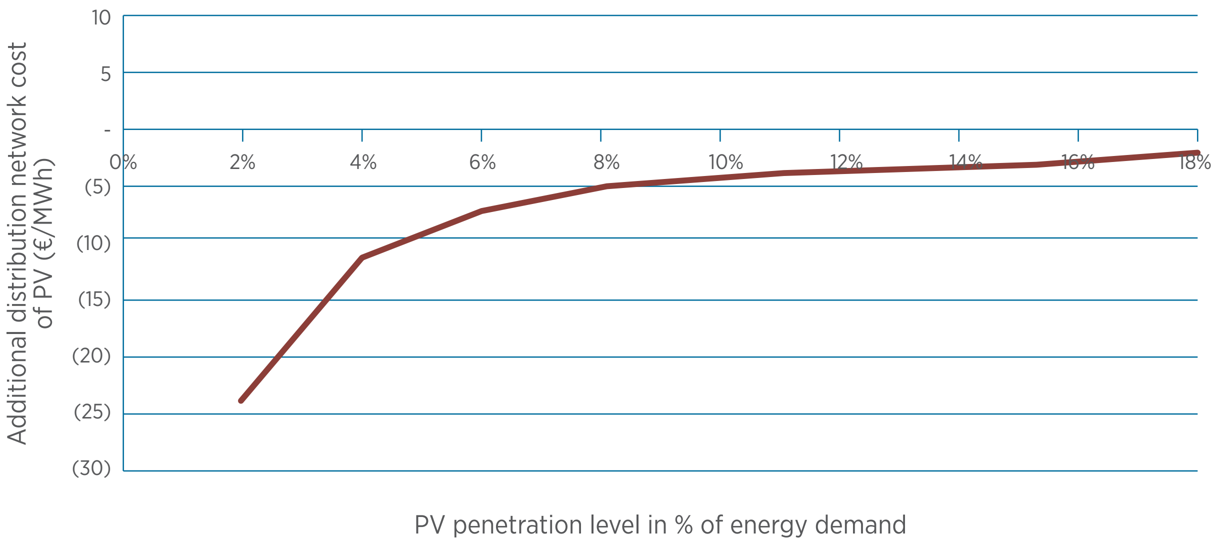


Table 19: EuroAsia Interconnector deployment details (CERA 2013)

From	To	Installation Year	Length (km)
Hadera (Israel)	Vasilikos (Cyprus)	2017	329
Crete (Greece)	Attica region (Greece)	2018	310
Vasilikos (Cyprus)	Crete (Greece)	2020	879

model can be revisited. Currently the only benefits modelled for the interconnector are the price reduction in case of low-priced imports and the removal of constraints to maximum penetration of variable renewables. This is a reasonable assumption based on the experiences of other countries with high share of variable renewables and interconnection to neighbouring countries. However, any investment necessary on grid strengthening or grid support services is not taken into account in this analysis, and will be determined by JRC analysis, and can be incorporated in a future revision of this model.

The base price of the EuroAsia Interconnector is given at EUR 90/MWh. In order to provide insights as to the electricity import price, a sensitivity analysis is carried out (Section 3.5.4), which relates a time-independent import price to the level of electricity imports during the projected time horizon.

3.4.7 Constraints related to system reliability

Solar PV, CSP and wind have naturally a variable output. The Cyprus power system currently has biomass-fired, wind and solar PV facilities. With the future additions in wind, solar PV and CSP capacity, the power system on the island will be less dispatchable. Currently, an additional concern is the lack of grid connections beyond the island, which can be beneficial to integration of larger amounts of renewable energy technologies. If the EuroAsia interconnector with Israel and Greece is implemented, Cyprus could gain access to the reserves offered by these countries, provided market design will allow for efficient cross-border trading of electricity and ancillary services. Excess power from variable renewables can also be exported, instead of curtailed, increasing the return on investments on variable RETs. **A portfolio of solutions exist to mitigate impacts of variable RET on grid reliability. In particular, a minimum-cost mix of investments should be considered, taking into account, among others, thermal plant flexibility, improved forecasting of RET generation, smart power electronics and demand response** (e.g. controllable loads like large cooling systems with ice or chilled water storage, desalination plants, etc.).

System operational reserve requirements

At present a conservative approach is taken to determine the amount of operational reserves required, so as to minimise the risk of power shortages caused by rapid changes in power output from variable renewable energy technologies or potential outages of thermal plants. As such, minimum requirements regarding fast-response (spinning) reserves are implemented. Spinning reserves are units that can be ramped up or down within seconds or minutes to limit sudden shifts in the frequency of the grid, for example due to outages. According to information provided by the TSO, in Cyprus these reserves should cover the aspects below.

- At any given point, 60 MW of spinning reserve needs to be available beyond the level generated to cover demand for electricity.
- An additional reserve corresponding to 50% of the predicted wind generation should be available.
- Additional to the above, fast-response reserve is needed to account for 10% of the predicted solar PV and CSP generation without storage.

It should be clarified that in the ESMC all existing and future centralised thermal plants are allowed to contribute to the aforementioned reserves, assuming that all remaining spinning capacity is that of fast-response-reserves.

At the moment, the above policy from the TSO is a guideline and it is expected to be refined and modified according to system specific conditions and requirements. Policy pertaining to system reserve will take into consideration the daily and seasonal variability of generation from the renewable energy sources, as well as the size of the largest generating unit of the system, which is currently a 130 MW steam turbine at the Vasilikos site (see Table 13).It should be noted that the proposed interconnector with Greece and Israel, and hence its associated reserves in the respective countries, may contribute to an extent to these reserves, but this decision is yet to be made. Therefore, the reserve requirements policy is kept the same in all scenarios, including those with the development of the interconnector.

System inertia, ramp rates and single point generation

As penetration of renewable energy technologies increases, fewer thermal generation units remain in service and the inertia of the electrical system is reduced. Imbalances between generation and demand are expected to create higher rates of change of frequency and larger deviations in frequency, affecting the stability of the electrical system of Cyprus in the absence of specific mitigation measures. No minimum percentage of thermal generation or minimum number of thermal generating units in operation at all times have been imposed explicitly, while operational reserve constraints have been considered explicitly

Due to the variability in the output of variable RETs, both upward and downward high ramp rates of generation are possible in absence of specific technical measures to reduce ramp rates. Minimum requirements for spinning reserve have been imposed as described in the previous section, while a specific treatment of system ramping requirements, frequency control requirements and the ramping capability of dispatchable generation are outside the scope of this study.

As geographical location of generation assets has not been explicitly modelled, no specific constraint on location of power plants has been assumed to increase or reduce geographical dispersion of power plants. If single point generation is considered to raise a concern in terms of system resilience, it is possible to enforce a constraint in the model to have thermal generation units operational in at least two different locations at all times. However, this is outside the scope of this analysis.

The JRC grid stability study is expected to take into consideration the above issues in evaluating the stability and reliability of the electrical system of Cyprus.

System capacity reserve requirements

No constraint is imposed on the capacity reserve margin required by the system. It is assumed that the RET technologies, the interconnector, and the storage facilities cover the security of the system with respect to adequacy of power generation sources to cover the system's capacity requirements. Hence, no additional thermal (dispatchable) capacity is installed to satisfy such a constraint. The above assumptions need to be re-examined in future analyses, as the contribution to "firm" capacity of each RET technology, storage facilities, or the interconnector is evaluated. It is reasonable to expect that the least-economic thermal plants will be used less every year, due to deployment of RETs. This can help in extending their lifetime beyond current estimated decommissioning dates, to contribute to the desired capacity reserve.

Limitations related to the penetration of solar PV and wind

In order to avoid unrealistic deployment of large shares of variable renewable technologies, and in the absence of an interconnector, the below limitations are placed on the amount of solar PV and wind that can enter the system without associated storage:

» The maximum capacity of solar PV without storage is set at 400 MW by 2018.

» The corresponding limit for wind is set at 200 MW by 2018.

The above limits are based on a study developed by the Cyprus Regulatory Energy Authority (CERA), where it was determined that, based on the existing grid configuration, up to 400 MW of solar PV and 200 MW of wind can be deployed by 2018 without storage requirements. These capacities represent respectively 40% and 20% of the peak demand for that year (CERA 2014). In the present analysis, these limits are allowed to increase after 2018 maintaining the same share on peak electricity demand, reaching 550 and 275 MW for solar PV and wind respectively by 2030 in the Energy Efficiency Scenario; the corresponding figures are 468 and 234 MW in the Extra Efficiency Scenario. Once these thresholds are reached, no new solar PV without storage or wind can enter the generation mix. Instead, the system can either:

» invest in storage options of 1 kWh for each 1 kWp solar PV; or

» deploy transmission connected storage (e.g. pumped hydro storage or flow batteries). For instance in case the 130 MW pumped hydro storage is deployed, an additional 130 MW of solar PV or wind can be installed.

It should be noted that in the case of CSP, only plants with thermal storage are allowed in the system. This is based on the assumption that it is cheaper to deploy solar PV systems without storage rather than CSP without storage. It is important to know that these thresholds are based on rule of thumb assumptions, and will have to be revised based on the grid study being carried out by JRC.

3.4.8 Renewable energy targets & environmental constraints

Renewable energy targets

As an EU member country, Cyprus has to comply with its agreed renewable energy targets. These targets currently exists for the whole energy sector and for the power sector up to 2020, but no such targets have been set beyond 2020 (Ministry of Commerce, Industry and Tourism 2010). However, an estimation of the aspirational renewable energy share for the period 2021-2030 has also been provided by the government and it is included in the model, as shown in Table 20. It should be noted that there is a rapid increase in years 2020-2021, which in reality could occur more smoothly.

Greenhouse gas emissions

Additional to existing renewable energy targets, Cyprus has to comply with a set of EU directives regarding greenhouse gasses. Annual free CO_2 allowances and annual Emissions Trading Scheme (ETS) projected price are as shown in Table 21.

In the case of CO_2, the target emission is included as a "soft" limit, which means that the limit can be exceeded, but a penalty will have to be paid (Table 21). This penalty is based on carbon cost projections from EU's ETS (European Commission 2013). It is important to note that from 2020 no free allocation of CO_2 emissions will be

Table 20: Minimum renewable energy 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 21: CO_2 free allowances and Emissions Trading Scheme price for CO_2 emissions (European Commission 2013)

	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO_2 (ktonnes)*	2,519	2,195	1,907	1,583	1,260	936	576	0	0
EUR/tonne CO_2	5	5	5	6	7	8	9	10	11
	2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
CO_2 (ktonnes)*	0	0	0	0	0	0	0	0	0
EUR/tonne CO_2	12	12	13	14	18	22	27	31	35

*The limit for CO_2 corresponds to free emission allowances, not to a strict constraint like in the case of NO_x and SO_x

available, and as such all technologies releasing this pollutant will be penalised.

Industrial emissions

Beyond its greenhouse gas limits, Cyprus has the obligation to comply with directives on other atmospheric pollutants. The emission limits presented in Table 22 for NO_x and SO_x are for the entire energy sector of the island and as such, this analysis cannot provide clear insights as to the performance of each of the scenarios. The limits of these two pollutants are not exceeded in the present model, but it is unclear whether this occurs when other energy sectors (i.e. heating and transport) are considered. If power sector-specific limits are provided, the present assumption can be revised.

One aspect that is not considered in the current setup of the model is the possibility of using abatement technologies to reduce emissions of atmospheric pollutants. Such options can influence decisions on potentially shifting the way units are operated or the fuels fired in these facilities. It would be important to evaluate the cost effectiveness of dispatching a plant with lower emissions but higher generation cost vis-à-vis retrofitting the plant with lower generation cost with abatement technologies. Even though this is certainly an important aspect, this is outside the scope of this study. Future revisions of this work can include this option, if deemed necessary by the relevant stakeholders.

3.4.9 Natural gas reserves and potential for exports

In the past few years, substantial volumes of gas have been discovered in the Eastern Mediterranean, in the Exclusive Economic Zones of Cyprus, Israel and Lebanon. Israel has been a producer of natural gas since 2004, but has been relying mostly on imported natural gas for its energy needs. However, since the discoveries of approximately 28 trillion cubic feet (tcf) of gas in the offshore fields of Tamar and Leviathan the energy outlook of Israel has changed.

In contrast to Israel, Cyprus has not yet started domestic production of natural gas, but it has started exploration. The first exploratory well started in autumn 2011 in Block 12 (one of the 13 offshore blocks) resulting in the "Aphrodite" discovery. The resource in this area is estimated to be between 3.6 and 6 tcf of natural gas, with a mean of 5 tcf. During the second licensing round for exploration, Cyprus has awarded additional exploration licenses for five offshore blocks to the Italian and Korean consortium Eni/KOGAS and the French Total. An intensive exploration program is scheduled by the licensees from the fourth quarter of 2014 onwards, with Eni/KOGAS already drilling their first exploration well in Block 9.

A conservative approach is taken in the analysis, as it is assumed that the proven 5 tcf from "Aphrodite" will be available for exploitation within the model period. Nonetheless, this is considerable volume taking into consideration the size of the Cyprus

Table 22: Annual emission limits of atmospheric pollutants

	2013	2014	2015	2016	2017	2018	2019	2020	2021
NO_x (ktonnes)	23.0	23.0	23.0	23.0	23.0	23.0	23.0	11.9	11.9
SO_x (ktonnes)	39.0	39.0	39.0	39.0	39.0	39.0	39.0	6.5	6.5
	2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
NO_x (ktonnes)	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	6.4
SO_x (ktonnes)	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	1.9

energy sector. Even though these parameters do not affect the current analysis, Table 23 shows cost assumptions included as placeholders in the model for production and development of these reserves.

As a result of the extensive volumes of gas, once domestic production commences, the power sector will largely rely on this resource. Even though production of domestic natural gas is expected to commence in 2022, this analysis assumes that domestic reserves will become fully available from 2023. Furthermore, available reserves are enough for exports to occur as well. Therefore, the construction of a liquefaction facility at Vasilikos for the production of liquefied natural gas (LNG) is currently under consideration. It is estimated that the LNG terminal would require dedicated generation units of 200 MW for self-consumption. This could potentially affect the ability of the island to reach its aspirational targets for the period 2022-2030, as a greater deployment of renewables will suddenly become necessary due to the significant additional electricity demand generated by the liquefaction terminal. The main assumptions for the LNG terminal are shown in Table 24.

Due to the price gap between oil and natural gas, the possibility of investing in a gas-to-liquids (GTL) facility has been an option taken up successfully in various parts of the world (Wood et al. 2012) to produce high quality petroleum products from natural gas. Even though this option is available in the model, it has not been considered in any of the examined scenarios. In case this is deemed as a viable option, the model can be used to assess such an alternative either for export purposes or for the internal market.

Table 23: Natural gas exploration and production assumptions (IEA ETSAP 2010b)

Parameter	Unit	Value
Exploration and development cost	EUR/Mbtu	2.24
Production cost	EUR/Mbtu	0.81
First year	yr	2022

Table 24: LNG terminal assumptions (IEA ETSAP 2011)

Parameter	Unit	Value
Liquefaction cost	EUR/Mbtu	0.75
Investment cost	EUR/Mbtu-yr	2.52
Efficiency*	%	89%
Construction time	yr	4
Technical lifetime	yr	25
First year	yr	2022
Capacity	million tonnes/yr	5

* The self-consumed gas is used to power the refrigerant cycle.

3.5 Modelling results

In this section the main results of all scenarios are presented and an attempt is made to illustrate the dynamics of the system. The section begins with a presentation of outputs from SC1, which is used as a point of comparison for the remaining scenarios in Section 3.5.2.

3.5.1 Energy Efficiency Scenario

Power supply system

As explained in the previous sections, the Cyprus power system will undergo significant changes in the coming years. Major infrastructure projects are under discussion, and a shift in fuel from oil products to natural gas is planned. This latter aspect is reflected in the results shown in Figure 18, which illustrates the fuel use in the power sector of the island. Whereas heavy fuel oil is the main fuel in the period 2013-2019, in 2020 strict regulations in regards to industrial emissions come into effect, forcing a switch from heavy fuel oil to more diesel and low-sulphur fuel oil. In addition, three years later, the situation changes abruptly once again as domestic natural gas production begins in 2022 and is fully introduced for power generation in 2023. Renewables are accounted for, in terms of primary energy, as equal to final supply, therefore they appear to have a limited share compared to fossil fuels, for which conversion efficiency is used to transform primary energy into final.

Figure 18: Primary energy use in the power sector to 2030

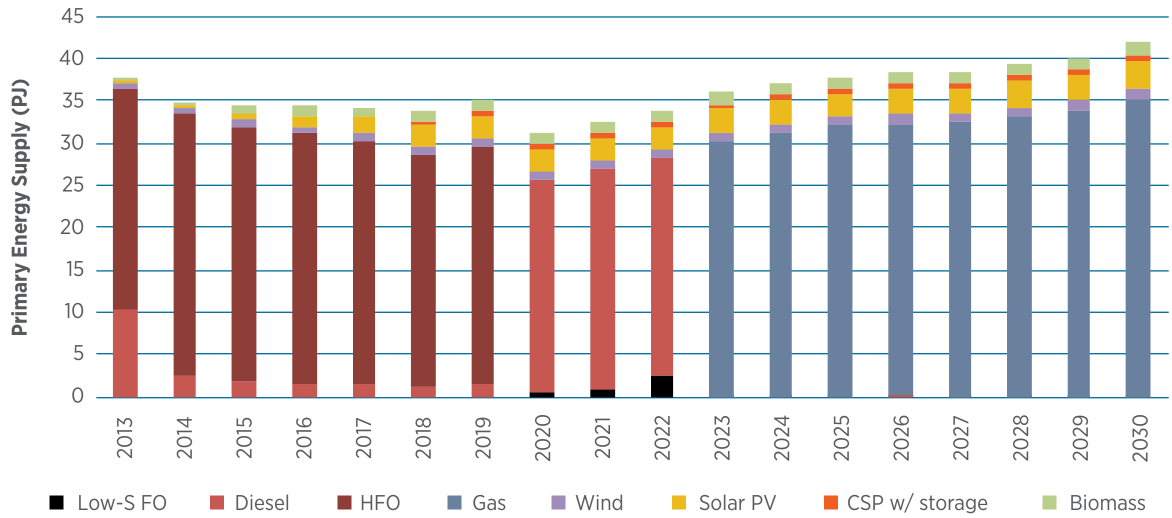
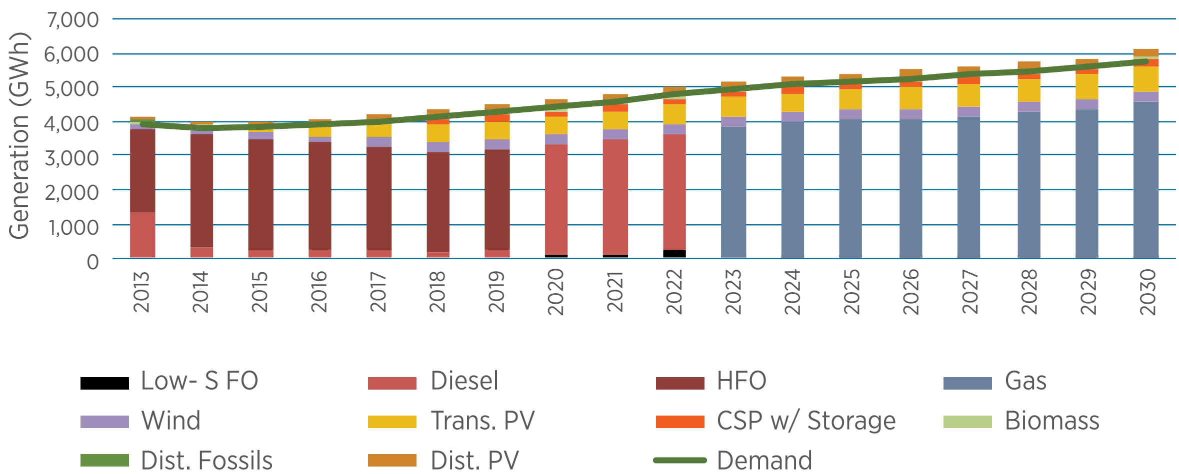


Figure 19: Evolution of generation mix in scenario SC1.

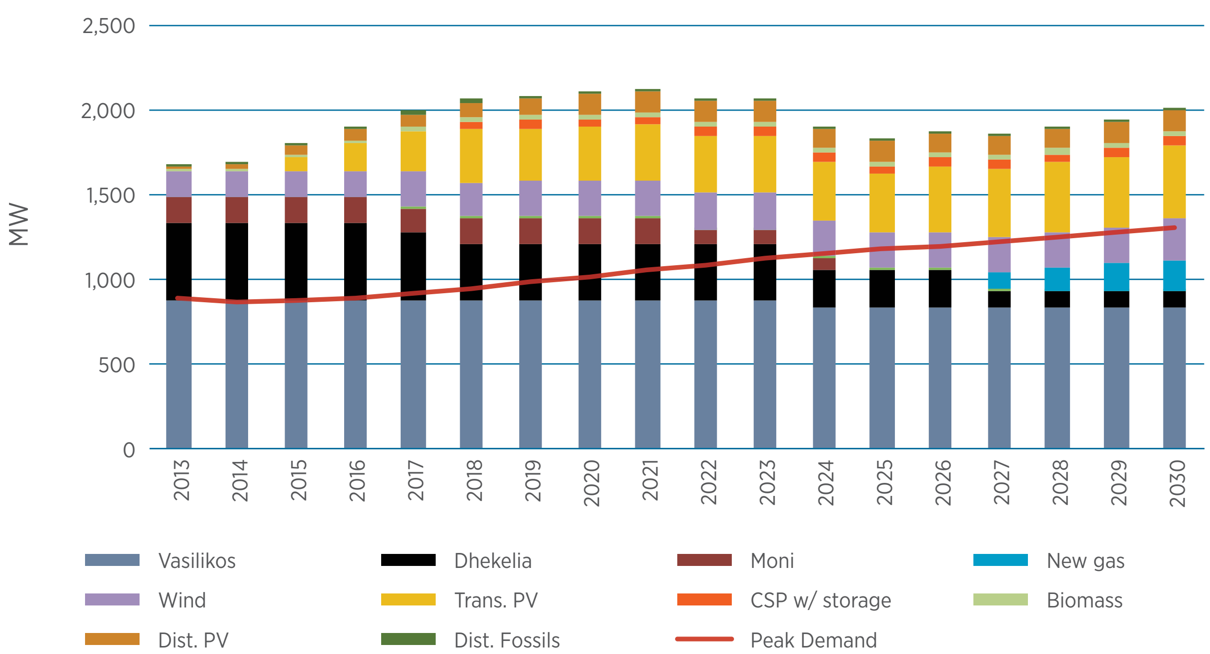


A similar observation can be made in regards to the generation mix (Figure 19). Heavy fuel oil is substituted by diesel and fuel oil with low sulphur content in 2020, while gas-fired generation replaces these in 2023. At the same time, generation from renewable energy sources steadily increases as a result of the renewable energy targets and environmental constraints elaborated in Section 3.4.8, but also due to their increased cost-competitiveness as investment costs reduce over time.

Solar PV has a capacity factor of about 18.5%, the corresponding value for wind is 16% (based on average recorded values provided by the TSO), while for CSP with storage this is approximated at 39% (according to project-specific documentation) and without storage at 27%. These values are lower than for fossil fuel-fired power plants. Consequently, a greater total capacity is needed to generate the same electrical energy as compared to thermal power plants. As a result of the increasing demand and the large investments in renewable energy technologies, the installed capacity of the island increases gradually from 1.68 GW in 2013 to 2 GW in 2030 (Figure 20).

It is interesting to note that small investments in new fossil fuel-fired facilities are to take place. A commissioning of a combined cycle gas turbine facility of about 170 MW appears to be necessary in the period 2027-2030. Therefore, for the most part, existing thermal capacity installed in recent years can supply the required levels of fossil fuel-based power until 2030. As mentioned above, no capacity reserve is used in the model. In SC1, by 2030 the capacity reserve margin will reach approximately 4%[23] , based on the current way of considering RETs as only providing limited to no capacity. However, in case there is a decision to keep a high capacity reserve margin up to 20%, as observed in previous years, additional capacity additions, most likely from thermal power plants, will be required. Similarly, the model assumes decommissioning of 510 MW from units in Moni and Dhekelia, which, if kept operational, would result in a reserve margin exceeding 40%. Reserve requirements will be evaluated by the system regulator, who might dictate these additions in the future or postpone retirement of the units in Moni and/or Dhekelia as strategic reserves.

FIGURE 20: TOTAL INSTALLED CAPACITY IN THE SC1 SCENARIO



[23] *This assumes a peak demand of 1,302 MW. The following capacity credits are given to the relevant generation options: 100% to conventional gener tion, CSP with storage and biomass, 30% to solar PV and 0% to wind.*

By 2030 the capacity of wind increases to 251 MW, while solar PV amounts to 559 MW, of which 433 MW are built at the transmission level (11 kV voltage system considered as transmission level). This is a clear indication that utility-scale solar PV is the most-competitive renewable energy technology option. Utility-scale PV has a lower investment cost than distributed solar PV, which makes the former more cost-effective. Capacity of distribution connected PV corresponds to existing installations plus the additional capacity to be installed as part of the Net Metering Scheme. However, taking into consideration that no utility-scale solar PV is currently deployed at the transmission level, impact on the grid may be significant and a more in-depth analysis is necessary to assess grid stability; this aspect is outside the scope of the present study.

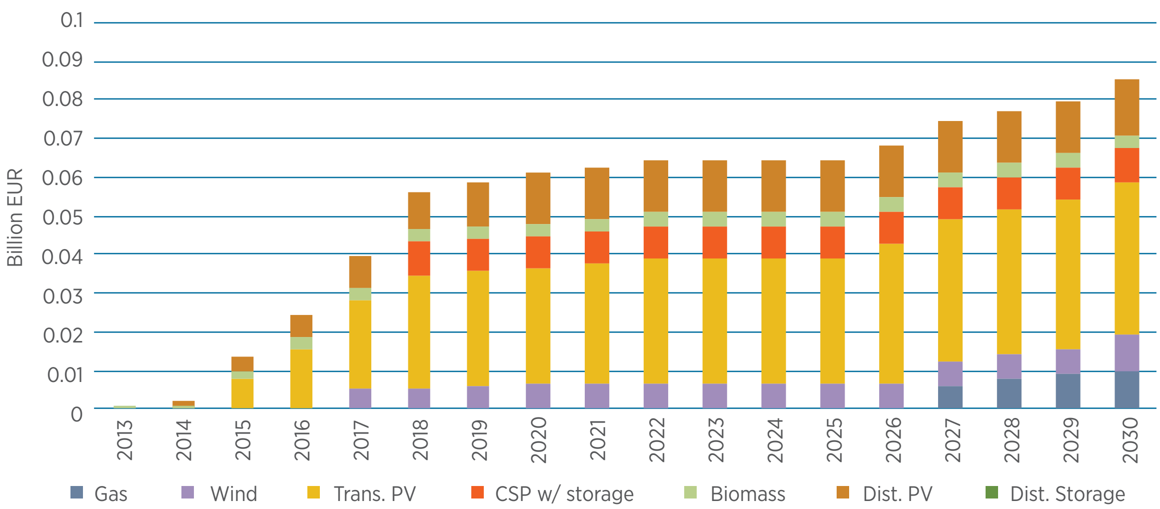
It is interesting to observe that CSP does not exceed the committed capacity level of 50 MW. However, capacity of biomass-biogas plants increases from 10 MW in 2013 to 28 MW in 2030. It is worth clarifying that deployment of biogas shown here is simply economically optimal and does not take into account availability of resources. One aspect that requires further investigation is the planned decommissioning of existing fossil fuel-fired power plants. At the moment, in the model the planned decommissioning is calculated based on the first year of operation of each unit and assumed lifetimes of each plant. For instance, the last units at Moni Power Station are fully decommissioned in 2024 in this assessment, while 360 MW of Dhekelia will be decommissioned by 2027, but this might not comply with the plans of the Electricity Authority of Cyprus and the policies of CERA. For instance, given Moni's current limited operating hours, it might be more cost-effective to extend its lifetime to provide capacity reserve, rather than investing in new facilities solely for this purpose.

When it comes to storage, it appears that based on the current assumptions neither centralised nor decentralised options are cost-effective within the model horizon. The installation of 50 MW CSP with thermal storage is treated as a committed project, whose cost-competitiveness is assessed in this study as part of a sensitivity analysis. Solar PV reaches its predefined limits without storage at 550 MW in 2030 (Section 3.4.7), while small installations of distributed storage allow the exceedance of this limit by 9 MW. It should be clarified that the level of storage shown in this analysis is indicative and a more detailed grid analysis and a specific techno-economic storage study will be required to assess both the levels of renewables in the system and the associated necessary storage.

Financial considerations

In order to achieve the renewable energy targets set by the European Union, substantial investments in RETs are necessary in the upcoming years. However, these investments, based on the

Figure 21: Annualised[24] investment cost per technology type in the energy efficiency scenario to 2030



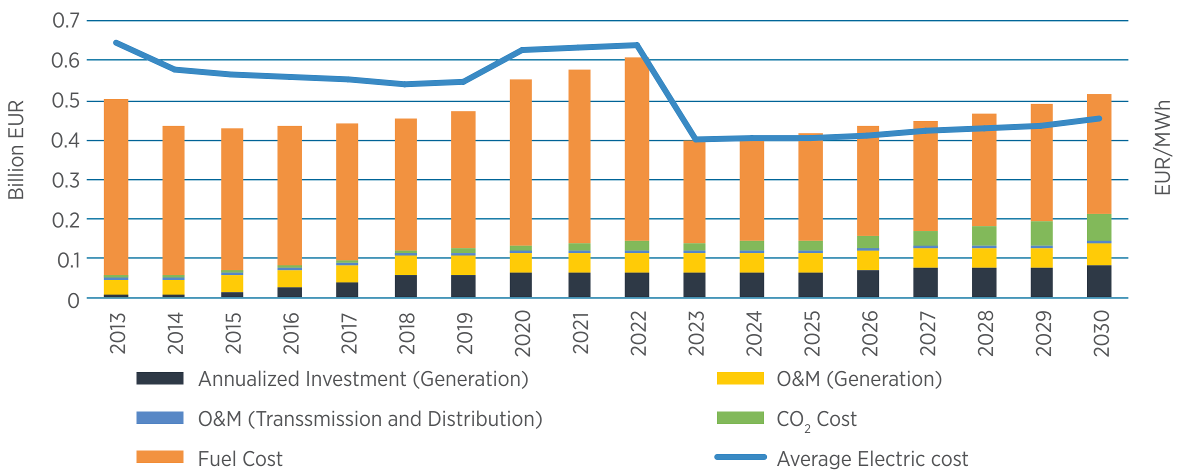
[24] *Annualised investment cost is calculated based on the assumed lifetime of each plant. For instance, investment in a wind facility is spread over its assumed 25 year lifetime, taking into account the discount rate of the system; 6% in this case.*

current analysis, will also reduce the cost of power generation in Cyprus, as RE targets are exceeded in the optimal solution for all scenarios and most years, indicating a clear roadmap in favour of RE technologies, not only to reach EU targets but also as a means to reduce electricity cost. The volume of investments in renewables increases from 2015 onwards, while in terms of generation capacity the majority of the costs are associated with PV installations at the centralised and decentralised levels. Additionally, a sizable overnight investment of EUR 115 million takes place for the 50 MW CSP with thermal storage to be installed in the fourth quarter of 2017, but assumed to be fully commissioned in 2018 in the present study. This investment cost takes into account funding of an additional EUR 60 million from the European Union for the installation and operation of this project.

It is worth clarifying that this analysis provides a comparative economic assessment of different pathways in terms of investment requirements and power generation costs, and does not have the capacity nor attempts to provide projections of future prices of electricity. As such, the values presented here are just for indicative purposes. That said, the model indicates a starting cost of electricity (excluding tax) at about EUR 129 /MWh[25] This figure is comparable to the EUR 133/MWh for 2010, but lower than the approximately EUR 158/MWh reported in international databases for 2011 (OECD 2014); in 2011 and 2012 price cost of electricity was high due to the inability to use the most cost-efficient units damaged by the accident that affected the Vasilikos facility. It is interesting to observe that the cost of electricity is initially expected to decrease slightly in 2014, as the more efficient steam turbines at Vasilikos are used to a greater extent until 2019 (Figure 22). The cost during this period stabilises at EUR 110-115/MWh. However, in 2020 when diesel and fuel oil with low sulphur content are used, the annualised cost of power increases back to EUR 125-128/MWh.

In 2023, use of domestic natural gas for power generation is assumed to commence, leading to a subsequent decrease to EUR 80/MWh for the cost of electricity. It should be noted that CO_2 costs and investments in renewable energy projects increase in the second decade of the model period. Despite the higher investments, due to the price of indigenous gas being cheaper than the alternatives of diesel and heavy fuel oil, average generation cost decreases substantially. As such, cost savings are achieved from comparatively lower fuel costs

Figure 22: Power system costs and annualised cost of electricity consumed in the energy efficiency scenario



[25] *Costs shown here take into account fuel costs, operation and maintenance costs of plants and grid network, CO_2 costs and investment costs for new facilities or storage. Potential costs for the expansion or strengthening of the grid are not included, while investments made before 2013 and have not been written off are also not accounted for.*

of gas and from renewable energy deployment, which keeps the cost of electricity in the range of EUR 80-90 /MWh for the period 2023-2030. Figures depicting annualised cost of electricity in each scenario are provided in Appendix V.

3.5.2 Scenario analysis

Brief scenario overview

The final electricity demand is a key driver for the mix of technologies chosen by the model. As such, when a lower demand is used in SC2 (see Figure 10 for final electricity demand comparison), the results change considerably. Even though in this scenario the Interim Gas Solution is assumed to materialise, conclusions can be made through a comparison with the baseline scenario for the latter half of the assessment period (i.e. 2023-2030). In the lower demand scenario, the total volume of electricity generated is considerably lower (Figure 23), with this also reflected in the total installed capacity (Table 25). No storage is installed in any of the scenarios.

While conventional generation contributes 4,550 GWh in SC1 in 2030, in 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.

Similarly, when the total installed capacities are compared for each of the identified scenarios (Table 26), the effect of energy efficiency can be observed. In scenario SC2, which has a lower final electricity demand, the total installed capacity by 2030 is lower by about 350 MW as compared to scenario SC1. SC2 shows a reduced need for investment in the power sector. This should be evaluated against the costs of achieving SC2.

In an Energy Efficiency Scenario with the Interim Gas Solution (SC3) the generation mix and total installed capacity is identical to SC1 by 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 the interim gas solution allows generation at lower costs than currently observed, which reduces to an extent the cost-competitiveness of renewables.

In case a liquefaction terminal is developed in Cyprus (SC4), increased 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.

Results from SC5 provide interesting insights. Since in this scenario Cyprus becomes interconnected with Greece and Israel, the limitations on variable renewable capacity and a greater flexibility is given to the model. In this case, installed capacities of PV and wind reach 968 and 372 MW respectively. In this scenario, no investments occur in new gas-fired facilities during the projected timeframe. As a result, the share of renewable energy generation exceeds 40% by 2030. It should be reminded that, as in all scenarios, an international market price is assumed for domestic natural gas, which enhances the cost-competitiveness of renewable energy technologies compared to, e.g., using a netback price (opportunity cost).

Similarly 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%, when we consider generation for self-consumption at the liquefaction facility (41% if we do not consider it). Contribution from renewables to the generation mix is comparable to SC4 until 2024 (both scenarios consider development of an LNG terminal), at which point in SC6 capacity additions of renewables without storage continue to occur, 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. It should be noted here that due to the predefined limit of 80 MW in annual capacity additions of transmission connected solar PV, wind installations occur in years 2022, 2023 and 2030. However, if we relax this constraint, then additional investments should occur in solar PV, as it remains the lowest-cost option throughout the model period.

Figure 23: Evolution of generation mix in the extra efficiency scenario

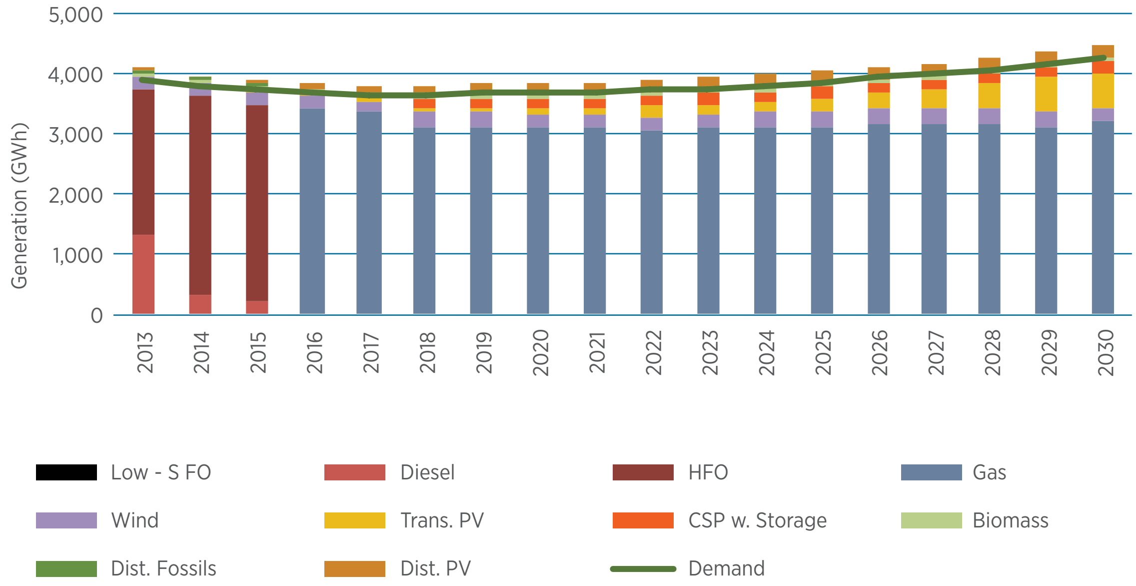


Table 25: Total installed capacity evolution in the six scenarios (MW)

		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)

Scenario comparison

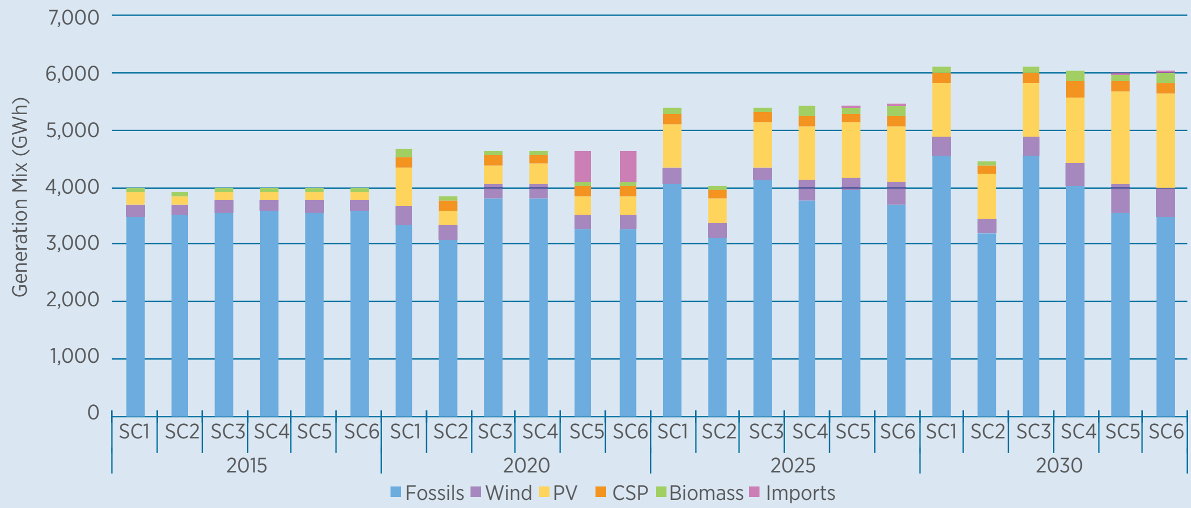
An interesting observation can be made when comparing the capacity evolution of different technologies. As mentioned above, solar PV at the transmission level is the most cost-efficient renewable technology for the case of Cyprus. Therefore, investments in this option are quite high in all scenarios; and exceptionally high in SC5 and SC6, which assume development of the EuroAsia Interconnector.

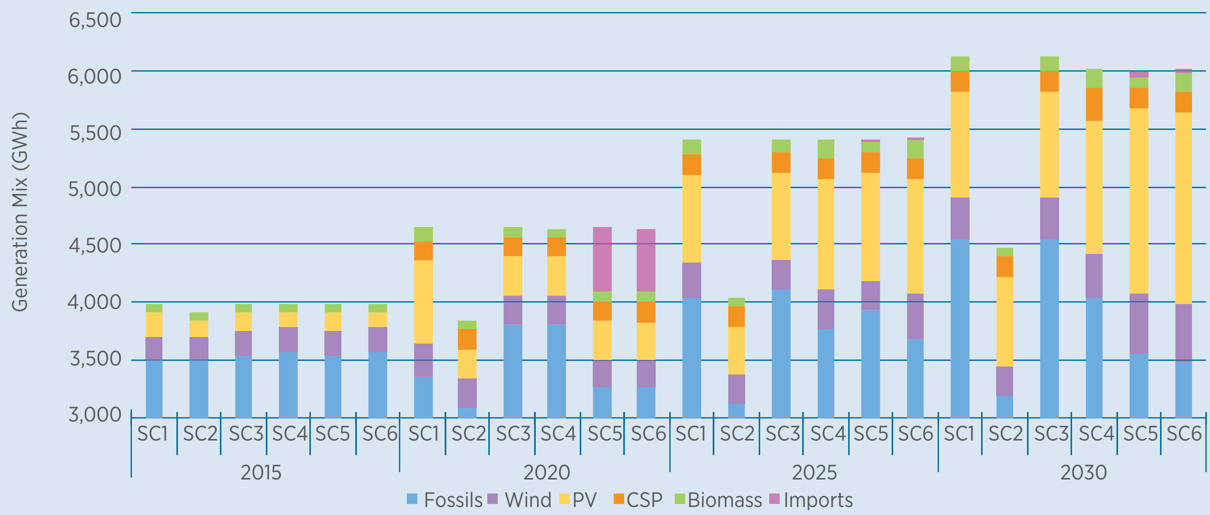
In the case of wind, no expansion occurs in SC2 beyond the committed level of 175 MW. In SC3, which assumes successful negotiation regarding the interim gas solution, there is no additional deployment beyond **committed projects during 2016-2022,** unlike what would have happened in absence of the **interim gas solution.** In SC5 and SC6 wind capacity in 2030 reaches 372 and 352 MW respectively. In SC4 wind capacity reaches 275 MW by 2030, which is the deployment limit without storage for that year.

Similarly, in the case of biomass minimal new installations occur in 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).

A similar picture of the aforementioned observations is also provided by comparing the generation mix in each scenario (Figure 24 and Table 27). **Solar PV** is the dominant renewable energy technology in **all scenarios,** with lower contributions from CSP, wind and biomass-fired facilities.

Figure 24: 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)





Based on the scenario results from SC5 and SC6, it could be argued that benefits from the development of interconnector are threefold. First, Cyprus gains access to the grid of two neighbouring countries, from which it can import during periods of peak demand as a substitute of expensive generation options (as in 2020 in Figure 24) or to cover periodic shortages in supply. Secondly, a higher share of variable renewables (i.e. solar PV and wind) can be deployed with lower requirements for storage, as variations in renewable energy generation can possibly be balanced via the grid interconnection. Similarly, exports of electricity can take place (although not explicitly modelled in this analysis), which can help prevent curtailment. Lastly, by replacing gas-fired generation with more renewables, a larger volume of indigenous gas is freed up for exports. Although it should be noted that the technical feasibility of these high level of variable renewables in the case of interconnection should be further examined through a separate grid analysis, examples of countries with good level of interconnection reaching high shares of variable renewables exist, in particular in Europe (e.g. Ireland and 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 RETs (EIRGrid 2008). The first step was a long-term energy planning study, like the present one, followed by a resource assessment, potential renewable energy project identification and location, dispatching study and finally a grid study. To conclude the analysis, a cost benefit study was performed. This represents a best practice for the planning process to be followed to successfully deploy high shares of variable RETs in a large island power system.

Table 26: Evolution of generation mix in the six scenarios (GWh)

		Fossil fuel	Wind	PV	CSP	Biomass	Imports
SC1	2015	3,499	205	208	0	84	0
	2020	3,353	298	708	172	120	0
	2025	4,049	298	762	172	120	0
	2030	4,547	350	927	172	120	0
SC2	2015	3,505	205	141	0	72	0
	2020	3,090	244	261	172	72	0
	2025	3,130	244	418	172	72	0
	2030	3,200	244	776	172	72	0
SC3	2015	3,549	205	162	0	81	0
	2020	3,818	244	332	172	81	0
	2025	4,113	244	769	172	100	0
	2030	4,547	350	927	172	120	0
SC4	2015	3,583	205	127	0	79	0
	2020	3,813	244	349	152	84	0
	2025	3,777	346	947	172	169	0
	2030	4,037	384	1,140	286	169	0
SC5	2015	3,549	205	162	0	81	0
	2020	3,265	244	332	172	81	553
	2025	3,934	244	942	172	93	12
	2030	3,555	520	1,605	172	101	40
SC6	2015	3,583	205	127	0	79	0
	2020	3,263	244	329	172	84	551
	2025	3,690	387	991	172	169	7
	2030	3,491	492	1,654	172	169	36

Two major issues are brought up in the scenarios with 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 be dependent on electricity supply from a neighbouring country. These issues are important and are worth keeping in consideration, although they are outside the scope of this study.

A financial comparison can be conducted based on the above scenarios with regards to the Interim Gas Solution. In order to approximate the cost of relying on heavy fuel oil and diesel until indigenous gas becomes available, results from the Energy Efficiency Scenario with and without this aspect are compared. Figure 25 shows the difference in power system costs between the two scenarios. In case the interim gas negotiations decide on a gas price as used in this study (Section 3.4.3), cost savings to the system are estimated in the range of EUR 90-100 million annually in the period 2016-2019 and roughly EUR 160-180million in the years 2020-2022; this represents a total savings of EUR 890 million during these seven years. The majority of this cost arises from higher fuel costs, as natural gas is cheaper than heavy fuel oil and diesel. At the same time, this includes an additional EUR 3-5 million, which will have to be paid annually in the period 2016-2022, for CO_2 trading in the ETS, since the carbon content of heavy fuel oil and diesel is higher than that of natural gas.

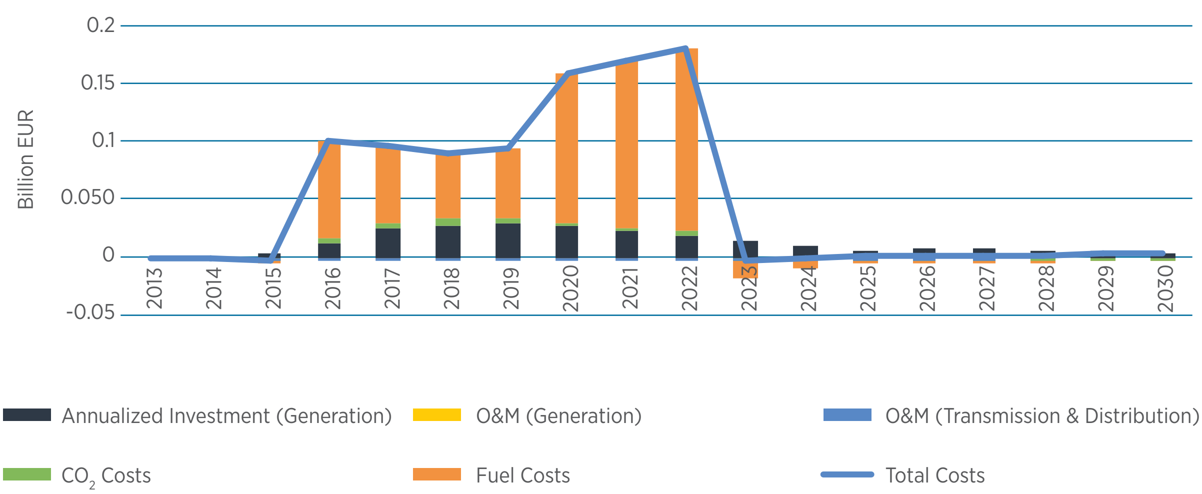
3.5.3 Cost-competitiveness of renewable energy technologies

In order to assess the cost-competitiveness of renewable energy technologies, a comparison of the renewable energy share in each scenario is provided (Table 27). As described in Section 3.4.8, a minimum renewable energy share is defined for all scenarios. However, results from the scenarios suggest that renewable energy technologies will increasingly gain competitiveness when compared to fossil fuel-fired generation

The share of renewable energy generation achieves and even 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 the annual installation until 2020 of 15 MW distributed PV for households and public buildings; in the model these are assumed to be committed installations. 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-sulphur fuel oil are the primary fuel sources.

Nonetheless, even though indigenous gas is expected to reduce Cyprus' generation cost, centralised solar PV, due to its assumed reduction

Figure 25: Power system cost differences in the energy efficiency scenario with and without interim gas solution



in investment cost, is more competitive than the most efficient gas-fired units throughout the model horizon (see Figure 18 for key technologies and fuels, and Appendix VI for a table with all generation technologies considered in the model). It should be clarified that here we are comparing the short-run marginal cost (SRMC)[26] of existing technologies against the long-run marginal cost (LRMC)[27] of power generating options that could be deployed in the future. Such a comparison is valid only if perfect foresight is assumed and the capacity deployment is considered optimal (Della Valle 1988); both aspects may apply in long-term energy modelling and specifically in this assessment. For instance, when we compare future wind deployment with a new gas combined cycle gas turbine facility fired on indigenous gas, we can see that wind is equally or more competitive. However, when we compare the same wind facility with existing combined cycle gas turbine facilities fired on indigenous gas, we can see that the latter option is more cost-effective.

As such, large solar PV capacity additions occur from 2023 onwards at levels that reach the limits set for this technology without storage. This explains the large share of renewable energy generation, which periodically exceeds the aspirational target and is observed in SC1 and SC3 during the period 2024-2030. As the share of solar PV without storage stabilises around 15% of the annual generation, since the remaining renewable energy technologies are not as cost-effective, the renewable energy share gradually reduces in SC1, as a result of the growing electricity demand.

It should be noted that in the case of SC4, the absolute contribution of renewable energy generation is very high during 2022-2030 due

Table 27: 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%	

[26] *The SRMC indicates the cost of producing an additional unit of energy from a technology, assuming investment on generation capacity is a sunk cost (or took place before the modelling period).*

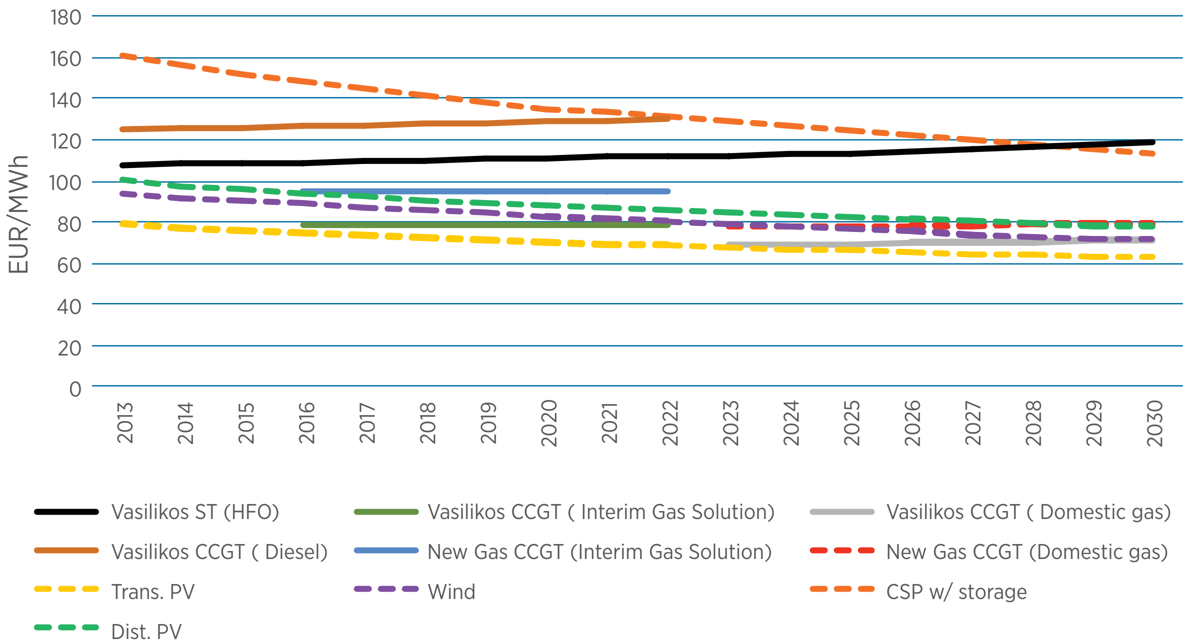
[27] *In addition to the cost given by SRMC, the LRMC takes into consideration expenditures to refinance the investment cost over the lifetime of a technology.*

to the existence of the liquefaction facility, whose electricity generation for self-consumption is driving further investments in renewables to satisfy the predefined renewable energy targets. In the case of SC5 and SC6, the implications of the interconnector on renewable energy generation have been discussed previously. These are the only scenarios where variable renewables have not been constrained to a maximum, and can therefore realise their full economic potential. Finally, the lower electricity demand of SC2, results in an overachievement of the aspirational renewable energy targets by the end of the model horizon, however the cost of the lower demand scenario (SC2) is not taken into account in this study or is beyond the scope of work of this study.

3.5.4 Sensitivity analysis

Certain aspects of the analysis at hand have been added as fixed constraints. This includes future projects and technical constraints on the deployment level on variable renewable energy technologies. To verify the impact of these constraints, SC1 and SC3 are run without taking for granted the deployment of the 50 MW CSP project expected to come online at the end of 2017. In both instances, partly due to the EUR 60 million grant offered by EU funds, the project is deemed cost-effective and has been invested in according to schedule. Furthermore, in another attempt to assess the effect of implemented constraints, SC3 has been run without constraints on deployment of variable renewables. In such a case, capacity of solar PV reaches 415 and 1,135 MW by 2020 and 2030 respectively; this is roughly double compared to the respective values of 200 and 559 MW in SC3 with constraints (Table 25). The key message is that constraints should be carefully evaluated in further studies, as the model suggests that the most economical generation mix should have twice as much PV compared to a scenario with constraints that have been considered as "temporary", in absence of more accurate studies. The focus should be on technical and market measures to integrate large shares of variable RET whenever economical, rather than on imposing limits on deployment. When the cost of RET plus integration measures exceeds the cost of alternative generation options (e.g. natural gas fired combined cycle gas turbines), this is when no further deployment should be considered to be beneficial. Assessing this threshold requires

Figure 26: Generation cost comparison: SRMC for Vasilikos (using different fuels) and LRMC for new gas CCGT, solar PV, CSP and wind



careful assessment of integration cost, to ensure that they are minimised.

The following sections provide a more detailed discussion regarding insights in other areas for which sensitivity analysis is conducted.

Price of imported electricity

In any modelling endeavour it is important to understand the effect of variations on key input parameters on the outputs. As a first step, the effect of electricity import price on the share of imports is investigated. The key question that this analysis is attempting to answer is what should be a maximum import price to be used in SC5. As shown in Table 28, minimal imports occur when the price is above EUR 90/MWh. However, when the price of imported electricity is set at EUR 90 /MWh, share of imports rises to 10-14% during 2017-2022. It should be clarified that an interim gas solution is allowed in this analysis, which results in reduced costs for generation during 2016-2022 as compared to current costs. This explains the low electricity imports observed for prices exceeding EUR 90/MWh.

Nonetheless, once indigenous gas becomes available for power generation in 2023, share of imports will be below 1% annually. Assuming a stable import price at EUR 75/MWh, the Cyprus power system will import about 15% of its total electricity demand during 2023-2030. It is worth noting that due to the predefined minimum renewable energy contribution, electricity imports are primarily competing with fossil fuel-fired generation. Assuming that a majority of imports will originate from Israel, it is assumed that this source cannot contribute to the renewable energy targets. At the moment, Israel's power sector relies almost entirely on hydrocarbons, but the government of Israel has set a renewable energy target of 10% in the power sector by 2020 (Ministry of National Infrastructures, Energy and Water Resources 2014). Hence, the assumption about renewable energy contribution through imports can be revised in the future. It is

Table 28: Share of imports as a function of electricity import price

	EUR 120 / MWh	EUR 113 / MWh	EUR 105 / MWh	EUR 98 / MWh	EUR 90 / MWh	EUR 83 / MWh	EUR 75 / MWh	EUR 68 / MWh
2017	0.0%	0.0%	0.0%	0.0%	11.2%	11.7%	11.8%	89.4%
2018	0.0%	0.0%	0.0%	0.0%	10.0%	10.6%	10.6%	84.4%
2019	0.0%	0.0%	0.0%	0.0%	11.3%	11.8%	11.8%	84.3%
2020	0.0%	0.0%	0.0%	0.0%	11.9%	11.9%	12.1%	82.6%
2021	0.0%	0.0%	0.0%	0.0%	12.5%	12.6%	12.5%	80.3%
2022	0.0%	0.0%	0.0%	0.0%	13.7%	13.8%	13.7%	79.3%
2023	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	13.8%	14.4%
2024	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	13.9%	15.4%
2025	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	13.6%	15.3%
2026	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	13.5%	15.1%
2027	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	13.5%	15.0%
2028	0.4%	0.5%	0.6%	0.6%	0.6%	0.6%	13.7%	15.0%
2029	0.5%	0.5%	0.6%	0.6%	0.6%	0.8%	14.1%	15.1%
2030	0.6%	0.6%	0.7%	0.7%	0.7%	0.9%	14.6%	15.4%

important to consider, in case of interconnection, the carbon intensity of the electricity imported, and its implications on CO_2 targets. Similarly, the export of renewable electricity to other EU countries through the interconnection towards Greece might provide additional revenues. However, since electricity prices in Israel and Greece are variable, estimating the volume of trade between these countries is difficult and this study refrains from doing such predictions, limiting itself to estimating imported volumes at different fixed prices (not variable hour-by-hour, as in reality). A separate study to estimate traded volumes for each hour of the year for the three countries may be considered in the future as part of the due-diligence for the investment in interconnection.

Price of gas for power generation

It is expected that the arrival of indigenous gas for power generation will have significant economic benefits for Cyprus, as it will reduce the price of electricity. The generation cost of thermal power plants is directly related to the fuel cost and the price at which domestic generators (e.g. EAC for its power plants) will purchase extracted natural gas is primarily a political decision, and one that is yet to be made. In order to investigate how the gas price influences the generation mix of the island, sensitivity analysis is carried out with SC3 used as a basis. 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 3.4.3 (approximately EUR 9/Mbtu).

Results from the two extremes of this sensitivity analysis are provided in Table 29. The generation mix and technology deployment schedule are identical for both instances during the period 2013-2022; this is the period when gas from the interim solution is used. As shown in Table 29, the shares of gas-fired and renewable energy generation do not change substantially from 2023 onwards. This can be attributed to a number of reasons. First of all, since there are aspirational targets for renewable energy generation until 2030, gas-fired generation cannot exceed a set threshold, even when the price is significantly lower. Secondly, large capacity additions occur up to 2023 in renewable energy generation and as such the 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. As renewables reach these limits, requirements for storage reduce cost-competitiveness of renewable energy generation.

Table 29: Share of gas-fired and renewable energy-based generation as a function of gas price in SC3

	Low netback price		Market price	
	Gas	Renewables	Gas	Renewables
2023	78%	22%	78%	22%
2024	78%	22%	77%	23%
2025	77%	22%	76%	24%
2026	77%	23%	75%	25%
2027	76%	24%	76%	24%
2028	75%	25%	75%	25%
2029	77%	23%	75%	25%
2030	75%	25%	74%	26%

In order to assess how an interconnector would affect this aspect, another round of sensitivity analysis is conducted, taking SC5 and altering the price of indigenous gas.

As shown in Table 30, the generation mix becomes more sensitive to the indigenous gas price when 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, the renewable energy share will reach 30% by 2030. This means that renewables will still manage to exceed the aspirational target of 25% by 2030. However, once the price of indigenous gas decreases to EUR 7.5/Mbtu, the generation share of renewables is limited to the aspirational targets. This suggests that gas prices below EUR 8.3/Mbtu can affect the deployment of renewables once indigenous gas is available.

It should be noted that the decision on the price of gas for the domestic power sector has the potential to affect volumes for export. For instance, by comparing two separate prices from Table 30 (EUR 7.5 and 8.3/Mbtu) we can estimate a difference in gas consumption of about 2.2 Tbtu only in 2030.

Renewable energy targets

In order to assess whether the aspirational renewable energy targets are the main factor driving investments in renewables, a simple experiment is conducted. Since, in the baseline scenario, it is evident that renewables are highly cost-competitive (refer to share of renewable generation in Table 28), SC3 is used as a point of reference. In this sensitivity analysis, renewable energy targets are assumed to remain at the compulsory levels as set by the European Union; 16% of generation for the period 2020-2030. As shown in Figure 27, differences in generation mix are not apparent.

If we take a look at system cost differences between the two cases (Figure 28), subtle variances can be observed. Investments are higher, while fuel and CO_2 costs are lower in the scenario with enforced aspirational renewable energy targets. These marginal differences lead to a higher total cost of EUR 4 million over the entire model horizon in this scenario. This suggests that, based on the assumptions on costs, performance and technical constraints, minimal additional investment requirements will be needed for Cyprus to achieve its aspirational renewable energy targets.

Table 30: Share of gas-fired and renewable energy-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

Figure 27: Generation mix in SC3 with (up) and without (down) aspirational renewable energy targets

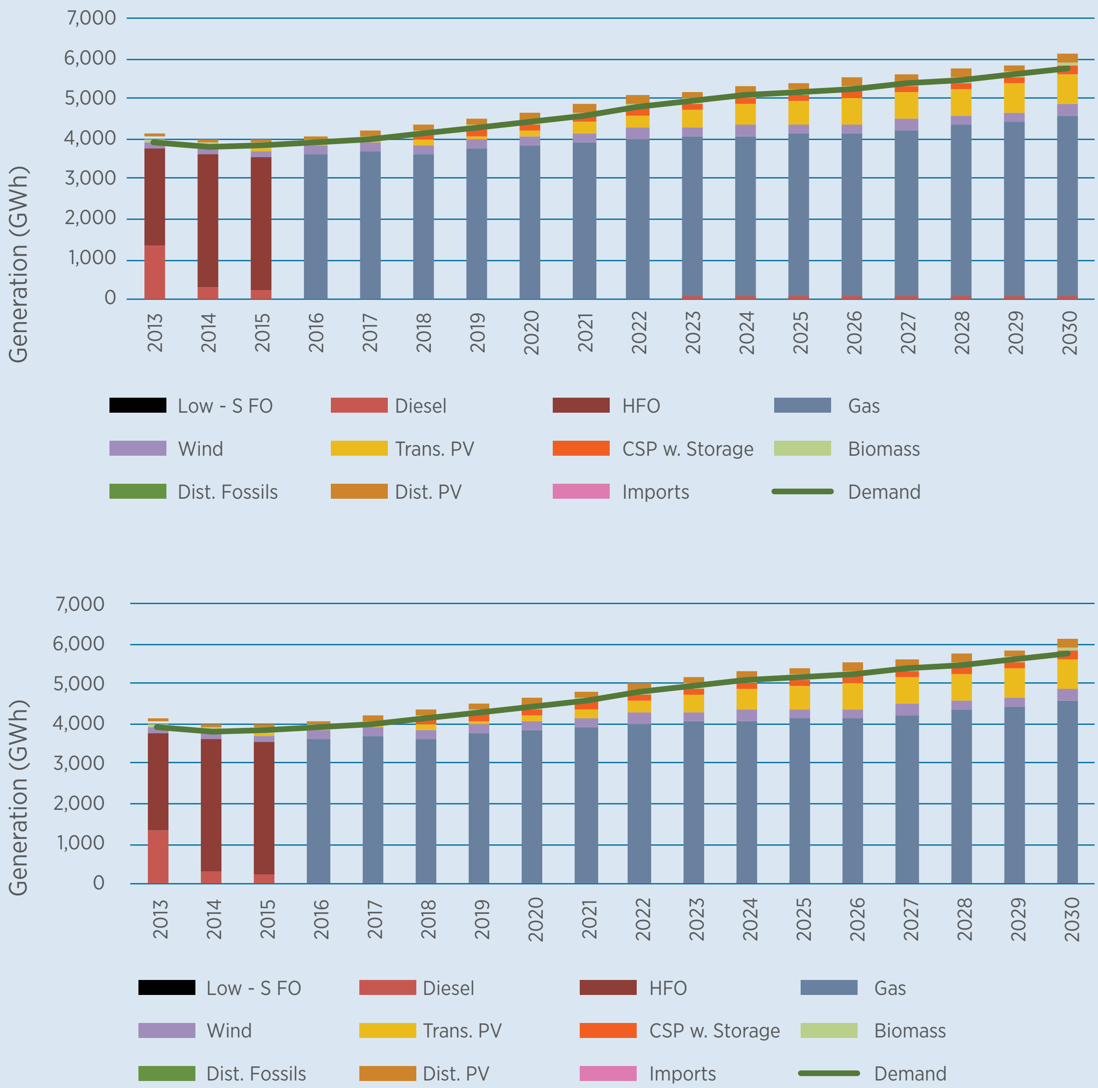
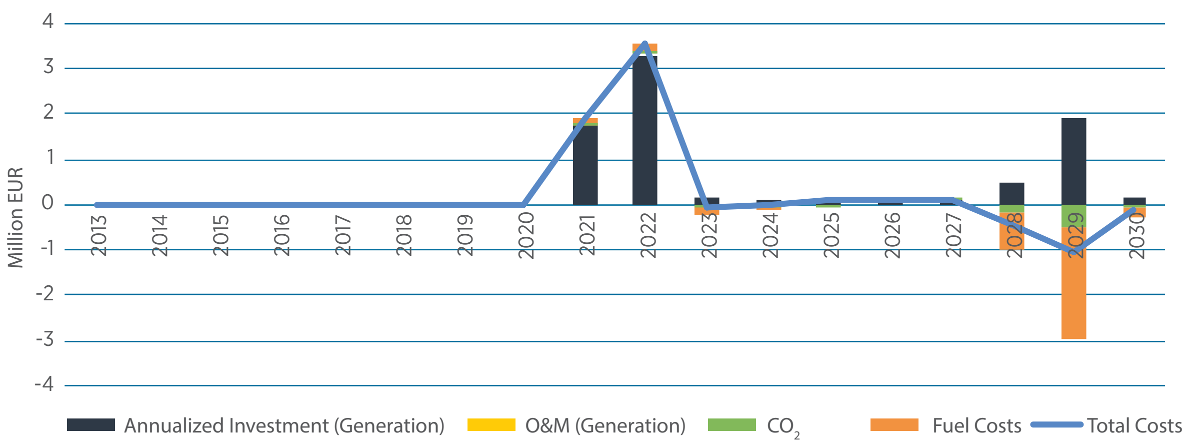


Figure 28: System cost differences between scenarios with and without aspirational renewable energy targets; negative values indicate a lower cost in the scenario with aspirational renewable energy targets



4 VRE forecasting

This section of the roadmap was produced by IRENA to cover a request in scope of work for “strategies for the optimal integration of variable renewable energy sources into island power grids: the role for production forecasting”. This section provides an overview of variable renewable energy (VRE) forecasting with a focus on how forecasting can support increased levels of VRE deployment in Cyprus. The specific topics covered are:

1. Current state of the art in VRE forecasting
2. Value of VRE forecasting
3. VRE forecasting recommendations for Cyprus
4. Expected developments in VRE forecasting

At a basic level VRE forecasting aims to predict the generation of renewable energy technologies with variable outputs that are strongly affected by weather (wind, sunshine, etc.). VRE forecasting was first developed for use by the wind power industry but has been adapted to provide forecasts for solar technologies including PV and CSP.

Modern VRE forecasting has achieved a high level of accuracy through a combination of models and analysis tools that use historic and real-time weather observations along with characteristics and real-time generation of VRE assets to predict VRE power generation. VRE generation can be forecast across numerous different time scales, from minutes to hours to days and across various system scales, from single wind turbines to PV panels to CSP units up to regional systems with gigawatts of generation capacity.

Forecasting aims to provide an accurate prediction of when and how much power VRE assets will generate at a given time in the future, along with an associated probability. This information supports TSOs and DSOs in reducing VRE integration costs and assists utilities and independent power producers (IPP) in more efficient operation of VRE assets, which increases revenue and makes VRE more attractive to investors. In short, forecasting helps to increase the share of VRE generation that can be safely and economically integrated into an electricity grid.

This section summarises the key findings of a VRE forecasting literature review and discussions with experts from industry and academia. The attached reference list is intended to serve as a reading guide for those wishing to further develop their understanding of VRE forecasting. Of particular interest are the following reports, which provide a broad overview of current capabilities and future developments in VRE forecasting:

Ela, E., et al. (2014) *Active Power Controls from Wind Power: Bridging the Gaps. National Renewable Energy Laboratory.*

Hulle, V. F., et al. (2014), *Economic grid support services by wind and solar PV, European Commission ReServices Project.*

Kleiss, J. (2010), *Current state of the art in solar forecasting, California Institute for and Environment.*

Parks, K., et al. (2011), *Wind Energy Forecasting: A Collaboration of the National Center for Atmospheric Research (NCAR) and Xcel Energy, NREL.*

Wilczak, J., et al. (2013), *The Wind Forecast Improvement Project WFIP Round One Final Report, National Oceanic and Atmospheric Administration.*

4.1 State-of-the-art in VRE forecasting

This section provides a summary of the key aspects that define current state-of-the-art VRE forecasting. A detailed review of VRE forecasting methodologies can be found in *Renewable Energy Integration* (Jones 2014). Figure 29 gives a simplified outline of the key features and functions of a generic VRE forecasting model, each of which is described in the following section (Jones 2014).

4.1.1 VRE function and structure

As illustrated in Figure 29, VRE forecasting uses the process below to generate predictions of VRE asset output.

Firstly, specific weather variables affecting VRE production are extracted from NWP models and local weather observations. These are then combined with the characteristics VRE system (location, technology type, etc.) in a localised weather forecasting model that predicts the key variable affecting VRE generation (e.g. wind speed, direct normal irradiance (DNI), global horizontal irradiance (GHI), etc.) at the location of each VRE asset. These generation-driving variables, along with VRE asset data, are lastly fed into a weather-to-power model that predict the future VRE power output with an associated error (Mahoney et al. 2012).

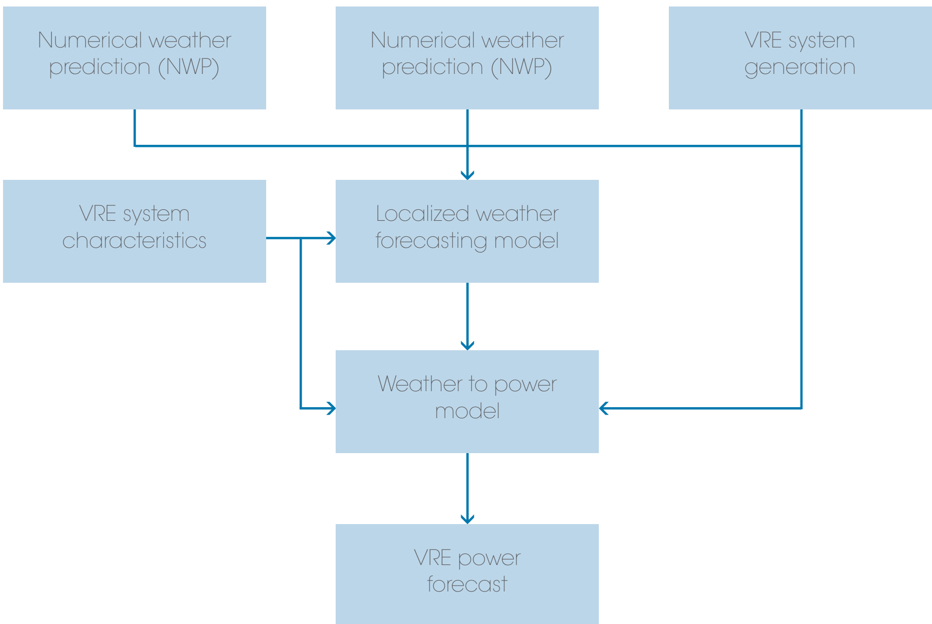
It is important to note that the basic model structure outlined in Figure 29 is used for both wind and solar forecasting, with adjustments to the particular models used and the types of data being collected and exchanged between the models. A short description of each of the key boxes shown in Figure 29 is given below.

» **Numerical weather prediction** (NWP) models predict numerous different aspect of weather on a macro scale, typically at the continental, regional or country level. NWP models are developed by numerous national and international bodies. The European Centre for Medium-Range Weather Forecasts (ECMWF) provides NWP models that will likely be of interest for VRE forecasting in Cyprus.

» **Weather observations** from a wide variety of technologies play a key role in VRE forecasting. These range from wind speed and irradiance sensors deployed at the site of the VRE generation assets to remote sensing equipment like radar and light detecting and ranging LIDAR. Kleiss, (2010) and Mahoney et al. (2012) provide overviews the numerous weather observation technologies currently used in wind and solar forecasting. Current and historic weather observation plays an important role in VRE forecasting serving as both inputs to the various forecasting models and as benchmarks to judge their accuracy.

» **VRE system characteristics and generation** play a similar role to weather observations. They are used as inputs into the various forecasting models and as benchmarks to judge the accuracy of the VRE forecasts. Comparisons of predictions to actual observations are a central aspect of forecasting. The forecasting model "learns" by using the

Figure 29: Simplified diagram of a VRE forecasting model



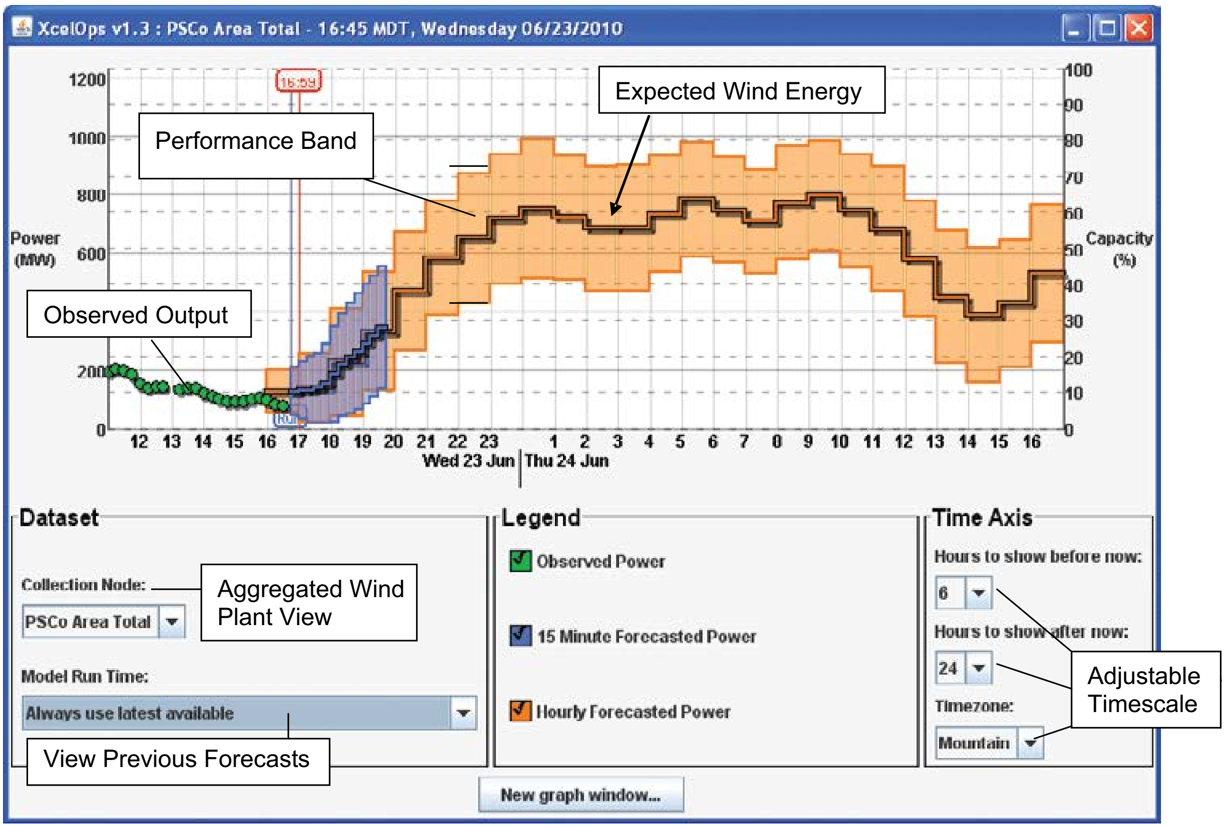
actual VRE generation to measure the accuracy of VRE predictions and adjusts the weight given to individual model components to move the prediction closer to reality.

» **Localised weather forecasting models** are used as intermediate step in the VRE forecasting. A combination of various models and analysis tools take macro level weather input and VRE asset characteristics to predict the key drivers for VRE generation. The particular models used and specific outputs depends on the type of VRE, e.g. wind speed is the primary driver for wind power, while direct normal irradiance (DNI) drives CSP and concentrating PV output and global horizontal irradiance (GHI) is the key factor affecting non-concentrating PV generation.

» **Weather to power models** are the final step that combine all the available data to output a usable prediction of VRE generation. Using complex models is necessary because the performance of VRE assets are affected by a wide range of parameters, e.g. while GHI may be the main driver for PV generation, there are other factors such as panel temperature that affect the output. The same is true of wind power, where additional factors like humidity and temperature affect the power that will be generated by a particular wind speed for a particular turbine type.

» **VRE power forecasts** are the final model output and give predictions for VRE generation that can be delivered for individual VRE units (turbine, PV panel, etc.) to full VRE systems that are viewed as a single generation asset (i.e. a particular wind farm or PV/CSP system) to forecasts across entire regions incorporating different VRE assets. A VRE forecast can be provided at a number of time scales, with the state-of-the-art forecasts reaching minute-ahead predictions. As an example of a typical forecasting model output, Figure 30 (Parks 2011) shows a wind power generation forecast from a state-of-the-art forecasting model developed for Xcel Energy by the US National Center for Atmospheric Research (NCAR). The green dots show the actual observed wind power while the solid lines give the expected forecasts for over a 15 minute

Figure 30: NCAR / Xcel Energy wind forecasting model GUI



timescale (in blue) and an hour timescale (in orange). The shaded areas indicate the possible error in the forecast (performance band), showing a 75% likelihood that the actual wind power output will fall in this range.

4.1.2 Hybrid/blended model approach

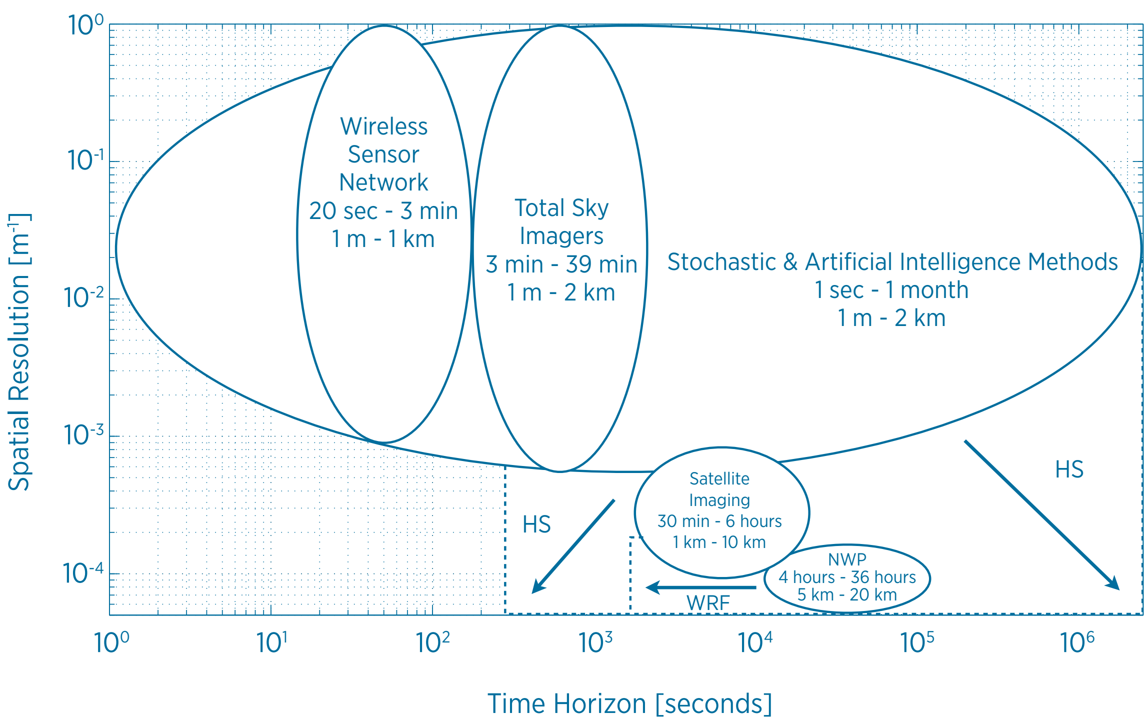
VRE forecasting is a developing field with many forecasting methodologies and analysis models being researched, developed, tested and actively deployed. The report *Solar forecasting methods for renewable energy integration* (Inman *et al.* 2013) and the Wind Power Improvement Project Final Report (Wilczak et al. 2013) are excellent references covering the wide variety of models and analysis tools being used in VRE forecasting.

Despite the broad range of forecasting techniques currently in use or under development, there is a general consensus among industry and academia that a hybrid/blended model approach, where several forecasting models and associated observation technologies are combined, is the most effective forecasting methodology (Kleiss 2010). The various models, analysis tools and observation technologies available for VRE forecasting cover diverse spatial and temporal ranges, i.e. each technique/system is only effective over a certain physical area and specific time horizon. Figure 31 illustrates the spatial and temporal ranges for several models and technologies used in solar power forecasting (Inman *et al.* 2013).

A hybrid/blended forecasting methodology integrates numerous models and observations to benefit from the accuracy of each component over a particular temporal and spatial resolution. This blending results in a forecast that covers all the major factors affecting VRE output, from macro scale weather patterns that take place over weeks across thousands of kilometres, to local weather phenomenon that can change in hours, to minute level changes taking place at each turbine or panel (Kosovic *et al.* 2014).

To illustrate the level of sophistication achieved by advanced hybrid forecasting models, Figure 32 shows a diagram detailing the forecasting model developed by NCAR for Xcel Energy. An in-depth explanation of the function and performance of this model can be found in NREL's report *Wind Energy Forecasting: A Collaboration of the National Centre for Atmospheric Research (NCAR) and Xcel Energy (Parks 2011). A Wind Power Forecasting System to Optimise Grid Integration*

FIGURE 31: TEMPORAL AND SPATIAL RESOLUTIONS OF VARIOUS INPUTS AVAILABLE FOR VRE FORECASTING



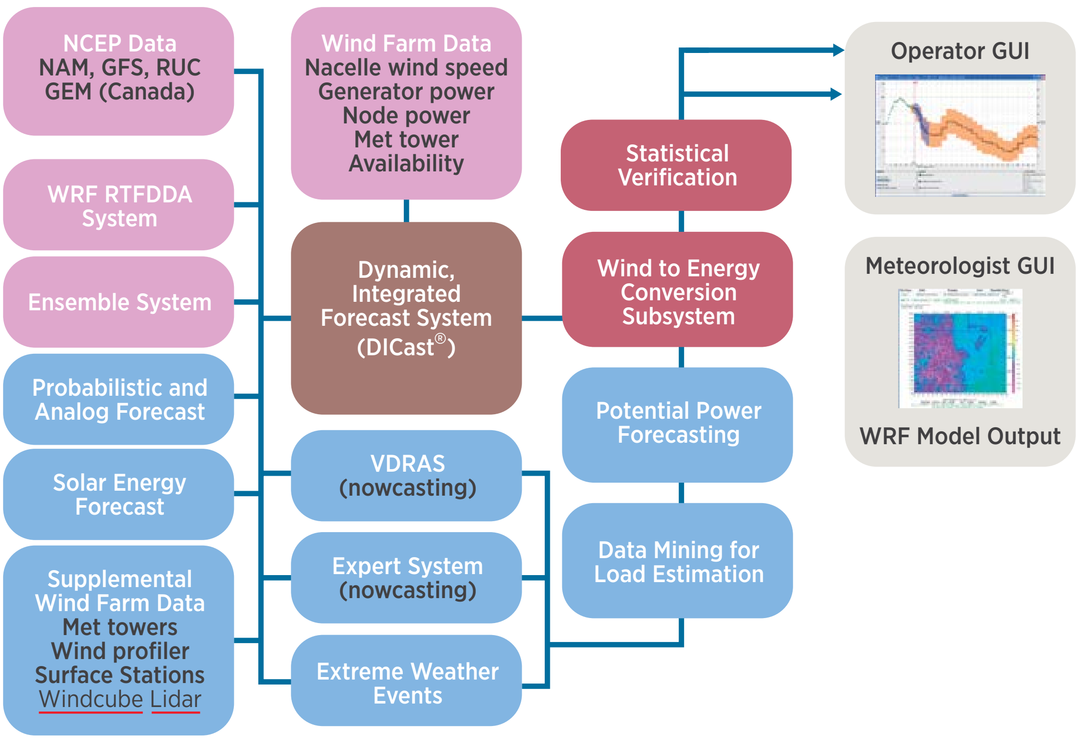
(Mahoney *et al.* 2012) and *Scientific Advances in Wind Power Forecasting* (Kosovic *et al.* 2014) also provide insight on the design, function and performance of a state-of-the-art hybrid forecasting model.

A key feature of current forecasting methodologies is the increasing accuracy of short-term prediction capability, often referred to as "now casting". New models and observation technologies are allowing the prediction of rapid changes in VRE output resulting from storm fronts, shifting of atmospheric boundary layers, sudden cloud cover and other weather phenomena. Predicting these rapid changes in VRE output is particularly valuable, as these events are the primary cost driver of VRE integration (Orwig *et al.* 2012). The importance of short-term forecasting will be expanded on in the following section on the value of forecasting.

Although the hybrid/blended model approach gives a forecasting methodology significant predictive power by combining a variety of models and observation technologies, this approach inherently requires that the methodology be tuned to local conditions and data availability (Jones 2014). This is because certain models are better at predicting one type of weather phenomenon or at effectively using a certain type of observational data or at converting a particular key weather indicator into power output for a certain VRE technology (Kleiss 2010). In addition, the dominant weather mechanism affecting wind and solar generation in Cyprus may be very different from the conditions driving renewable energy generation in areas where advanced forecasting techniques have been developed and tested, e.g. there is currently research taking place on improving the models that predict blade icing, a key issue for wind turbines at northern latitudes but not likely to be of value in Cyprus (Wilczak *et al.* 2013). As such Cyprus should make an effort to understand which weather phenomena are the key drivers of VRE in Cyprus and which models and observation technologies are best suited to analyse these key weather conditions in order to understand which forecasting methodologies can offer the best forecasting accuracy for Cyprus.

Finally, it should be noted that although numerous VRE forecasting products are commercially available, the majority of these products/services are proprietary and there is little information available

Figure 32: Xcel Energy's wind forecasting model developed with NCAR



http://nar.ucar.edu/2013/ral/renewable-energy on the model structure and function they employ. Because these products have been developed for a certain region where the key weather phenomena driving VRE generation may not match with those in Cyprus, the previous performance of a particular forecasting methodology may not be the best indicator of how well it will perform in Cyprus. As such Cyprus should emphasise the use of local test results when evaluating third party forecasting products.

4.2 Value of VRE forecasting

VRE forecasting has proven to be a valuable tool that reduces production costs, operational reserve costs, and financial risk, increases the return on investment for VRE assets and in general simplifies the management of VRE to allow the integration of high levels of VRE.

At the simplest level VRE forecasting uses models, historic data and real time observations of weather and VRE assets to provide an expected power generation with the associated error/probability. These predictions can be given across a range of timescales from minutes to days and even weeks ahead and a range of system sizes from individual turbines or panels up to forecasts for entire regions that cover gigawatts of generation from numerous types of VRE technologies. Generally forecasts are provided at a set time of the day and are updated on a regular basis (dependent on the forecast time scale) as more up-to-date information is received and processed by the model. Thus forecasting provides a continuously updated estimate of a VRE asset generation that can be used in the day-ahead, hour-ahead and intra-hour planning of VRE asset and grid operations (Jones 2014).

The US National Renewable Energy Laboratory (NREL) notes that "even with imperfect forecasts, large-scale wind integration studies have demonstrated that using day-ahead wind power forecasts for unit commitment can dramatically improve system operation by reducing overall operating costs, reducing unserved energy, and reducing wind curtailment, while maintaining required levels of system reliability" (Lew *et al.* 2011). Similar impacts have been found for short-term wind forecasting (Orwig *et al.* 2012) and for solar forecasting. "Solar forecasts on multiple time horizons become increasingly important as solar penetration grows for the purposes of grid regulation, load-following production, power scheduling and unit commitment. Short-term, intra-hour solar forecasts are particularly useful for power plant operations, grid balancing, real-time unit dispatching, automatic generation control (AGC) and trading. Forecasts for longer time horizons are of interest to utilities and ISOs for unit commitment, scheduling and for improving balance area control performance" (Inman 2013).

VRE forecasting creates value for a number of players in electricity markets; in particular, accurate forecasts lower VRE integration costs for TSOs and DSOs while reducing financial risk and increasing revenues for IPPs and utilities operating VRE assets. A review of the value of forecasting to these players is given below.

4.2.1 Transmission system operators

Transmission system operators (TSOs) use VRE forecasts in combination with demand forecasts to determine the type and capacity of the dispatchable units that will be operated to support the integration of VRE generation while ensuring grid stability. Having an accurate forecast allows the TSO to commit the most cost-effective combination of thermal generation assets and operate them in an efficient manner. Accurate VRE forecast can reduce TSO costs in several areas.

- **Production costs savings:** Accurate VRE forecasts can lower production cost by helping TSOs commit an optimal set of generation units that can react to the variability of VRE generation in an efficient manner and avoid extreme events. The main savings from accurate VRE forecasts come from reducing/eliminating large forecasting errors while additional savings can be captured by reducing/eliminating small-scale errors (Marquis *et al.* 2011).
    - **Large under-generation errors:** If VRE generation drops significantly below the predicted output then the supporting thermal units will have to be quickly ramped up and additional quick start units deployed. The rapid ramping up of thermal generation reduces efficiency and unit lifespan. The unexpected commitment of additional units increase costs as cold starts reduce efficiency and lifespan, while in addition

these units may have a higher generation cost.

   - **Large over-generation errors:** If VRE generation greatly exceeds the forecasted output then thermal units will have to be rapidly scaled down or shut off, once again decreasing unit efficiency and lifespan. Once the lower limit of the thermal generation system is reached, VRE assets will have to be curtailed leading the loss of zero marginal cost generation.

   - **Smaller forecasting errors:** Even smaller forecasting errors that do not require commitment of quick start assets or VRE curtailment still increase cost by reducing unit efficiency and lifespan through rapid unit cycling.

- **Operational reserve savings:** Additional savings from accurate VRE forecasts can be realised through the reduction in operating reserves. If uncertainty in the forecast is high then a larger number of units will likely be committed and must be kept running to cover a broader range of potential VRE outputs. With a more accurate forecast the uncertainty in VRE output is reduced to smaller range and thus fewer units need to be up and running to cover potential changes. The amount of savings is greatly dependent on the type of units deployed. (Ela *et al.* 2010)

- **Understanding VRE effects on demand forecasting:** Many VRE assets, particularly PV, are being deployed as distributed generation (DG) that is integrated into the electricity grid at the distribution level. Currently many DG PV systems are treated as negative load, where increased PV production is seen as a lower demand. As a result, significant DG deployment can lead to variability in demand tied to VRE production that is not covered by traditional demand forecasting techniques. By incorporating VRE forecasting of DG assets, TSOs can develop more accurate demand forecasts that will support efficient unit commitment and system operation.

4.2.2 Distribution system operators

Distribution system operators (DSO) can also benefit from VRE forecasting of DG assets connected to the distribution system. The primary cost saving benefits exists where some level of power control electronics have been incorporated with the DG assets. This allows the DSO to use forecasts to determine when voltage drops or other grid stability issues relating to VRE will take place and use the control systems to adjust VRE output. The benefits from forecasting for DSOs will grow as technologies like demand side management, smart grids and distributed energy storage become more common.

4.2.3 VRE asset owners and investors

IPPs and utilities operating VRE assets along with investors in VRE assets can all benefit from accurate VRE forecasts. It should be noted that for these players to realise the full value of forecasting there needs to be an efficient electricity market that is fully open to VRE producers. In this case, accurate forecasts can directly increase revenues by giving VRE asset operators more information on when they will be able to place and fulfil market bids. Accurate forecasting can also reduce the financial risk for VRE operators and investors by increasing the likelihood that VRE assets will meet power production and financial performance targets. In general, the more market access VRE operators have the more valuable forecasting is to their bottom line and thus the more likely they are to invest in high quality forecasting models and observation technologies.

There are also some non-market benefits associated with accurate VRE forecasting. For example, they can avoid the “out-of-bounds” penalties for failing to meet forecasted generation or the ability to schedule maintenance or downtime during periods with a low production forecast.

4.2.4 VRE forecasting case studies

In general, the primary value of forecasting is that it supports the integration of high levels of VRE into electricity grids in a manner that support stable grid operation and lowers generation costs. Two key examples of the positive impacts and value of accurate VRE forecasting are given below.

- **Xcel Energy** is a major US utility, servicing approximately 3 million customers. Xcel currently operates over 4,000 MW of wind power, making it the largest wind power operator in the US (Xcel Energy, 2014). Xcel has worked extensively with the US National Center for Atmospheric Research (NCAR) to deploy an advanced wind forecasting system (Mahoney et al. 2012). On 6 October 2011, after deploying the first iteration of the NCAR forecasting system, Xcel was able to achieve 55.6% instantaneous wind power penetration with 3,400 MW of wind capacity. Further improvements to the forecasting system allowed Xcel to reach over 60% instantaneous wind power penetration in May 2013. The same year Xcel was able to produce 15% of their total annual generation using wind power. Xcel plans to use additional improvements in forecasting and advanced controls to achieve over 50% total annual generation from wind in the near future (Pager, F. 2014). Xcel's investment in NCAR's advanced forecasting system generated USD 37.5 million in savings from 2009-2013 (Bartlett 2014). This represents a yearly savings of USD 9.375 million, equivalent to around 5% of Xcel's 2013 annual operational income of approximately USD 1.84 billion (Xcel Energy 2014).

- **Wind power in Spain:** Spain is among the leaders in VRE generation forecasting, which is co-ordinated through the national Control Centre of Renewable Energies (CECRE). CECRE operates an advanced VRE forecasting system that helps to integrate wind and solar assets across the entire country. With the help of VRE forecasting Spain covered 35% of the total annual demand using wind and solar resources and achieved very high instantaneous VRE penetrations, including 64 % of demand supplied by wind generation in 2012 (Gil 2014).

Additional information on the economic benefits of VRE forecasting can be found in the NREL report titled *The Value of Wind Power Forecasting* (Lew *et al.* 2011) and the American Meteorological Society report titled *Forecasting the Wind to Reach Significant Penetration Levels of Wind Energy* (Marquis *et al.* 2011). In 2015, the US Department of Energy plans to publish an extensive report on the economic value of forecasting as the final output of its multi-year Wind Forecast Improvement Project (Wilczak *et al.* 2013).

4.3 VRE forecasting: Recommendation for Cyprus

Cyprus is at a critical stage in defining the future of its power sector. It is likely that a significant deployment of VRE assets will take place in the near term and grow into a major component of the island's power generation portfolio. VRE forecasting can play a significant role in the successful integration of this expanding share of VRE generation. Based on IRENA's review and information provided by the government of Cyprus on current use of forecasting and proposed electricity market design IRENA has compiled several recommendations, detailed below, to support the effective use of VRE forecasting in Cyprus.

4.3.1 Strong correlation between market structure and value of forecasting

There is a broad consensus among experts from industry and academia that forecasting is most effective at supporting VRE integration and increasing the return on investment of VRE assets in countries with an efficient electricity market that allows full participation of all VRE producers. For example, the report *Economic Grid Support Services by Wind and Solar* (Hulle *et al.* 2014) states "The functioning of existing day-ahead and intraday markets must be improved with shorter gate closure and more cross-border integration in order to give VRE (sic) producers (short-term) opportunities to trade their imbalances. A shorter forecasting time horizon would not only help to set up a level playing field for balancing conventional and variable generation, but would also lower the system operation costs." Jones (2014) notes "It is expected that new market products, such as ramp product, and new optimisation algorithms, such as robust unit commitment, will be adopted by the wholesale electricity markets to provide a reliable and competitive environment for VRE integration."

Forecasting provides predictions of VRE output on a number of timescales from day-ahead power estimates that can be used in day-ahead unit commitment to short-term forecasts that can be used in real-time power system operation. However, in order to be economically valuable, VRE power predictions on a certain timescale require a market with a corresponding timescale. For example, Cyprus' proposed day-ahead electricity market can give value to established day-ahead forecasting techniques. As VRE asset producers can use these forecasts to make bids with more certainty they will be able to fulfil them (increasing revenue) and the TSO will have more certainty in using these bids in day-ahead unit commitment, reducing generation costs.

Accurate prediction of **short-term rapid ramping** in VRE generation is one of the most valuable services of **advanced forecasting techniques** (Jones 2012). These short-term predictions can prevent extreme events, e.g. VRE curtailment and unplanned unit quick starts or shutdowns and rapid unit cycling of thermal generation, which have the largest impact on VRE asset revenue and integration costs. However, accessing the economic value of this information requires a **short-term electricity market** that will allow VRE producers to make bids and trade imbalances on a time scale that match the **short-term forecast predictions.**

Advances in power electronics and controls currently allow VRE assets to provide a range of ancillary/grid support services and this ability is expanding rapidly. Having full access to an ancillary services market would provide a financial incentive for VRE producers to invest in the latest power electronics and advanced forecasting techniques as this would provide an additional revenue stream. At the same time this would reduce TSO operational burdens in providing ancillary services to support VRE integration, by having them traded and acquired from the system that can provide them at minimum cost in each trading period.

In light of what is discussed above, IRENA makes the following recommendations regarding the use of VRE forecasting in Cyprus.

» **Development of short-term markets:** The proposed structure for the Cyprus electricity market currently being debated includes the possibility of opening short-term markets at some point in the future. IRENA's literature review shows that flexible short-term markets greatly enhance the value of VRE forecasting, allowing VRE producers to take advantage of predictions of rapid changes in VRE output and trade imbalances. The introduction of some form of accurate short-term forecasting can have major positive effects on integrating additional VRE generation. As such it is recommended that Cyprus investigate current short-term market structures and make plans to implement an appropriate short-term-market in the near future.

» **Confirmation of short-term market = investment in weather observation:** Once it is known that a short-term market will be created, Cyprus should perform a full review of the available weather observation and remote sensing technologies that support short-term forecasting to determine which system can be most effective in Cyprus.

» **Proposed day-ahead market = research to improve day-ahead forecasts:** The current proposed electricity market includes a day-ahead market. As such Cyprus should undertake a review of available forecasting methodologies to determine how day-ahead forecasts can be improved in Cyprus. One area to include in this investigation is Numerical Weather Prediction (NWP), as these models have a high impact on the accuracy of day-ahead VRE forecasting. Currently available NWP models should be examined to see how well they predict the key weather variables affecting solar and wind generation in the specific context of Cyprus.

» **Full market participation for IPPs:** Allowing VRE producers full market access (short-term, ancillary services, etc.) provides a strong incentive for IPPs to purchase and maintain state of the art forecasting systems and advanced power electronics. These systems in turn reduce the TSO's VRE integration costs. IRENA has noted a few concerns regarding the proposed market structure that would likely limit VRE producer market participation at levels including the ancillary services market. These limits would reduce the value of forecasting and its ability to support VRE integration. Specifically, the focus on forward markets strongly favours thermal generation at the expense of VRE. In addition, the proposed market design allows no same day renomination for VRE producers, this is only allowed in the day-ahead market at 3 p.m., this will likely limit VRE market participation and greatly reduce the value of forecasting, especially short-term forecasting, which can have the greatest benefit to VRE integration. It is recommended that Cyprus examines the proposed market structure with emphasis on allowing full participation of VRE at all levels.

4.3.2 Minimise grid code requirements for VRE

In relation to the need for an efficient market with full access to VRE producers IRENA also recommends that hard requirements relating to VRE performance in TSO and DSO grid codes should be kept to a minimum. Well-written market rules can provide a more flexible and self-correcting mechanism for ensuring that VRE producers generate power in a manner that can be easily integrated into the grid. Grid codes can distort markets, often do not keep up with advances in the performance of forecasting/power electronics and can reduce the value of forecasting to VRE producers, thereby decreasing their incentive to invest in accurate forecasting.

However, certain areas are of great importance for improving the quality of forecasting and ensuring an efficient interaction with the grid and should likely be included as hard requirements in the grid codes. These primarily include requiring provision of forecasts, weather observations and VRE asset data. In addition, for VRE producers that exist outside of the market system, requiring forecasting and enforcing "out-of-bounds" penalties may be necessary as the incentives of these players to invest in forecasting are reduced compared to a full market participant.

4.3.3 Cyprus VRE forecasting accuracy competition

As noted, the majority of advanced forecasting methodologies use a hybrid/blended model approach that must be tuned to local conditions. This region / country specific tuning limits the ability to use a forecasting method's previously reported accuracy when selecting a model to use in Cyprus as the key condition affecting the model's accuracy may be very different in Cyprus versus the region where the model delivered a high accuracy. In addition, commercially available forecasting products are proprietary, greatly limiting the available information on model structure and function and thereby reducing the ability to determine which product would best fit the weather conditions in Cyprus. These factors can greatly complicate the selection of forecasting products by VRE producers in Cyprus and by the TSO, which will likely want its own forecasting tool that can be used a benchmark for judging the quality of forecasts provided by VRE asset operators.

Following the example of the California Independent System Operator (CAISO), Cyprus could consider organising a one year forecasting competition. CAISO has used these studies to evaluate forecasting products for both wind and more recently solar power. The competition should be designed in consultation with research and industry experts to ensure the outcomes are valuable and should be open all third-party forecast providers. Additional details on the competition structure and goals along with a list of companies providing solar forecasting productions are provided in the *Current state-of-the-art in solar forecasting* (Kleiss 2010).

California has shown that such competition can be an effective method for determining which of the available forecasting products is best matched to a particular area. Relating to the completed wind power forecasting competition the report *Status of Centralized Wind Power Forecasting in North America* (Porter, and Rogers, 2010) noted "CAISO recently concluded a year-long wind power forecasting competition among three companies for providing day-ahead and hour-ahead wind power forecasts. Each wind power forecasting provider was responsible for supporting day-ahead and hour-ahead forecasts for four wind projects. AWS Truewind was selected as the winner of the competition and received a new contract to continue wind power forecasting for CAISO. As part of the competition, CAISO conducted a statistical analysis of the wind power forecasts and found the following:

- aggregate day-ahead wind forecast error was decreased to less than 15% RMSE;
- aggregate hour-ahead wind forecast error was reduced to less than 10% RMSE, which is a 20% improvement over current hour-ahead forecasts used by CAISO for PIRP."

4.3.4 Review of forecasting accuracy metrics

As part of a VER forecasting accuracy competition or in separate study, Cyprus should consider an investigation of how well current VRE forecasting accuracy metrics predict the economic value of current forecasting methodologies. Research from NREL titled *A Suite of Metrics for Assessing the Performance of Solar Power Forecasting* (Zhang *et al.* 2014) notes that "One of the key challenges is the unavailability of a consistent and robust set of metrics to measure the accuracy of a solar forecast. This report (sic) presents a suite of generally applicable and value-based metrics for solar forecasting for a comprehensive set of scenarios (i.e., different time horizons, geographic locations, and applications) that were developed as part of the US Department of Energy's SunShot Initiative's efforts to improve the accuracy of solar forecasting." A review of this report would assist Cyprus in understanding which accuracy metrics should be considered when developing in-house forecasting or selecting a third party forecast provider for solar generation in Cyprus.

As noted previously, in 2015 the US Department of Energy plans to publish an extensive report on the economic value of forecasting as the final output of its multi-year Wind Forecast Improvement Project (Wilczak *et al.* 2013). This report could provide another reference point for judging the value of particular forecasting methodologies and accuracy metrics.

4.4 Future of forecasting: Grid services and dispatchable VRE

Several recent studies show that a combination of advanced VRE forecasting and power electronics/control systems are allowing VRE assets to act as dispatchable units capable of providing the full suite of grid support services available from traditional generation units.

The January 2014 NREL report titled *Active Power Controls from Wind Power: Bridging the Gaps,* notes that "the studies detailed in this report have shown tremendous promise for the potential for wind power plants to provide APC (active power control, sic). Careful consideration of these responses will improve power system reliability. Careful design of the **ancillary services markets** will result in **increased revenue for wind generators** and **reduced production costs for consumers** when these services are provided. Careful design **of control systems** will result in responses that are in many ways superior to those of conventional thermal generation, all while resulting in very little effect on the loading and life of the wind turbine and its components. With all these benefits that may result from careful engineering analysis, there should be no reason that wind power plants cannot provide APC to help support the grid, and help wind power forever abandon its classification as a 'non-dispatchable' resource" (Ela 2014).

One of the field trials that contributed to the above NREL study was executed by Xcel Energy and showed that a wind plant using automatic generation control (AGC) could "respond directly to the area control error (ACE, sic) and provide exceptionally fast regulation responses and offer excellent ACE compliance (Ela 2014). In 2012 3.5% of the wind energy generated in Xcel's Colorado grid was already being deployed through AGC. (Bartlett 2013).

The REserviceS project was a major study undertaken from April 2012 to September 2014 to examine economic grid support from variable renewables at the European Union level. This project, funded by the European Commission's Intelligent Energy Europe programme, determined that "Wind power and solar PV technologies can provide ancillary or grid support services (GSS) for frequency, voltage and certain functions in system restoration. The REserviceS project confirmed that variable renewable energy sources like wind and solar PV generation (VAR-RES) meet most of the capability requirements for delivering such services, as prescribed in grid codes. Where enhanced capabilities would be required, **technical solutions exist, but are not used today because of economic reasons** due to additional costs, which REserviceS has assessed. While in some countries financial incentives for VAR-RES with enhanced capabilities exist, this remains the exception rather than the rule in Europe. Appropriate **operational and market frameworks** are therefore needed for **enhanced participation of VAR-RES** in GSS" Hulle *et al.* 2014).

The REserviceS project also clearly points out the important role that VRE forecasting plays in supporting the ability of VRE assets to provide

GSS and the need for markets to support these capabilities. "Accurate forecasts are key to the cost-efficient provision of GSS with VAR-RES since the availability of wind and sun changes stochastically. It is important to recognise the need for different types of forecasts for different kinds of GSS. The most important time horizons for GSS are the short- and shortest-term forecasts (from day-ahead to minute scale). Medium-term forecasts are required to plan the operation of the grid at seasonal, weekly or for few days in advance, and are only partly relevant for GSS. A further reduction in the uncertainty can be achieved by using probabilistic forecasting reaching confidence intervals similar to non-VAR-RES power plants. Therefore, the use of probabilistic forecasts, together with pre-qualification methods adapted to the characteristics of wind and PV power, is an essential enabler for the efficient participation of VAR-RES in GSS provision" (Hulle *et al.* 2014).

Addition information relating to the power electronics and controls enabling GSS from VRE assets are given in the next section of Cyprus renewable energy roadmap.

IRENA recommends that Cyprus review the above NREL and REserviceS studies in detail to determine how current and near-term capabilities of VRE assets to provide GSS could impact the proposed electricity market structure, grids codes and aspirational renewable energy targets. In general IRENA expects that these developments could help Cyprus in stability and economically deploying very high shares of VRE.

4.5 VRE forecasting: Conclusions

IRENA's review of VRE forecasting has determined that it is an essential tool that should be used to support the integration of VRE in Cyprus. In particular it makes a number of conclusions.

- » Accurate forecasts support high levels of VRE generation by reducing integration costs for the TSO and DSO while also reducing financial risk and increasing revenues of IPPs and utilities operating VRE assets.
- » There is a strong correlation between the value of forecasting and electricity market design. In particular short-term markets and full market access (i.e. including participation in the ancillary services market) for VRE producers increases the efectiveness of forecasting in reducing VRE integration costs and increasing the share of VRE generation. Great care should be taken to ensure that the design of Cyprus' emerging electricity market allows VRE to reduce generation cost for the country, while minimising grid integration costs.
- » Cyprus has numerous options to improve the accuracy and use of VRE forecasting, however, this will require systematic evaluation forecasting options with real-world testing to confirm the forecasting accuracy. IRENA has referenced a "forecasting accuracy competition" pioneered by California as a potential option for evaluating VRE forecasting products/methodologies in practical use for Cyprus.
- » Current and near-term advances in forecasting and power control electronics allow VRE assets to provide grid support services and could soon support fully dispatchable VRE. These capabilities should be factored into Cyprus' proposed market design and future energy planning.

5 State-of-the-art of technologies for the provision of GSS from VRE systems

In support of the Cyprus renewable energy roadmap, IRENA conducted a literature review covering the ability of advanced power electronics and controls that allow VRE systems, in particular wind and solar PV, to provide GSS. Highlights from IRENA's review are below.

» The inverters deployed with most VRE assets can support a wide variety of GSS through pre-programming and simple information taken from the point of connection to the grid e.g. local voltage.

» These GSS functions are frequently disabled to comply with grid codes designed for one way power flow. As such, accessing current built-in GSS capabilities will likely require a revision of applicable grid codes.

» Provision of GSS from VRE usually requires the reduction of active power fed into the grid, which in many electricity markets is the only remunerated service for VRE generators (i.e. payment for kilowatt-hours fed into the grid). As such, provision of GSS can result in a loss of revenue for VRE operators. To rectify this, a market mechanism compensating VRE operators for GSS provision need to be established.

» Reaching the full potential of supplying GSS from VRE will require inverters with bidirectional communication capabilities along with grid codes and market mechanisms that support these new capabilities.

» Inverters with bidirectional communication capabilities are already being deployed. Making provision for these functionalities in grid codes can greatly accelerate their full-scale deployment.

» For different generation technologies, system scale and grid characteristics it is important to identify which GSS capabilities can provide benefits that will exceed the GSS deployment costs. This will inform development of future grid codes.

» Compared with traditional GSS provision from centralised thermal power stations, inverters and associated control systems distributed across the electricity grid can more effectively and efficiently provide GSS. This is achievable because distributed inverters are closer to both VRE generation and the loads being serviced, thus reducing line losses and the need for grid investments in the distribution system.

» Inverters can supply GSS even when no VRE generation is available, by drawing active power from the grid to locally inject reactive power when needed.

» The deployment of technologies allowing GSS from distributed VRE will push the supply-demand balancing down to the distribution level of the grid. This will require a higher level of efficient communication between the TSO and DSO.

» Inverters also support the provision of GSS from energy storage. The combination of VRE, energy storage and inverters is extremely effective at supply the full range of GSS. In particular, the inclusion of even small amounts of storage increases the ability to provide "regulation up" and "spinning reserve" services.

» All of the above capabilities greatly reduce the cost and complication of integrating high shares of VRE into isolated electricity grids.

IRENA's review also uncovered a number of major recent studies focused specifically on using VRE assets to provide a wide range of GSS in support of integrating higher shares of VRE into electricity grids. The key findings of these studies are detailed in the following section along with links to final project reports that serve as excellent information sources for those interested in a comprehensive understanding of provision of GSS from VRE. In addition, the references included at the end of this section of the roadmap serve as reading list to further expand the understanding of the ability of current inverter and power control technologies to allow VRE to supply GSS and thereby greatly reduce the complications of integrating high shares of VRE in isolated electricity grids.

This review covers some of the most recent studies that describe the state-of-the-art of technologies, and the requirements for further technological developments for the provision of additional useful GSS from VRE. The developments in Europe and US somehow differ, mostly in terms of market and regulatory framework under which these services will be provided, while the common driver remains to enable VRE to provide frequency and voltage support functions. This can be achieved mostly through improved communication capabilities and software improvements in the power electronics, which need to be clearly defined and implemented together with equipment manufacturers.

5.1 REserviceS project: Economic grid support from variable renewables

The REserviceS project is a major initiative of the European Commission's Intelligent Energy Europe Programme, which examined possible solutions for the provision of GSS from wind and solar assets across the entire EU. The quotes below highlight some of the key findings from the project's final report (Hulle *et al.* 2014).

» **Wind power and solar PV technologies** can provide **ancillary or GSS** for frequency, voltage and certain functions in system restoration. The REserviceS project confirmed that variable renewable energy sources like wind and solar PV generation (VRE) meet most of the capability requirements for delivering such services, as prescribed in grid codes. Where enhanced capabilities would be required, technical solutions exist, but are not used today because of economic reasons due to additional costs, of which REserviceS has made an assessment. While in some countries financial incentives for VRE with enhanced capabilities exist, this remains the exception rather than the rule in Europe. Appropriate operational and market frameworks are therefore needed for **enhanced participation of VRE** in GSS.

» As GSS come with a cost, **requirements for generator capabilities and service provision** should demand only what is

Figure 33: Summary of technical measures to facilitate the integration of variable RE into power grids. Source: Balke 2014

Measure	Areas of possible cost reductions		
	Generation	Transmission	Distribution
Ancillary services from RES-E plants	√		(√)
Utilisation of demand response	√	√	√
Regional sharing of operating reserves	√		
Improved RES- S forecasts	√		
Reactive power from DG-RES			
Restricted DG-infeed by solar PV			
Improved network monitoring and control		√	
More flexible conventional plants	√		
Technology improvements of RES-S	√	(√)	(√)
Pan-European overlay grid		√	
Innovative transmission technologies		√	
Use of 'smart grid' technologies	(√)		√
Decentralised storage	(√)		√

needed by the system to **avoid excessive system costs.** Importantly, REserviceS analyses found that **frequency management** can be adequately and economically achieved with only a **fraction of all installed VRE generators** participating in frequency support.

- The functioning of existing day-ahead and intraday markets must be improved with **shorter gate closure and more cross-border integration** to give VRE producers (short-term) opportunities to trade their imbalances. **A shorter forecasting time horizon** would not only help to set up a level playing field for balancing conventional and variable generation, but **would also lower the system operation costs.** Frequency support related GSS provided by VRE requires harmonised gate closure times as close as possible to delivery and minimised timeframes (less than one hour).

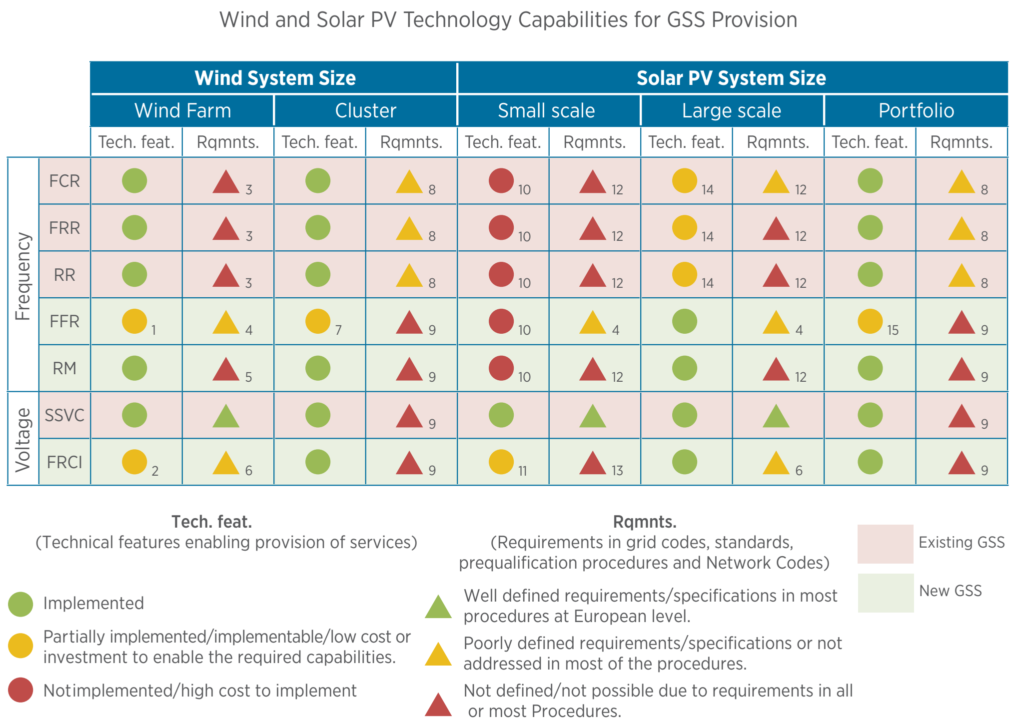
- **VRE's capability to provide frequency support,** in particular Frequency Containment Reserve (FCR) and Frequency Restoration Reserve (FRR), to the extent that it is beneficial (reliability versus cost) to the system **should be financially compensated,** as well as its readiness and utilisation costs.

- For cost-efficient offers to be provided with high certainty, the **market design** should encourage PV and wind to offer **reserve products from aggregated portfolios** of several PV and wind power plants, which can be spread across wider areas. Alternatively, the uncertainty can be aggregated over all units participating in the reserve. This function should be **facilitated by the system operator** and would eliminate the need for overlapping safety margins due to forecast inaccuracy, unexpected power plant failure and performance compliance.

A very comprehensive overview of the GSS that can be provided by wind and solar PV, at different scales and level of aggregation, is shown in Figure 34 (Van Hulle *et al*. 2014).

In addition to the final report referenced below, the REserviceS project produced several additional reports and annexes covering topics that are central to the challenges of widespread deployment of inverters with advanced GSS capabilities. The following list summarises the subjects covered by the REserviceS reports, which can be found at: http://www.reservices-project.eu/publications-results/

Figure 34: Capability of wind and solar PV system to provide grid support services



- System needs for ancillary services
- Wind and PV ancillary services capabilities and costs
- Wind and PV ancillary services in future systems – case studies
- Recommendations for a future EU market for ancillary services

5.2 PV GRID Project

The PV GRID Project is another major initiative of the European Commission's Intelligent Energy Europe Programme. This project is based on the collaboration between 16 European Union countries and seeks solutions to legal, administrative and regulatory barriers to larger scale deployment of distributed PV generation. In relation to GSS from VRE the projects specifically examines "enhancing PV hosting capacity in distribution grids by favouring the adoption of available technical solutions" (Barth *et al.* 2014).

This PV GRID Project focused on technical solutions that provided GSS related to voltage quality and local congestion in the distribution section of the electricity grid. These solutions were developed through a project consortium that "collected several documents mainly originating from national, European and international R&D projects, grid codes and technical standards. In order to complement the project consortium's expertise, several external experts were selected amongst stakeholders of the European electricity sector: representatives of TSO, DSOs, inverters and storage manufacturers. Technical solutions variants and combinations were discussed in depth through a series of project workshops, in order to reach a large consensus between stakeholders" (Barth *et al.* 2014). The solutions developedin the above process are detailed in Table 32.

TABLE 31: SUMMARY OF TECHNICAL SOLUTIONS FOR CONGESTION MANAGEMENT AND VOLTAGE QUALITY ISSUES

Category	Technical solution
DSO	Network Reinforcement
	On Load Tap Changer for MV/LV transfromer
	Advanced voltage control for HV/MV transfromer
	Static VAr Control
	DSO storage
	Booster Transfromer
	Network Reconfiguration
	Advanced Closed- Loop Operation
PROSUMER	Prosumer storage
	Self-consumption by taniff incentives
	Curtailment of power feed-in at PCC
	Active power control by PV inverter P(U)
	Reactive power control by PV inverter Q(U) Q(P)
INTERACTIVE	Demand response by local price signals
	Demand response by market price signals
	SCADA + direct laod control
	SCANDA+ PV inverter control (Q and P)
	Wide area voltage control

The PV GRID Project notes that “With the target of increasing the distribution grid hosting capacity of PV generation but also of other distributed energy resources, the PV GRID consortium addressed two main constraints the distribution grid would have to cope with: the voltage rise and the congestion management” (Barth *et al.* 2014).

The following three sections are taken directly from the PV GRID Project report and serve to further define the technical solutions provided in Table 32. As noted in the PV GRID Project report “The identified technical solutions are categorised in DSO, Prosumer and Interactive solutions. DSO solutions are installed and managed on the grid side and do not require any interaction with the consumers or the PV plants. The Prosumer solutions are installed before the metre and react based on the grid characteristics at the point of common coupling, without any communication with the DSO. The Interactive category requires a communication infrastructure linking the hardware located in different grid locations” (Barth *et al.* 2014).

5.2.1 DSO solutions

- **Network reinforcement** - Further grid hosting capacity is provided by additional cable and transformer capacity installations.
- **On Load Tap Changer (OLTC) (medium voltage/low voltage transformer)** - The OLTC device is able to adjust the lower voltage value of an energised transformer.
- **Advanced voltage control (HV/MV transformer)** - This solution includes new control methods for existing HV/MV transformers with already installed OLTC.
- **Static VAR control** - Utilising Static VAR Compensators (SVC) enables to provide instantaneously reactive power under various network conditions.
- **DSO storage** - Storing electricity with a central storage situated in a suitable position of the feeder enables to mitigate voltage and congestion problems.
- **Booster transformers** - Boosters are medium voltage-medium or low voltage-low voltage transformers which are used to stabilise the voltage along a long feeder.
- **Network reconfiguration** - Revising network operational conditions by reconfiguration, in particular at the boundaries between feeders in medium voltage networks, is a solution to ensure the voltage profiles stay within regulated boundaries in distribution networks.
- **Advanced closed-loop operation** - Two feeders are jointly operated in a meshed grid topology controlled by smart grid architecture to decrease the circuit impedance.

5.2.2 Prosumer solutions

- **Prosumer Storage** - Storing electricity at the prosumer level allow for the mitigation of voltage and congestion problems provided that a reduction of the feed-in peaks can be ensured.
- **Self-consumption by tariff incentives** - With a fixed tariff structure (e.g. feed-in price lower than consumption price), the prosumer is incentivised to shift its electricity consumption in order to reduce its injected PV energy. A maximum feed-in power based tariff (e.g. kWh price set to zero or to negative values above some feed-in power limits) could further support in reducing injected PV peak power.
- **Curtailment of power feed-in at power control centre**- The meter at the customer’s site controls that the feed-in power is never above the contracted maximum power or above a fixed value (e.g. 70% of the installed PV capacity as implemented in the German Renewable Energy Act). This solution requires the meter to be able to control down the PV production or to activate a dump load.
- **Active power control by PV inverter P(U)** - Voltage and congestion problems can be solved by curtailing the PV feed-in power. Contrary to the fixed power curtailment as described in previous solution, the low-voltage grid voltage is used as an indicator for the grid situation and for the curtailment level.

- **Reactive power control by PV inverter Q(U), Q(P)** - Providing reactive power as a function of the local voltage value [Q=Q(U)] or as a function of the active power production [Q=Q(P)], limits the voltage rise caused by distributed generation.

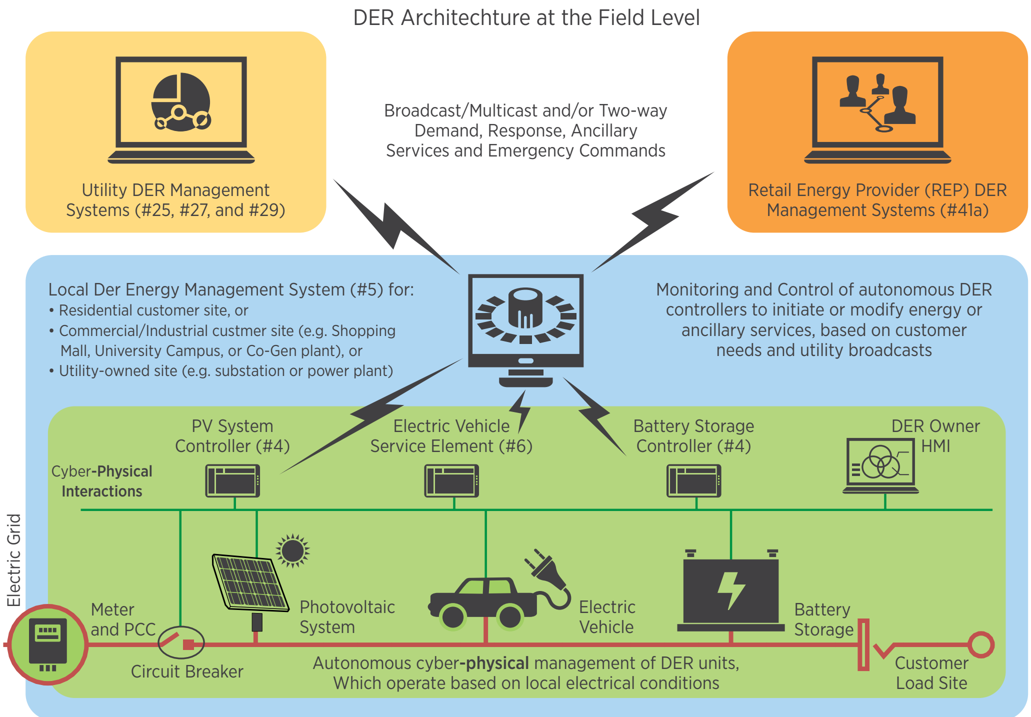
5.2.3 Interactive solutions

- **Demand response by local price signals** - Demand response is triggered by local price signals available only to consumers located in feeders, which experience voltage and/or congestion problems.
- **Demand response by market price signals** - Demand response is triggered by electricity market price signals, which are identical for consumers wherever they are located.
- **Supervisory Control and Data Acquisition (SCADA) + direct load control** - In critical grid situations, DSOs or energy aggregators are allowed to remotely activate or curtail dedicated consumer loads, based on agreed contract.
- **SCADA + PV inverter control (Q and P)** - The level of reactive power provision and the active power reduction of dedicated PV inverters are remotely controlled by a feeder supervisory control system.
- **Wide area voltage control** - All controllable equipment (like transformers with OLTC, static VAR compensators, dedicated loads and PV inverters) are co-ordinated to optimise voltage and power factor in the whole DSO area. Smart grid technologies are applied to measure the voltage and power factor at several points, controlling the equipment, co-ordinating and optimising the generation and load.

5.3 California distributed energy deployment project

The State of California is currently pursuing an ambitious project to add 12 GW of distributed generation to its electricity grid by 2020. In support of this deployment "the Smart Inverter Working Group (SIWG) [...] was formed in early 2013 as a joint effort between the California Public Utility Commission (CPUC) and California Energy Commission (CEC) in order to develop recommendations to the CPUC for the technical steps to be taken in order to optimise Inverter-based Distributed Energy Resource (I-DER) to support

Figure 35: Schematic representation of information flows in an interactive DER management system. Source: Seal, 2012



distribution system operations" (SIWG, 2014). In January 2014 the SIWG issued a final report with detailed recommendations for the use of advanced inverters to allow VRE assets to provided GSS. Below are some key highlights from this report.

» Current grid structure and related grid codes are designed for one way power flow but have been able to accept a small share of VRE integration.

» The envisioned deployment of 12 GW of distributed generation will likely result in system stability issues unless the deployed VRE assets included inverters that allow the provision of GSS.

» A reworking of grid codes and creation of market mechanism for compensation are required to allow use of current and developing inverter capabilities.

» It is key that inverter manufacturers are kept informed of what GSS will be required and when those requirements will become effective.

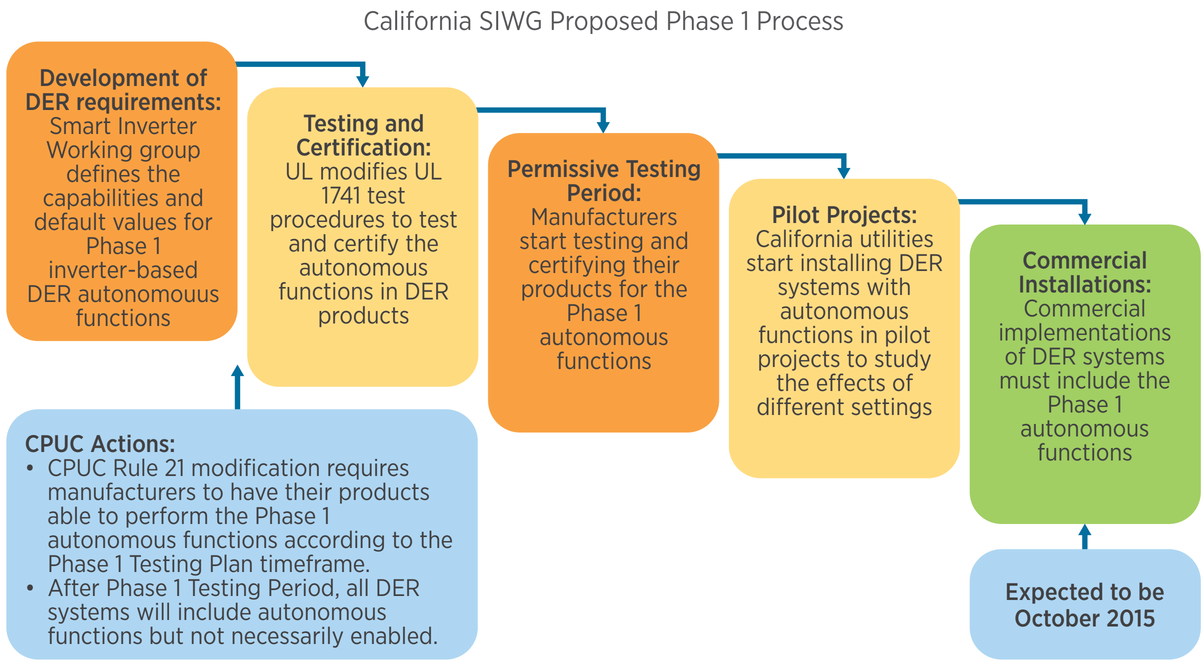
» A phased approach, detailed below in Figure 36, is extremely useful for incorporating new inverter capabilities into the grid and thereby progressively increasing the controllability of VRE and the amount of GSS that they can provide.

The SIWG gives a recommendation for a phased approach for the development and implementation of desirable functions for I-DER, in which "Phase 1 addresses autonomous functionalities, Proposed Phase 2 addresses communications standards, and Proposed Phase 3 identifies advanced functionalities, some of which utilise Phase 2 communications standards. The SIWG approach to Proposed Phase I is diagrammed below (Figure 36). Phases 2 and 3 will each follow a similar model" (SIWG 2014).

Specifically Phase 1 proposes the following inverter capabilities (SIWG 2014), which should be implemented commercially in all new I-DER installed in California as of October 2015:

1. Anti-Islanding Protection
2. Low/High Voltage Ride-Through (L/HVRT)
3. Low/High Frequency Ride-Through (L/HFRT
4. Dynamic Volt/Var Operations
5. Ramp Rates

Figure 36: Structure of Phase 1 of SIWG proposed inverter deployment



6. Fixed Power Factor

7. Reconnect by "Soft-Start" Methods

8. Phase 1 I-DER System Parametersand Monitored Points

The Phase 2 recommendations focus on establishing bidirectional communication capabilities using recommendations from the IEEE 1547.3 *Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems,* and the IEC 61850 communications standard, with the understanding that these communications requirements will need to be adapted (SIWG 2014). It discusses the below communications technologies and capabilities.

1. Provide capability for including and/or adding communications modules for different media interfaces.

2. Provide the TCP/IP internet protocols.

3. Use the international standard IEC 61850 as the information model for defining the I-DER data exchanges.

4. Support the mapping of the IEC 61850 information model to one or more communications protocols.

5. Provide cybersecurity at the transport and application layers.

6. Provide cybersecurity for user and device authentication.

The SIWG report clearly notes that although the Phase 1 recommendations for inverter capability do not explicitly require bidirectional communication, realising the full potential of inverters to support GSS from VRE communication plays a critical role for the following reasons (SIWG 2014):

» ability to update default or pre-set parameters to meet changing power system requirements. For instance, if an I-DER system is installed with specific parameter values, but six months later, either additional I-DER systems are installed on the same circuit or the circuit itself is reconfigured, then those parameter values may need to be updated;

» ability to monitor and control I-DER systems so that the state of the power system can be better understood and managed by the utility;

» ability to upgrade smart inverter functions so that new understandings of how I-DER systems interact with power system equipment or impact power system operations can be reflected in improved I-DER functional capabilities (this capability is particularly important since many studies and analyses will need to take place on how best to integrate the smart I-DER functions with existing utility equipment capabilities); and

» ability to respond to safety and other emergencies through direct control actions on the I-DER systems.

The SIWG report also defines the following potential Phase 3 inverter functionalities that would be enabled by an efficient and broadly available communication system (SIWG 2014):

1. Provide emergency alarms and information.

2. Provide status and measurements on current energy and ancillary services.

3. Limit maximum real power output at an Electrical Connection Point (ECP) or the Point of Common Coupling (PCC) upon a direct command from the utility.

4. Support direct command to disconnect or reconnect.

5. Provide operational characteristics at initial interconnection and upon changes.

6. Test I-DER software patching and updates.

7. Counteract frequency excursions beyond normal limits by decreasing or increasing real power.

8. Counteract voltage excursions beyond normal limits by providing dynamic current support.

9. Limit maximum real power output at the ECP or PCC to a pre-set value.

10. Modify real power output autonomously in response to local voltage variations.

11. Set actual real power output at the ECP or PCC.

12. Schedule actual or maximum real power output at specific times.

13. Smooth minor frequency deviations by rapidly modifying real power output to these deviations.

14. Follow schedules for energy and ancillary service outputs.

15. Set or schedule the storage of energy for later delivery, indicating time to start charging, charging rate and/or "charge-by" time.

In general the SIWG report notes that the **benefits from advanced inverter capabilities "will increase utility visibility and control over the grid, improve grid stability, respond to utility emergencies, provide very fast counteractions to voltage and frequency fluctuations, improve power quality, and increase grid efficiency"** (SIWG 2014).

5.4 NREL and EPRI project on wind power provision of grid support services

The US National Renewable Energy Laboratory (NREL) and the Electric Power Research Institute (EPRI) worked together on a major project to "understand the ways in which wind power technology can assist the power system by providing control of its active power output being injected into the grid. The three forms of APC (active power control, sic) that this study focuses on are synthetic inertial control, primary frequency control (PFC), and automatic generation control (AGC)" (Ela *et al.* 2014).

The NREL report *Active Power Controls from Wind Power: Bridging the Gaps,* summarises the results of this project, noting that "the studies detailed in this report have shown tremendous promise for the potential for wind power plants to provide APC (active power control, sic). Careful consideration of these responses will improve power system reliability. Careful design of the ancillary services markets will result in increased revenue for wind generators and reduced production costs for consumers when these services are provided. Careful design of control systems will result in responses that are in many ways superior to those of conventional thermal generation, all while resulting in very little effect on the loading and life of the wind turbine and its components. With all these benefits that may result from careful engineering analysis, there should be no reason that wind power plants cannot provide APC to help support the grid, and help wind power forever abandon its classification as a 'non-dispatchable' resource" (Ela *et al.* 2014).

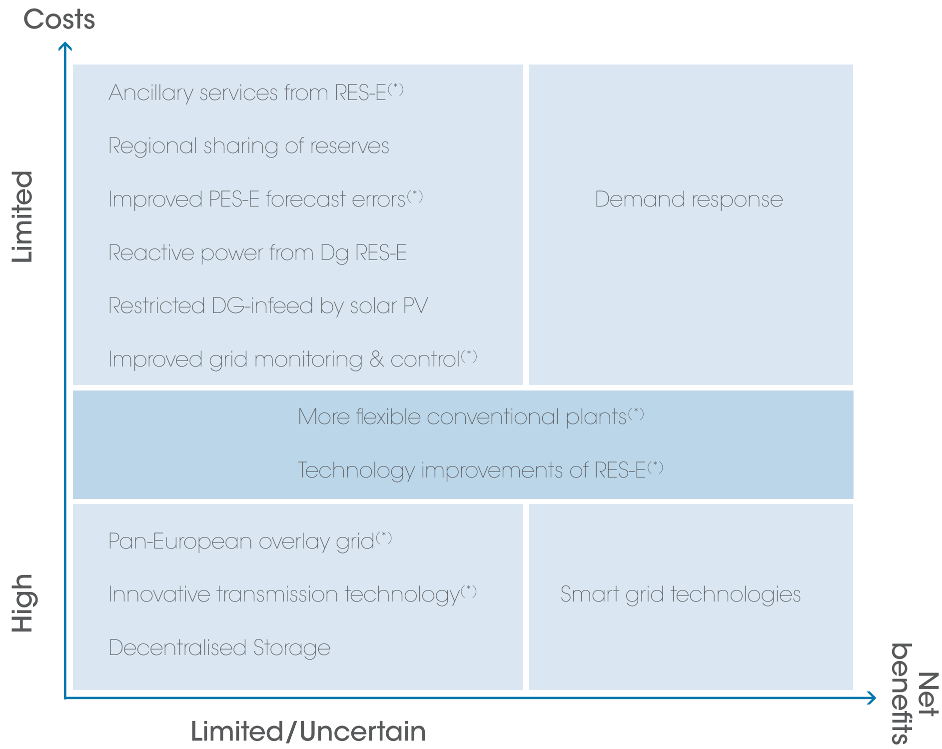
One of the field trials that contributed to the above NREL study was executed by Xcel Energy and showed that a wind plant using automatic generation control (AGC) could "respond directly to the area control error (ACE) and provide exceptionally fast regulation responses and offer excellent ACE compliance (Ela *et al.* 2014).

5.5 Advanced technologies for VRE grid services: Conclusions

As policy makers become concerned about the reliability of power grids in the presence of high shares of variable renewable energy generation, regulations are developed to push for technology developments in the area of provision of GSS from VRE. As this brief review of the state of the art in Europe and US shows, most GSS services can indeed be provided by VRE. The key policy challenge is to ensure that deployment of GSS-capable VRE takes place in parallel with the development of cost-effective solutions for the provision of these services. On one hand, imposing costly requirements for GSS on all VRE generators through grid codes, without differentiating between size and technology, will unnecessarily reduce the competitiveness of renewable energy and ultimately increase the electricity price to consumers. On the other hand, delaying the introduction of requirements for GSS in grid codes (just those that are strictly necessary or that can be provided with a negligible incremental cost) and through smart market design, will cause a higher integration cost at a later stage (e.g. need for replacement or retrofitting of non-controllable inverters).

As technology develops, more and more GSS can be provided by VRE. At the same time, the incremental cost of providing these services will continue to decrease, as more and more manufactures are able to provide them in their standard line of products. It is key that policies and regulations keep up to date with technological developments, to allow for the growth of the share of VRE in power systems to continue, while ensuring reliable grid operations and minimisation of integration costs.

Figure 37: Qualitative cost-benefit analysis of technical solutions for the provision of GSS from VRE. Source: Balke, 2014



6 Roadmap conclusions

It is clear that the electricity mix of Cyprus will change to a considerable degree in the near future. Investments in renewable energy technologies are not only necessary for Cyprus to achieve its EU targets, but will also result in a reduction of power generation cost up to 2023 in all the scenarios examined.

The extent to which new capacity installations are required will be determined by the evolution of final electricity demand. Total installed capacity is lower by 350 MW in 2030 in the scenario with lower demand (SC2), compared to the other scenarios that assume a higher demand, in line with the official forecast; the electricity demand in SC2 is based on an energy demand scenario that assumes a decoupling between economic growth and energy demand, and a more aggressive deployment of energy efficiency solutions.

In terms of generation technologies in which most investment will occur, solar PV at the utility-scale is the most competitive renewable option, as 433 MW are deployed by 2030 in SC1 and SC3. Storage options do not appear to be highly cost-effective: other than the committed CSP project with thermal storage, new installations of storage options occur only in SC4 to serve 138 MW of distributed solar PV. This scenario requires a higher deployment of renewables due to the LNG terminal.

One aspect that needs further assessment is the need for soft-linking of these results with further study, as per international best practice. The results from this long-term energy planning study will need to be evaluated in terms of implications on optimal electricity dispatching, and the threshold for maximum penetration of variable renewables need to be set by a dynamic stability analysis of the Cyprus power grid (currently based on a provisional study, will be revised by a detailed grid study from JRC). Similarly, the possible need for energy storage under each scenario has not been examined from the operational and technical point of view, but rather from an economics perspective. Additionally, 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. A separate grid analysis is required to assess the technical feasibility of high penetration of renewables and suggest the most cost effective manner to integrate them (e.g. through grid strengthening, storage, smart grids, advanced controls, forecasting techniques, interconnection and any combination of these). As the model used for the definition of electricity supply scenarios has been handed over to the government of Cyprus, it is envisioned that an update of the model can be done on a regular basis by the government, whenever new information from other studies become available, or new policies are considered.

Once indigenous natural gas will become available, Cyprus will be shifting from mostly imported oil -based power generation to fully domestic-based power generation, dominated by solar PV, wind and domestic natural gas, improving the trade balance, increasing energy security and significantly reducing cost of electricity supply. This study represents a contribution to expand the knowledge on the impact of energy policies on the electricity sector of Cyprus, and through six different scenarios defines a roadmap for a sustainable energy future for Cyprus.

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Appendices

Appendix I: Final energy consumption, 1990-2010, compared to demand forecasts

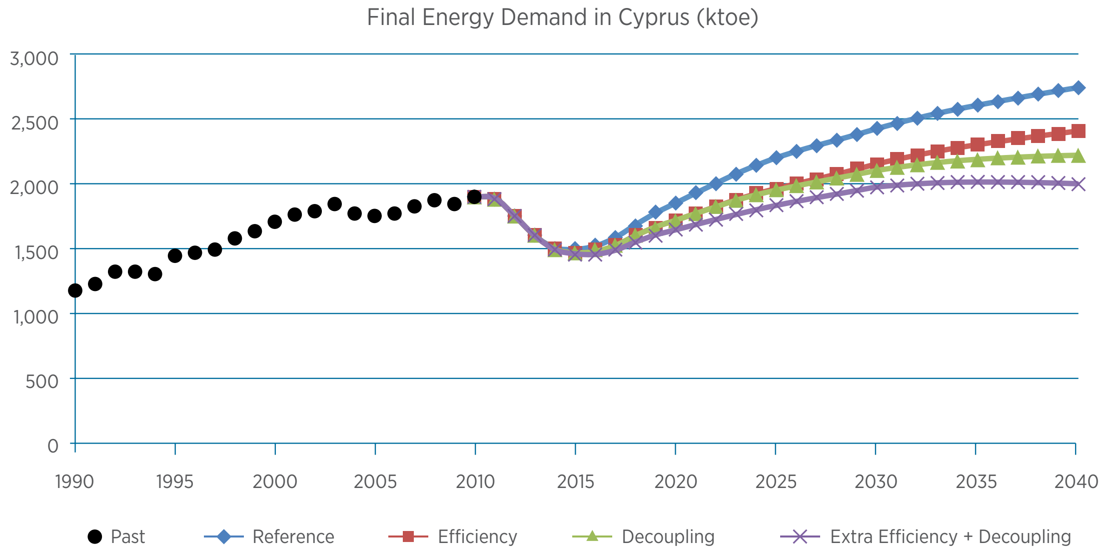
In the absence of official energy balances or comprehensive final energy demand statistics for most years of the past, there has been an attempt to construct such a time series in the frame of this study. The result is shown in this appendix. For electricity and most petroleum products, the figures shown here have to be considered as accurate. Furthermore, some estimates have been made about the contribution of solid fuels, biomass and biofuels. Based on the table with historical data shown in the next page, this appendix contains graphs comparing the scenario forecasts presented in Sections 2.5.1 and 2.5.2 of this report with historical data.

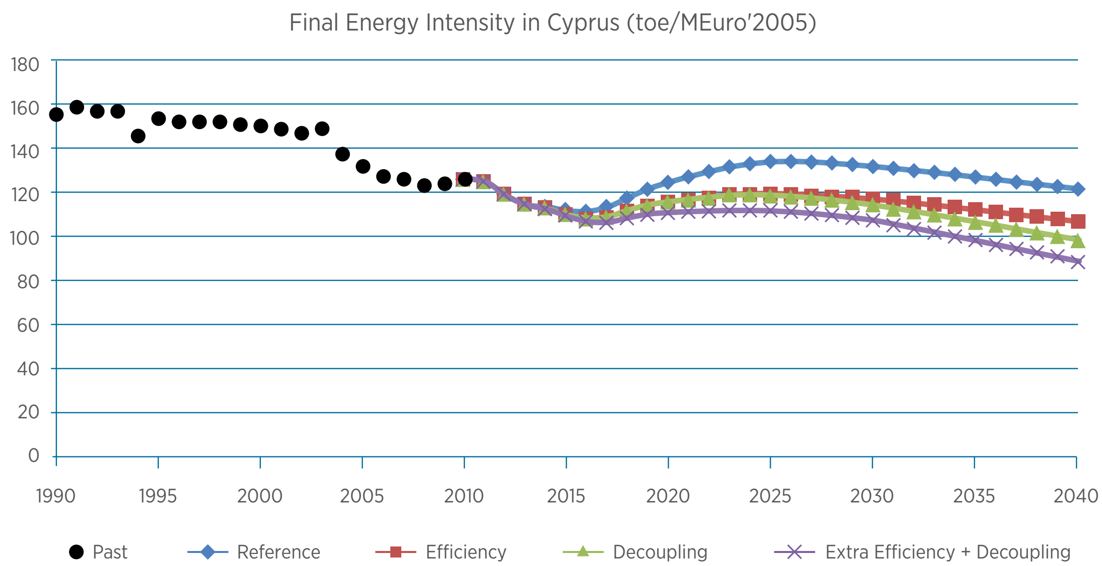
Historical Data, Cyprus, 1990-2010

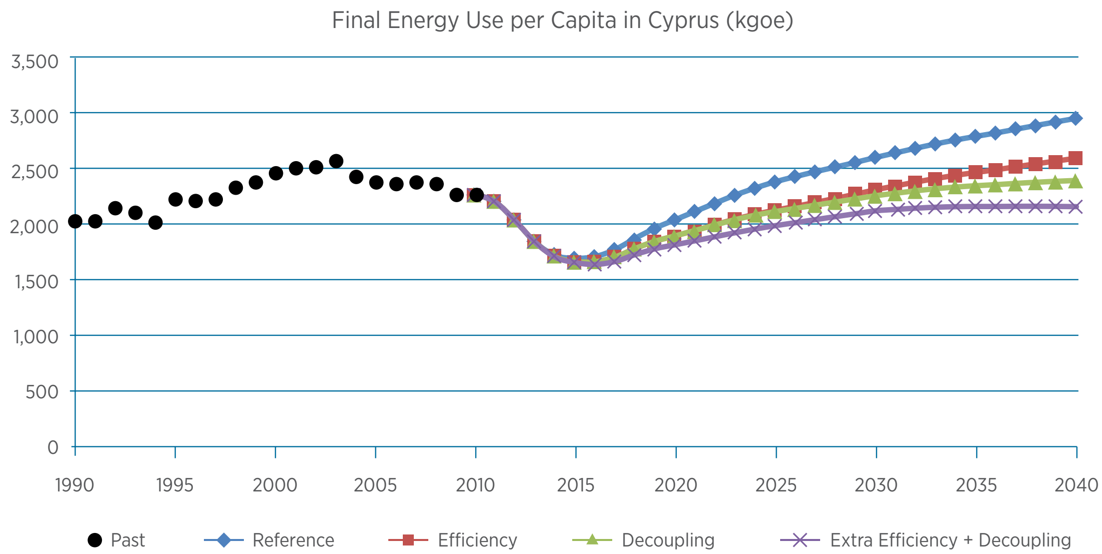
Final energy demand (ktoe)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Gasoline	171	169	181	183	187	192	196	201	206	213	217	230	241	273	296	318	339	370	392	403	410
Kerosene	12	12	17	17	15	17	18	20	21	20	24	24	29	31	24	16	16	16	14	19	14
Gas/Diesel oil	335	334	403	410	420	465	494	520	567	598	619	601	609	589	552	528	510	519	519	492	534
Light fuel oil	104	90	93	89	95	104	116	118	111	126	136	127	125	116	82	67	50	41	36	31	31
Fuel oil for cement industry	49	50	36	72	17	56	31	20	19	0	2	1	0	0	7	14	15	22	24	14	14
LPG	54	54	61	56	55	56	56	57	55	54	58	58	59	62	61	58	60	61	58	61	58
Aviation fuel*	242	288	279	237	243	267	256	252	265	271	275	322	310	332	303	299	308	295	294	272	277
Electricity	124	129	151	164	175	188	199	206	226	240	259	269	292	314	321	338	352	370	392	400	411
Solar**	34	34	34	34	34	35	35	35	35	35	36	36	36	37	38	39	40	53	56	58	61
Total	1125	1161	1254	1261	1241	1381	1400	1428	1505	1557	1626	1669	1701	1755	1684	1678	1690	1747	1784	1751	1810
Adjusted total	**1181**	**1219**	**1317**	**1324**	**1304**	**1450**	**1471**	**1500**	**1581**	**1635**	**1708**	**1753**	**1787**	**1843**	**1769**	**1762**	**1775**	**1834**	**1874**	**1839**	**1901**

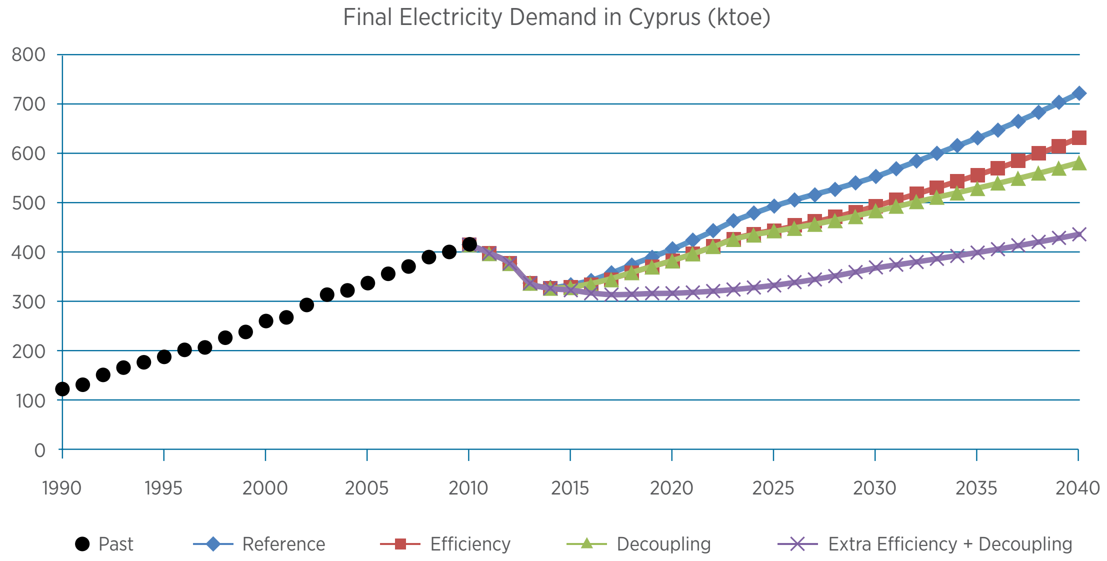
Energy system indicators	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
GDP (mio Euros'2005)	7650	7704	8428	8487	8988	9502	9674	9899	10392	10893	11439	11900	12153	12380	12904	13402	13955	14666	15192	14910	15106
Population (000)	587	603	619	633	645	656	666	675	683	691	698	706	714	723	733	744	758	776	797	819	840
Final energy intensity (toe/Meuro'2005)	154	158	156	156	145	153	152	152	152	150	149	147	147	149	137	131	127	125	123	123	126
Final electricity intensity (toe/Meuro'2005)	16	17	18	19	19	20	21	21	22	22	23	23	24	25	25	25	25	25	26	27	27
Final energy use per capita (kgoe)	2012	2022	2128	2093	2020	2210	2207	2221	2314	2368	2448	2485	2503	2550	2413	2368	2343	2363	2351	2245	2264
Final electricity use per capita (kWh)	2462	2492	2831	3020	3148	3323	3475	3541	3850	4034	4317	4429	4765	5057	5087	5283	5402	5536	5717	5684	5694

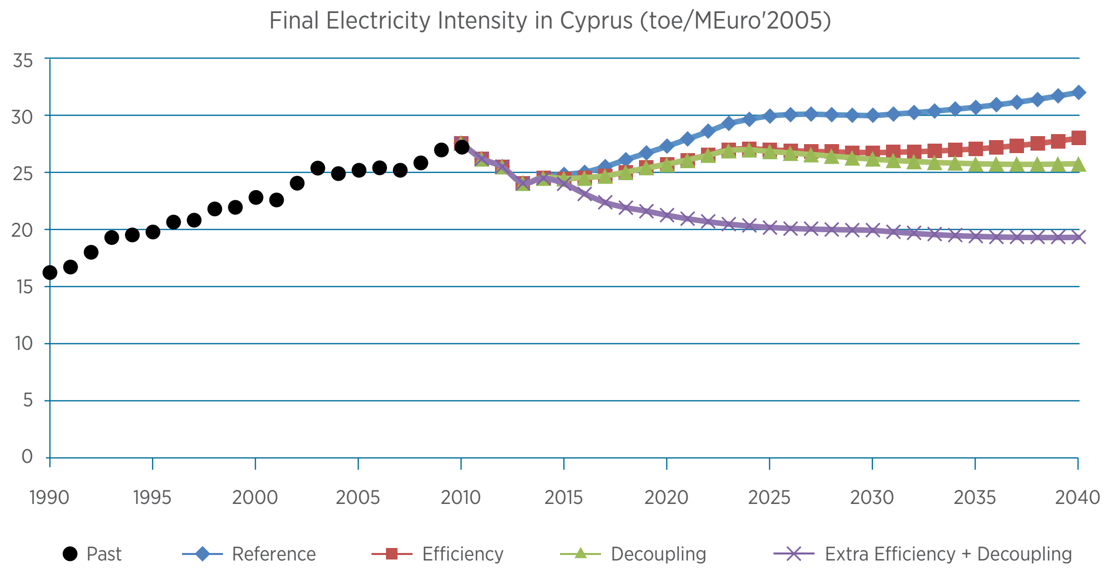
Source: Industrial statistics, Cyprus Statistical Service.
Adjustments were necessary in order to account for consumption of solid fuels, biomass and biofuels not reported in statistical publications
* Source: Eurostat data retrieved from Odyssee database
** Source: Odyssee database

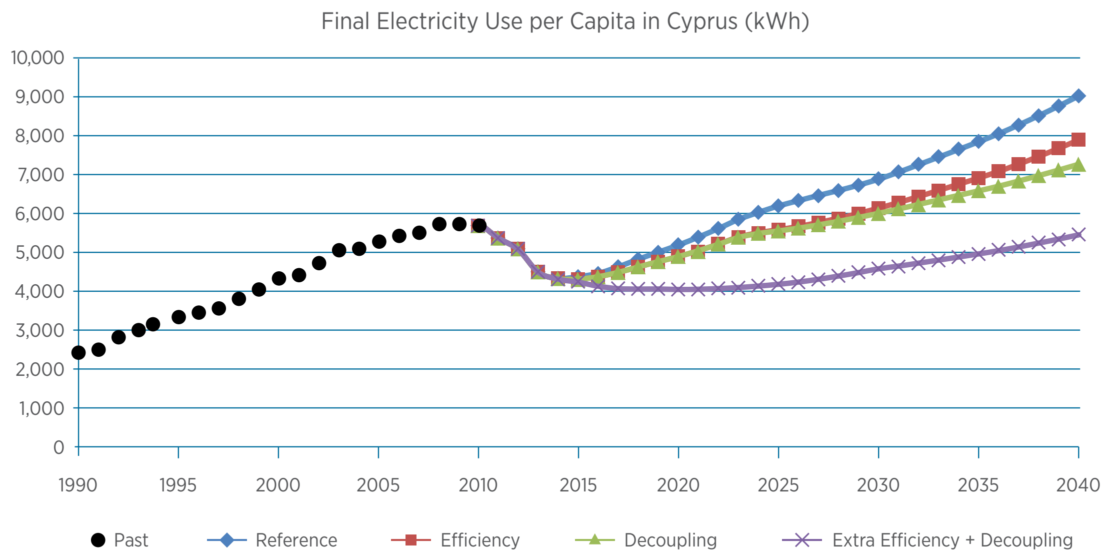

Final Energy Demand in Cyprus (ktoe)
3,000
2,500
2,000
1,500
1,000
500
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
Past
Reference
Efficiency
Decoupling
Extra Efficiency + Decoupling


Final Energy Intensity in Cyprus (toe/MEuro'2005)
180
160
140
120
100
80
60
40
20
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
Past
Reference
Efficiency
Decoupling
Extra Efficiency + Decoupling


Final Energy Use per Capita in Cyprus (kgoe)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
Past
Reference
Efficiency
Decoupling
Extra Efficiency + Decoupling


Final Electricity Demand in Cyprus (ktoe)
800
700
600
500
400
300
200
100
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
Past
Reference
Efficiency
Decoupling
Extra Efficiency + Decoupling


Final Electricity Intensity in Cyprus (toe/MEuro'2005)
35
30
25
20
15
10
5
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
Past
Reference
Efficiency
Decoupling
Extra Efficiency + Decoupling


Final Electricity Use per Capita in Cyprus (kWh)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
Past
Reference
Efficiency
Decoupling
Extra Efficiency + Decoupling

Appendix II: Energy balances of the Republic of Cyprus for years 2012 and 2013

Cyprus: Energy balance for the year 2012 in tonnes of oil equivalent	LPG	Unleaded 95 oct	Unleaded 98/100 oct	Aviation fuel	Kerosene	Automotive diesel	Biofuels	Gas oil S 0,1%	Marine gas oil	Light fuel oil	Heavy fuel oil S≤1%	Heavy fuel oil S>1%	Used oils	Bitumen	Lubricants	Pet-coke	Coal	Tyres and other fuels	Solar thermal	Geothermal	Biomass	Biogas	Solar PV	Wind	Electricity by EAC [includes RES generation fed to the Grid]	Electricity by cement plant	Electricity from autonomous biomass plants	Electricity from autonomous PV Systems	Electricity from autonomous wind power stations	Total Electricity	**Total**
Production of primary energy							586 4												644 77	147 7		122 88	180 6	159 11							101 824
Net imports	619 62	365 383	265 82	276 309	192 61	313 896	106 30	347 367	679 70	203 47	855 275	130 897		316 88	561 2	638 85															
Change in stocks	- 576	388	487	413 5	212 1	- 966	- 506	114 4	- 174 8	- 827	0	0		- 365	144																
Bunkers									697 18	0	0	122 294																			
Gross inland energy consumption	**625 37**	**364 995**	**260 95**	**272 175**	**171 40**	**314 862**	**170 01**	**346 223**	**0**	**211 75**	**855 275**	**860 3**	**0**	**320 53**	**546 7**	**638 85**	**0**	**0**	**644 77**	**147 7**	**154 80**	**122 88**	**180 6**	**159 11**	**0**	**0**	**0**	**0**	**0**	**0**	**252 003 3**
Transformation input						0	0	215 811	0	0	855 275	175 4	0	0	0	0	0	0	0	0	0	122 88	180 6	159 11	0	0	0	0	0	0	110 395 3
Power generation (EAC)	0	0	0	0	0	0	0	215 780	0	0	855 275	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	107 105 6
Power generation (cement plant)	0	0	0	0	0	0	0	30	0	0	0	175 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	289 2

(cont'd on next page)

Cyprus: Energy balance for the year 2012 in tonnes of oil equivalent (cont'd from previous page)	LPG	Unleaded 95 oct	Unleaded 98/100 oct	Aviation fuel	Kerosene	Automotive diesel	Biofuels	Gas oil S 0,1%	Marine gas oil	Light fuel oil	Heavy fuel oil S≤1%	Heavy fuel oil S>1%	Used oils	Bitumen	Lubricants	Pet-coke	Coal	Tyres and other fuels	Solar thermal	Geothermal	Biomass	Biogas	Solar PV	Wind	Electricity by EAC [includes RES generation fed to the Grid]	Electricity by cement plant	Electricity from autonomous biomass plants	Electricity from autonomous PV Systems	Electricity from autonomous wind power stations	Total Electricity	**Total**
Power generation (RES fed to the grid)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	924 6	170 5	159 11	0	0	0	0	0	0	**268 62**
Power generation (other RES)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	304 3	102	0	0	0	0	0	0	0	**314 4**
Transformation output	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	405 187	718	106 5	102	0	407 071	**407 071**
Consumption of energy branch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	138 61	41	0	0	0	139 01	**139 01**
Transmission & distribution losses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	130 70	0	0	0	0	130 70	**130 70**
Non energy use	0	0	0	0	0	0	0	0	0	0	0	0	0	320 53	546 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**375 20**
Consumption of occupied areas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	561	0	0	0	0	561	**561**
Final energy consumption	**625 37**	**364 995**	**260 95**	**272 175**	**171 40**	**314 862**	**170 01**	**130 412**	**0**	**211 75**	**0**	**684 8**	**0**	**0**	**0**	**638 85**	**0**	**0**	**644 77**	**147 7**	**154 80**	**0**	**0**	**0**	**377 696**	**677**	**106 5**	**102**	**0**	**379 539**	**175 809 9**
Industry, of which:	784 3	10	0	0	16	553 0	0	101 16	0	152 39	0	684 8	0	0	0	638 85	0	0	0	0	322 0	0	0	0	543 28	677	0	0	0	550 05	**167 712**
Mining and quarrying	0	1	0	0	0	351 4	0	185 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	227 0	0	0	0	0	227 0	**764 2**
Water supply	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	140 86	0	0	0	0	140 86	**140 88**

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Cyprus: Energy balance for the year 2012 in tonnes of oil equivalent (cont'd from previous page) ↓	LPG	Unleaded 95 oct	Unleaded 98/100 oct	Aviation fuel	Kerosene	Automotive diesel	Biofuels	Gas oil S 0,1%	Marine gas oil	Light fuel oil	Heavy fuel oil S≤1%	Heavy fuel oil S>1%	Used oils	Bitumen	Lubricants	Pet-coke	Coal	Tyres and other fuels	Solar thermal	Geothermal	Biomass	Biogas	Solar PV	Wind	Electricity by EAC [includes RES generation fed to the Grid]	Electricity by cement plant	Electricity from autonomous biomass plants	Electricity from autonomous PV Systems	Electricity from autonomous wind power stations	Total Electricity	**Total**
Food, beverages and tobacco	5067	0	0	0	15	251	0	3336	0	9532	0	0	0	0	0	0	0	0	0	0	55	0	0	0	15522	0	0	0	0	15522	**33779**
Textiles	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	534	0	0	0	0	534	**543**
Leather	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Wood	3	0	0	0	0	25	0	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	574	0	0	0	0	574	**672**
Paper and pulp	260	0	0	0	0	6	0	190	0	464	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1655	0	0	0	0	1655	**2576**
Refined petroleum products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3002	0	0	0	0	3002	**3002**
Chemicals	158	0	0	0	0	178	0	1506	0	338	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2180**
Plastic products	155	0	0	0	0	23	0	61	0	716	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2280	0	0	0	0	2280	**3235**
Non-metallic minerals, *of which:*	1476	0	0	0	0	1452	0	1670	0	4160	0	6848	0	0	0	63885	0	0	0	0	3165	0	0	0	9989	677	0	0	0	10666	**93323**
Cement industry	1146	0	0	0	0	0	0	77	0	0	0	326	0	0	0	63885	0	0	0	0	3165	0	0	0	8002	677	0	0	0	8679	**77278**
Basic metals	673	8	0	0	0	53	0	1299	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1725	0	0	0	0	1725	**3787**
Machinery and equipment	30	0	0	0	1	10	0	107	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	384	0	0	0	0	384	**532**
Electrical & optical equipment	20	0	0	0	0	5	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68	0	0	0	0	68	**98**

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Cyprus: Energy balance for the year 2012 in tonnes of oil equivalent (cont'd from previous page)	LPG	Unleaded 95 oct	Unleaded 98/100 oct	Aviation fuel	Kerosene	Automotive diesel	Biofuels	Gas oil S 0,1%	Marine gas oil	Light fuel oil	Heavy fuel oil S≤1%	Heavy fuel oil S>1%	Used oils	Bitumen	Lubricants	Pet-coke	Coal	Tyres and other fuels	Solar thermal	Geothermal	Biomass	Biogas	Solar PV	Wind	Electricity by EAC [includes RES generation fed to the Grid]	Electricity by cement plant	Electricity from autonomous biomass plants	Electricity from autonomous PV Systems	Electricity from autonomous wind power stations	Total Electricity	**Total**
Transport equipment	0	0	0	0	0	4	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	145	0	0	0	0	145	161
Other industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2094	0	0	0	0	2094	2094
Transport, *of which:*	0	364985	26095	272175	0	309332	17001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	989588
Road transport	0	364985	26095	0	0	309332	17001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	717414
Air transport	0	0	0	272175	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	272175
Households	41151	0	0	0	15630	0	0	63430	0	0	0	0	0	0	0	0	0	0	54805	1475	5750	0	0	0	143688	0	0	102	0	143790	326032
Agriculture	230	0	0	0	0	0	0	24886	0	0	0	0	0	0	0	0	0	0	0	0	4317	0	0	0	11057	0	1065	0	0	12122	41555
Services, *of which:*	13314	0	0	0	1989	0	0	26756	0	2844	0	0	0	0	0	0	0	0	9672	2	2351	0	0	0	165442	0	0	46	37	165525	222451
Hotels	268							3254											614	4										8801	12941

Cyprus: Energy balance for the year 2013 in tonnes of oil equivalent	LPG	Unleaded 95 oct	Unleaded 98/100 oct	Aviation fuel	Kerosene	Automotive diesel	Biofuels	Gas oil S 0,1%	Marine gas oil	Light fuel oil	Heavy fuel oil S≤1%	Heavy fuel oil S>1%	Used oils	Bitumen	Lubricants	Pet-coke	Coal	Tyres and other fuels	Solar thermal	Geothermal	Biomass	Biogas	Solar PV	Wind	Electricity by EAC [include RES generation fed to the Grid]	Electricity by cement plant	Electricity from autonomous biomass plants	Electricity from autonomous PV Systems	Electricity from autonomous wind power stations	Total Electricity	**Total**
Production of primary energy							5864												65539	1477		11845	4047	19866							108638
Net imports	58477	347245	21156	238096	12368	271345	14777	349011	84712	19741	620098	158584		15610	4444	91148															
Change in stocks	2028	883	603	-5087	612	3274	-5728	811	923	1733	0	0		-3167	117																
Bunkers									83789	0	0	149982																			
Gross inland energy consumption	**56449**	**346362**	**20552**	**243182**	**11756**	**268071**	**14913**	**348200**	**0**	**18008**	**620098**	**8603**	**0**	**18777**	**4327**	**91148**	**0**	**0**	**65539**	**1477**	**6289**	**11845**	**4047**	**19866**	**0**	**0**	**0**	**0**	**0**	**0**	**2179510**
Transformation input						0	0	238123	0	0	620098	2010	0	0	0	0	0	0	0	0	0	11845	4047	19866	0	0	0	0	0	0	895989
Power generation (EAC)	0	0	0	0	0	0	0	238110	0	0	620098	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	858207
Power generation (cement plant)	0	0	0	0	0	0	0	13	0	0	0	2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2023
Power generation (RES fed to the grid)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8802	3896	19829	0	0	0	0	0	0	32527
Power generation (other RES)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3043	151	37	0	0	0	0	0	0	3231

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Cyprus: Energy balance for the year 2013 in tonnes of oil equivalent (cont'd from previous page)	LPG	Unleaded 95 oct	Unleaded 98/100 oct	Aviation fuel	Kerosene	Automotive diesel	Biofuels	Gas oil S 0,1%	Marine gas oil	Light fuel oil	Heavy fuel oil S≤1%	Heavy fuel oil S>1%	Used oils	Bitumen	Lubricants	Pet-coke	Coal	Tyres and other fuels	Solar thermal	Geothermal	Biomass	Biogas	Solar PV	Wind	Electricity by EAC [include RES generation fed to the Grid]	Electricity by cement plant	Electricity from autonomous biomass plants	Electricity from autonomous PV Systems	Electricity from autonomous wind power stations	Total Electricity	**Total**
Transformation output	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	365697	694	1065	151	37	367645	**367645**
Consumption of energy branch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14674	39	0	0	0	14713	**14713**
Transmission & distribution losses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16562	0	0	0	0	16562	**16562**
Non energy use	0	0	0	0	0	0	0	0	0	0	0	0	0	18777	4327	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**23104**
Consumption of occupied areas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Final energy consumption	**56449**	**346362**	**20552**	**243182**	**11756**	**268071**	**14913**	**110077**	**0**	**18008**	**0**	**6592**	**0**	**0**	**0**	**91148**	**0**	**0**	**65539**	**1477**	**6289**	**0**	**0**	**0**	**334462**	**655**	**1065**	**151**	**37**	**336370**	**1596787**
Industry, *of which:*	4781	10	0	0	16	5530	0	8080	0	12120	0	6592	0	0	0	91148	0	0	0	0	580	0	0	0	50031	655	0	0	0	50686	**179543**
Mining and quarrying	0	1	0	0	0	3514	0	1484	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2090	0	0	0	0	2090	**7089**
Water supply	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12972	0	0	0	0	12972	**12974**
Food, beverages and tobacco	3088	0	0	0	15	251	0	2665	0	7582	0	0	0	0	0	0	0	0	0	0	55	0	0	0	14295	0	0	0	0	14295	**27951**
Textiles	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	492	0	0	0	0	492	**501**

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Cyprus: Energy balance for the year 2013 in tonnes of oil equivalent (cont'd from previous page)	LPG	Unleaded 95 oct	Unleaded 98/100 oct	Aviation fuel	Kerosene	Automotive diesel	Biofuels	Gas oil S 0,1%	Marine gas oil	Light fuel oil	Heavy fuel oil S≤1%	Heavy fuel oil S>1%	Used oils	Bitumen	Lubricants	Pet-coke	Coal	Tyres and other fuels	Solar thermal	Geothermal	Biomass	Biogas	Solar PV	Wind	Electricity by EAC [include RES generation fed to the Grid]	Electricity by cement plant	Electricity from autonomous biomass plants	Electricity from autonomous PV Systems	Electricity from autonomous wind power stations	Total Electricity	**Total**
Leather	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Wood	2	0	0	0	0	25	0	56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	528	0	0	0	0	528	**611**
Paper and pulp	159	0	0	0	0	6	0	152	0	369	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1524	0	0	0	0	1524	**2211**
Refined petroleum products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2764	0	0	0	0	2764	**2764**
Chemicals	96	0	0	0	0	178	0	1203	0	269	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1746**
Plastic products	95	0	0	0	0	23	0	48	0	569	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2100	0	0	0	0	2100	**2835**
Non-metallic minerals, *of which:*	900	0	0	0	0	1452	0	1334	0	3308	0	6592	0	0	0	9148	0	0	0	0	525	0	0	0	10318	655	0	0	0	10973	**116233**
Cement industry	857	0	0	0	0	0	0	0	0	100	0	440	0	0	0	9148	0	0	0	0	525	0	0	0	9604	655	0	0	0	10259	**103330**
Basic metals	410	8	0	0	0	53	0	1038	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1589	0	0	0	0	1589	**3120**
Machinery and equip-ment	18	0	0	0	1	10	0	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	354	0	0	0	0	354	**468**
Electrical & optical equip-ment	12	0	0	0	0	5	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63	0	0	0	0	63	**84**
Transport equipment	0	0	0	0	0	4	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	133	0	0	0	0	133	**147**
Other industry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	809	0	0	0	0	809	**809**

(cont'd on next page)

Cyprus: Energy balance for the year 2013 in tonnes of oil equivalent (cont'd from previous page)	LPG	Unleaded 95 oct	Unleaded 98/100 oct	Aviation fuel	Kerosene	Automotive diesel	Biofuels	Gas oil S 0,1%	Marine gas oil	Light fuel oil	Heavy fuel oil S≤1%	Heavy fuel oil S>1%	Used oils	Bitumen	Lubricants	Pet-coke	Coal	Tyres and other fuels	Solar thermal	Geothermal	Biomass	Biogas	Solar PV	Wind	Electricity by EAC [include RES generation fed to the Grid]	Electricity by cement plant	Electricity from autonomous biomass plants	Electricity from autonomous PV Systems	Electricity from autonomous wind power stations	Total Electricity	**Total**
Transport, *of which:*	0	346352	20552	243182	0	262541	14913	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	887541
Road transport	0	346352	20552	0	0	262541	14913	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	644359
Air transport	0	0	0	243182	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	243182
Households	38924	0	0	0	9859	0	0	52665	0	0	0	0	0	0	0	0	0	0	55868	1475	3226	0	0	0	123419	0	0	12	0	123431	285447
Agriculture	151	0	0	0	0	0	0	24024	0	0	0	0	0	0	0	0	0	0	0	0	210	0	0	0	111103	0	1065	0	0	12168	365553
Services, *of which:*	12593	0	0	0	1882	0	0	25308	0	5888	0	0	0	0	0	0	0	0	9672	2	2273	0	0	0	149920	0	0	140	37	150097	207715
Hotels	268							3254											614	4										8801	12941

Table III.1 – Final electricity demand in the energy efficiency scenario (Zachariadis *et al.* 2014).

Final electricity demand by sector (GWh)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Freight transport	0	0	1	1	2	4	5	7	8	11	13	16	20	24
Road passenger transport	0	1	2	4	7	13	20	27	36	46	59	73	89	107
Cement industry	119	116	114	110	108	107	107	107	109	111	114	115	115	116
Other industries	470	432	417	413	422	436	453	468	484	501	519	530	537	545
Households	1,436	1,378	1,374	1,406	1,441	1,474	1,507	1,545	1,592	1,644	1,701	1,735	1,758	1,784
Services	1,746	1,733	1,774	1,830	1,901	1,988	2,071	2,144	2,224	2,307	2,393	2,447	2,485	2,523
Agriculture	142	137	135	134	135	138	141	143	145	148	150	151	151	151
Total	3,912	3,797	3,816	3,899	4,016	4,160	4,302	4,440	4,600	4,767	4,949	5,067	5,155	5,249
Final electricity demand by sector (GWh)	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Freight transport	30	36	43	52	63	76	91	108	129	152	179	209	244	282
Road passenger transport	128	152	180	213	250	291	338	390	448	513	583	660	744	834
Cement industry	117	118	119	121	122	123	124	126	127	128	129	130	131	132
Other industries	552	560	568	577	584	590	596	601	605	609	613	617	620	624
Households	1,812	1,844	1,877	1,913	1,953	1,990	2,026	2,059	2,089	2,119	2,149	2,180	2,209	2,239
Services	2,561	2,603	2,647	2,693	2,740	2,785	2,827	2,866	2,903	2,938	2,972	3,004	3,036	3,066
Agriculture	151	151	151	150	151	152	152	152	152	152	151	151	150	149
Total	5,351	5,463	5,586	5,721	5,863	6,007	6,154	6,302	6,453	6,610	6,776	6,951	7,134	7,326

Table III.2 – Final electricity demand in the extra efficiency scenario (Zachariadis *et al.* 2014).

Final electricity demand by sector (GWh)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Freight transport	0	0	1	1	2	4	5	7	8	11	13	16	20	24
Road passenger transport	0	1	2	4	7	13	20	27	36	46	58	72	88	106
Cement industry	119	116	112	105	98	94	90	87	85	84	83	82	82	82
Other industries	470	432	411	392	383	382	385	386	388	391	394	398	402	406
Households	1,436	1,386	1,363	1,342	1,326	1,319	1,314	1,307	1,306	1,309	1,316	1,327	1,342	1,362
Services	1,746	1,713	1,722	1,706	1,698	1,710	1,729	1,736	1,748	1,760	1,774	1,790	1,808	1,828
Agriculture	142	137	133	128	125	123	122	121	120	119	118	118	117	117
Total	3,912	3,785	3,745	3,677	3,639	3,646	3,665	3,670	3,692	3,720	3,757	3,803	3,858	3,923
Final electricity demand by sector (GWh)	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Freight transport	29	35	43	51	61	72	85	100	118	138	160	186	214	245
Road passenger transport	126	149	176	206	238	274	314	359	407	460	517	579	644	714
Cement industry	82	82	83	83	83	84	84	84	84	84	84	84	84	84
Other industries	410	415	420	426	428	429	430	430	430	430	430	429	428	427
Households	1,385	1,411	1,438	1,467	1,480	1,492	1,503	1,511	1,519	1,525	1,530	1,533	1,536	1,537
Services	1,848	1,871	1,894	1,917	1,931	1,942	1,951	1,956	1,959	1,960	1,959	1,956	1,952	1,946
Agriculture	116	116	115	115	115	114	114	113	112	111	110	108	107	105
Total	3,996	4,079	4,168	4,265	4,336	4,408	4,480	4,554	4,629	4,707	4,789	4,875	4,965	5,058

Appendix IV: Detailed power plant assumptions for future projects

Table IV.1 – Plant cost and performance parameters for future projects.

Technology type	Input fuel	Efficiency	Variable operation and maintenance cost (EUR /MWh)	Fixed operation and maintenance cost (EUR/kW)	2013 Inv Cost (EUR /kW)	Capacity factor	First year	Construction time (years)	Plant life (years)
Combined cycle	Gas	47.50%		33.1	828	86.02%	2019	3	30
Gas turbine	Diesel/Gas	44.00%		27.1	677	82.80%	2019	2	30
Steam turbine	HFO or Low-S FO	38.46%		27.1	1,016	80.10%	2019	2	30
Wind			14.3		1,310	16.00%	2015	1	25
Biomass		32.00%		75.3	2,800	48.50%	2015	2	25
Solar PV utility			15.1		1,332	18.50%	2015	1	25
Solar PV rooftop			11.3		1,665	18.50%	2014	<1	20
CSP w/ storage			21.8		6,200	39.25%	2017	2	25

Table IV.2 – Renewable energy technology investment cost projections.

EUR/kW

	2013	2014	2015	2016	2017	2018	2019	2020	2021
Wind	1,417	1,389	1,361	1,334	1,307	1,281	1,255	1,230	1,205
Biogas-biomass	2,800	2,748	2,695	2,643	2,590	2,537	2,485	2,432	2,406
Solar PV utility	1,332	1,279	1,253	1,228	1,203	1,179	1,156	1,138	1,121
PV rooftop	1,665	1,598	1,566	1,535	1,504	1,474	1,445	1,423	1,402
CSP w/ storage	6,200	6,009	5,818	5,679	5,541	5,403	5,264	5,126	5,032
	2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Wind	1,181	1,158	1,135	1,112	1,090	1,068	1,046	1,026	1,020
Biogas-biomass	2,380	2,353	2,327	2,301	2,275	2,248	2,222	2,196	2,169
Solar PV utility	1,105	1,088	1,072	1,056	1,040	1,024	1,009	994	984
PV rooftop	1,381	1,360	1,340	1,320	1,300	1,280	1,261	1,242	1,230
CSP w/ storage	4,938	4,844	4,751	4,657	4,563	4,469	4,376	4,282	4,188

Appendix V: Annualised cost of electricity in each scenario

Figure V.1: Power system costs and annualised cost of electricity consumed in SC1

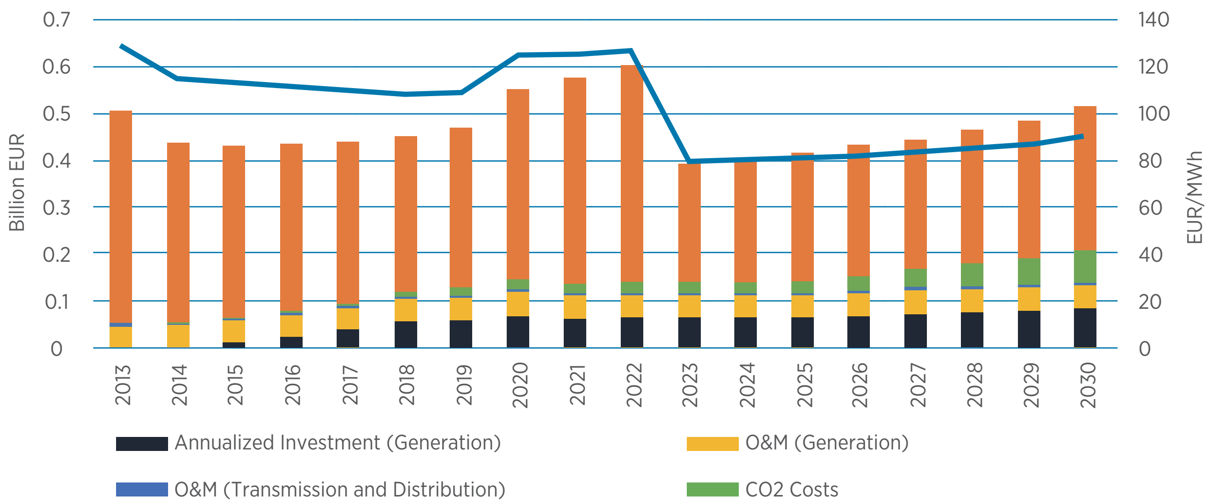


Figure V.2: Power system costs and annualised cost of electricity consumed in SC2

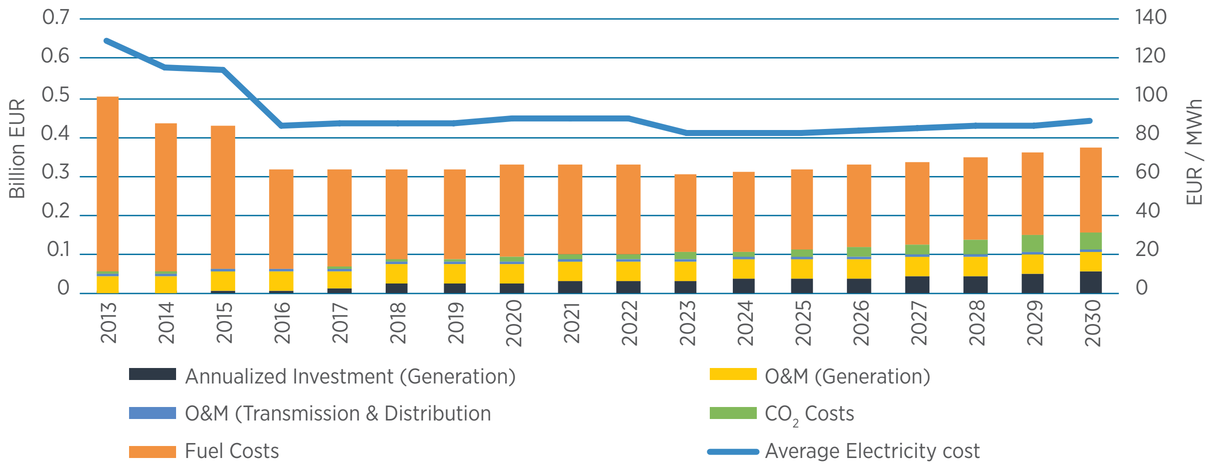


Figure V.3: Power system costs and annualised cost of electricity consumed in SC3

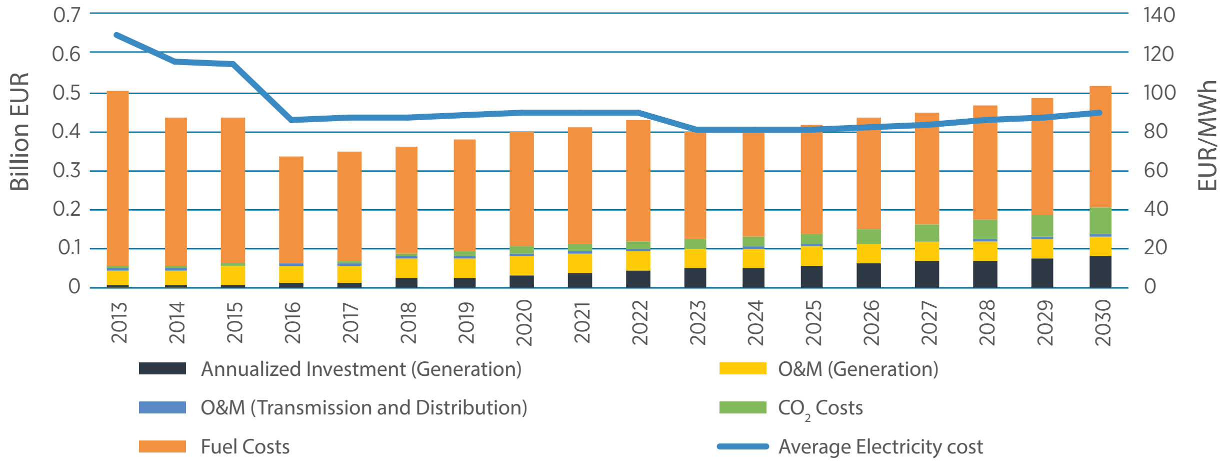


Figure V.4: Power system costs and annualised cost of electricity consumed in SC4

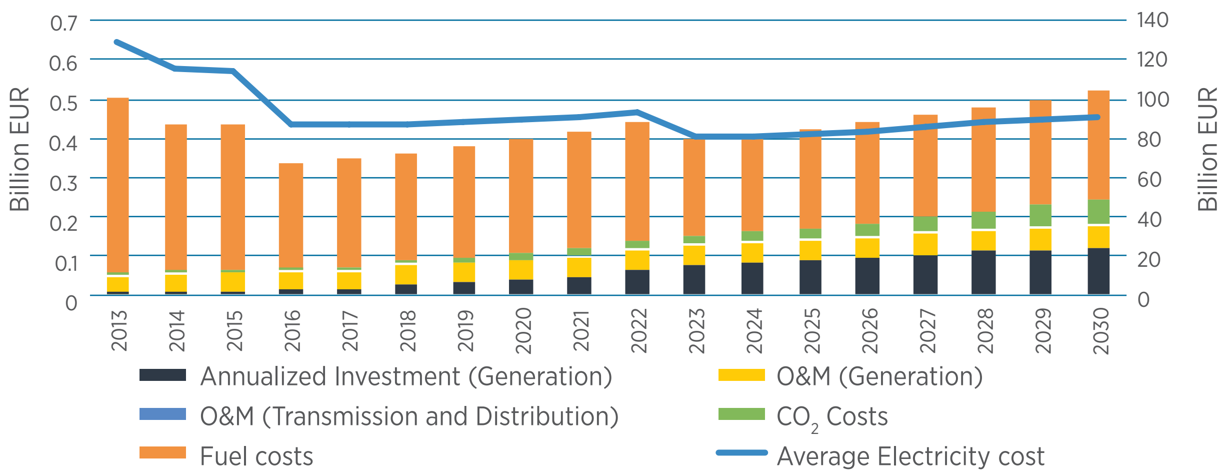


Figure V.5: Power system costs and annualised cost of electricity consumed in SC5

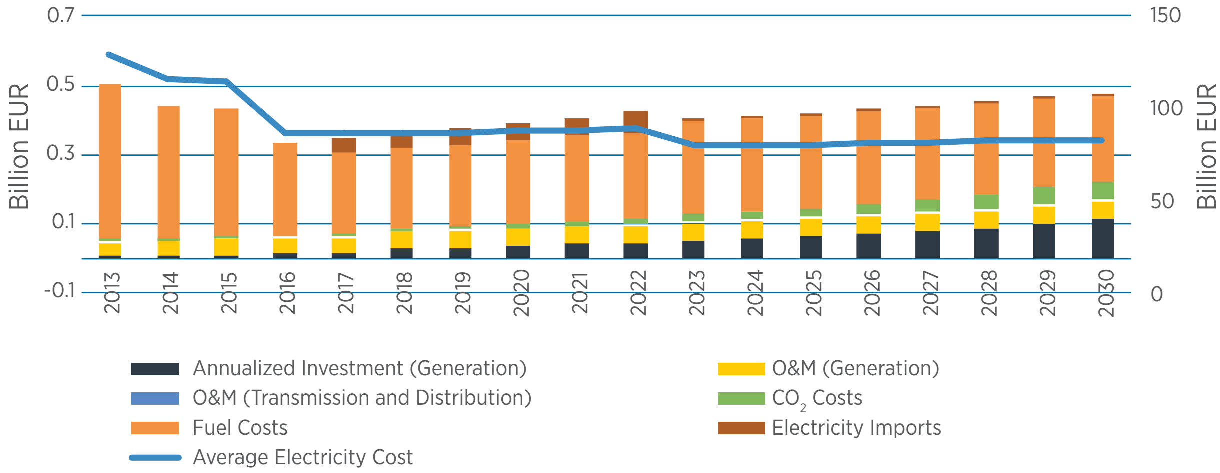
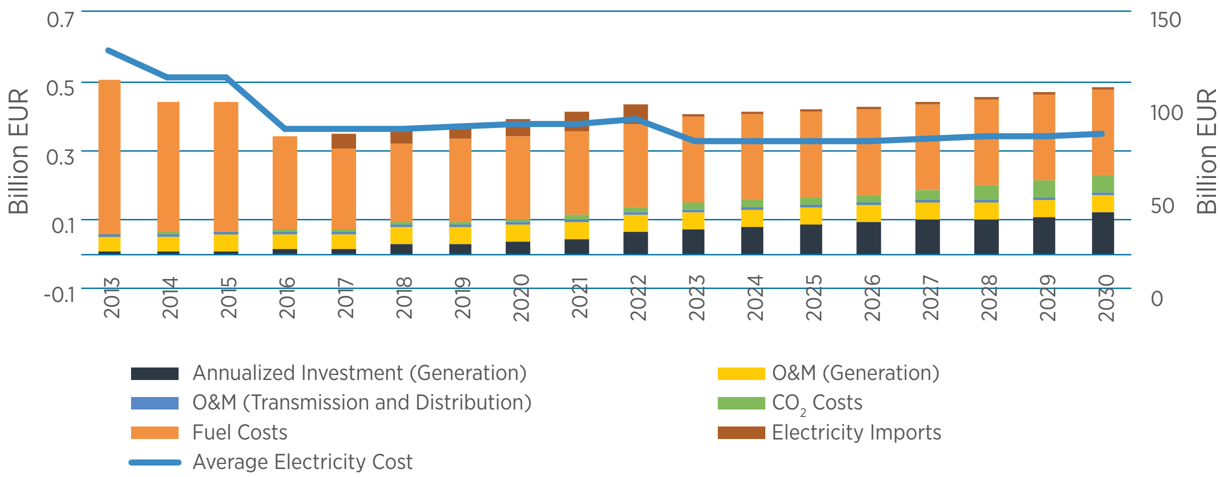


Figure V.6: Power system costs and annualised cost of electricity consumed in SC6



Appendix VI: Cost of generating electricity

Table VI.1 – Short-run marginal cost for existing plants (underlined) and long-term marginal cost for future generation options, for all technology-fuel combinations

	2013	2015	2020	2025	2030
	EUR/MWh	EUR/MWh	EUR/MWh	EUR/MWh	EUR/MWh
Vasilikos CCGT (diesel)	125.0	126.1	128.8	132.1	137.6
Vasilikos ST (HFO)	107.5	108.4	110.8	113.6	118.3
Vasilikos GT (diesel)	255.6	257.9	263.6	270.5	281.9
Vasilikos CCGT (indigenous gas)	N/A	N/A	N/A	69.3	70.9
Vasilikos ST (indigenous gas)	N/A	N/A	N/A	84.0	86.0
Vasilikos GT (indigenous gas)	N/A	N/A	N/A	139.3	142.7
Vasilikos CCGT (Interim Gas Solution)	N/A	N/A	78.0	N/A	N/A
Vasilikos ST (Interim Gas Solution)	N/A	N/A	94.8	N/A	N/A
Vasilikos GT (Interim Gas Solution)	N/A	N/A	157.5	N/A	N/A
Dhekelia ST (HFO)	143.0	144.3	147.5	151.3	157.6
Dhekelia ICE (HFO)	101.8	102.7	104.9	107.6	112.0
Dhekelia ST (Low-S FO)	N/A	N/A	199.9	205.1	213.7
Dhekelia ICE (Low-S FO)	N/A	N/A	141.8	145.4	151.5
Moni GT (diesel)	255.6	257.9	263.6	270.5	281.9
New Gas CCGT (indigenous gas)	N/A	N/A	N/A	77.8	79.4
New Gas GT (indigenous gas)	N/A	N/A	N/A	90.9	92.9
New Gas CCGT (Interim Gas Solution)	N/A	N/A	94.5	N/A	N/A
New Gas GT (Interim Gas Solution)	N/A	N/A	111.6	N/A	N/A
New Low-S FO ST	145.0	159.2	162.4	166.3	172.9
Trans. PV	79.4	75.6	70.1	66.1	62.6
Wind	93.4	90.3	83.0	76.4	71.3
CSP w/ storage	160.4	151.4	135.2	124.2	113.2
Biomass-biogas	77.3	75.2	69.9	65.6	63.0
Dist. PV	100.8	95.5	87.8	82.3	77.4

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