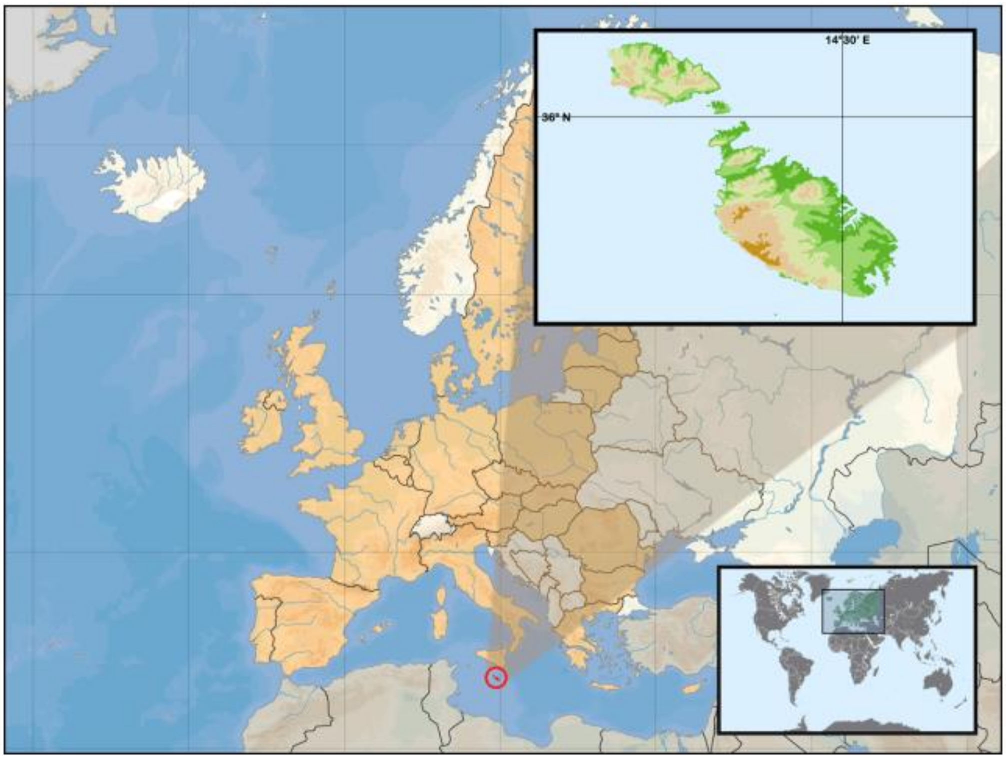
# Modelling Malta's Energy System towards Sustainability

A path to

- EU Guideline Compliance
- Cost Efficiency
- and System Stability



Sustainable Energy planning and Management

Master thesis: Modelling Malta's Energy System towards Sustainability

Project period: 01.02.2014 – 03.06.2014

Supervisor: **Associate Professor David Connolly**


**ABSTRACT**

This project aims at investigating how the Maltese energy system could move towards more sustainability in order to comply with the European targets for 2020, while maintaining system stability and being cost effective.

The results in this project point out that sufficient renewable energy source [RES] potential is prevalent on Malta in order to install sufficient RES technology capacity to reach the assigned country's specific 10 % RES share on final energy consumption within the 2020 EU target guideline. Despite the currently backlogged development of RES technologies in the Maltese energy system and despite severe land utilisation conflicts in relation with the deployment of RES, a first step towards a decarbonisation of the Maltese energy sector is possible and is rather a political issue than a technical or economic problem.

The major role for a transformation of Malta's energy system would lie in the use of solar water heaters and heat pumps, which would have almost no impact in regards of the land consumption issue and on the energy system's stability. Both options imply positive economic, environmental and system stabilizing effects for Malta's energy system. The installation of PV technology, which would have the highest theoretic potential among all considered technologies in this project, is strongly restrained through Malta's geography and its energy system design. However, PV technology is also a viable solution when deployed in bounds according to a limitation of excess energy production. A major improvement for Malta's energy system would be the introduction of e-mobility, which would have a positive impact on the use of PV panels as well.

All the considered measures in this project, the technically maximal deployment of SWHs and HPs as well as a PV share of nearly 30 % within power production would allow increasing the RES share on final energy consumption from the current few percentage points to 20 % in 2030 without causing extra costs or system instability.



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# Preface

Although the project refers to a country strictly related to the British world, commas are chosen as decimal mark, while thousands are separated by dots. The energy unit is TWh in output and GJ or TWh in input. Volumes are referred to in cubic meters. Conversions from values in Btu, ktoe and cubic feet are operated. Installed capacity is expressed in MW. All prices in the project are reported in € and when the sources presented values in USD, the conversion factor used was 1,3.

Since the authors used TWh in the modelling software EnergyPLAN, most of the numbers referring to energy quantities within the project are indicated in TWh as well. In most of the figures, energy quantities are indicated with three decimals, which seems rather dainty considering the lack of data to calculate precise numbers. However, the energy system on Malta is so small and minor differences in numbers expressed in TWh can already make a difference, which would be lost when too much rounding is applied. Nevertheless, the authors will at least round most of the numbers to two decimals within the text to make comprehension smoother to the reader.

This study has been supported also by documents and informal information provided by relevant stakeholders, therefore the sources are not always publicly available.

Despite cooperation with official institutions, this study has been conducted in a context of lack of data. Hence, numerous assumptions and approximations had to be made. A detailed methodology is provided in most of the chapters to justify assumptions to some extent. Nevertheless, the authors don´t take responsibility for the correctness of the provided results, in particular concerning the heating and cooling sector and the specific destination of electricity.

# List of abbreviations

| | |
|---|---|
| CEEP | Critical Excess Energy Production |
| CHP | Combined heat and power |
| EEEP | Exportable Excess Energy Production |
| EVs | Electric Vehicles |
| EU | European Union |
| FiT | Feed in Tariffs |
| G2V | Grid to vehicle |
| GSA | Gas supply agreement |
| GWh | Gigawatt hour |
| HP | Heat Pumps |
| IGA | Intergovernmental agreement |
| KWh | Kilowatt hour |
| LNG | Liquefied Natural Gas |
| LPG | Liquefied Petroleum Gas |
| MS | Member State |
| MWh | Megawatt hour |
| PPA | Power Purchase Agreement |
| PV | Photovoltaic |
| RES | Renewable Energy Sources |
| SWH | Solar Water Heaters |
| TWh | Terawatt hour |
| V2H | Vehicle to Grid |

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# 1. Introduction

Malta is the EU Member State characterized by the smallest area, the smallest population and the highest population density of the whole European Union. Malta is stretched on five Islands located in the central Mediterranean Sea. The archipelago is located around the 36$^{th}$ latitude, 81 km south of Sicily and 350 km north of Algeria's harbor city Al Khums. Its overall land area embraces 316 $m^2$. Only the main Island Malta (246 $m^2$) and the two Islands Gozo and Comino in the northwest are populated. The main Island stretches about 30 km from the northwest to the southeast and roughly 15 km from west to the east. Gozo' s dimensions are about half of the main Island's dimension. Malta's overall population amounts to 425.384 (2013) inhabitants[1], which equals a population density of 1.346 inhabitants per square kilometer. Denmark has about 130, and the Netherlands about 400 inhabitants per square kilometer.[2]

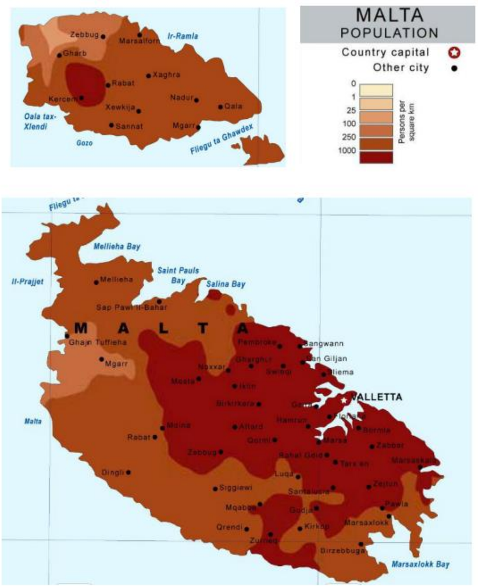



*Figure 1: Distribution of Malta's population [3]*

Additionally the country is highly penetrated by tourism (1,7 million and almost half a million cruise line tourists in 2014)[4], with 37 % of the tourists visiting Malta in the third quarter of the year. As a result, land area is very scarce and intense competition in utilization of the latter exists. This factor requires the system to be relatively flexible and oversized in its facilities and services for most of the year.

In terms of energy system, the Maltese archipelago has been a fully isolated system and has been completely dependent on the import of fossil fuels until now, since no domestic fossil resources are available and no relevant alternative resources are tapped yet. In fact, Malta presents the second lowest deployment of RES within the EU, just after Luxembourg. In the perspective of the country specific targets imposed by the EU, which are set for 2020, Malta has to implement concrete actions in short- to mid-term in order to achieve its 10 % RES target on final energy consumption.

For this reason, Malta accessed a sum of the European cohesion funds to develop a study, whose scope is to design and evaluate possible scenarios for the energy sector of the Maltese islands towards decarbonisation, i.e. the achievement of the targets set for 2020 and onwards. Different stakeholders are involved in that project, i.e. the European Union, the government of Malta, the entities involved in power generation and a consultancy company. Since some of the stakeholders could be biased in their approach due to interest conflicts and business relationships, this project is undertaken independently by the authors.

The study is inserted in the context of a country with the highest overall solar irradiation in Europe, which is hardly utilized so far. PV accounts almost exclusively for all RES power production on Malta so far and is anticipated to be the most relevant contribution to the achievement of Malta's country specific decarbonisation targets. However, the organizational status quo of the power system, as well as the limited land resource prove to be a major barrier for further PV deployment.

Several units of two aged oil power plants used to combine a capacity of 600 MW covering the complete annual power demand, which slightly fluctuated around 2,2 TWh in the last 10 years. The annual peak demands typically occur in the summer months July and August reaching peaks above 400 MW. Minimum loads between 150 to 200 MW occur throughout the year, except in summer season, when minimum loads stay above 250 MW. The power plant fleet and the distribution of electricity are operated by Enemalta, the state owned monopole energy entity of Malta, whose major owner is the Maltese Ministry of Energy and health.

The first major transformation of Malta's energy system is already initiated. A long-term PPA (power purchase agreement) referring to a new gas power plant has been signed between Enemalta and an IPP (independent power producer). Such supply source will substitute one of the country's oil power plants, which is presently running against the European environmental regulations. The PPA will lead to two main changes in the Maltese system. First, a shift towards a less pollutant fuels, natural gas, will occur. Secondly, Enemalta's monopole in the power generation sector is affected by the entrance of an independent power producer.

Enemalta is also planning to refurbish the newest of their oil power plants to be run on natural gas also and agreed on a GSA (gas supply agreement) with the same gas-supplying stakeholder, which also supplies the independent power producer with natural gas. The commitment in a not flexible long term PPA and GSA could turn out in contrast with larger shares of RES, which must be installed anyway due to European requirements. That is because both options (PPA with IPP and RES installations) can be considered as economical must run technologies. The gas power plant because, Malta is bound to the PPA, whereas RES should have dispatch priority, since marginal costs are close to zero.

Another relevant change in the Maltese energy system will be an electric interconnection between Malta and Sicily (Italy), which has just started operations. However, in the short term, the operation of that interconnector is expected to be difficult, since Sicily itself has a very fragile power system, which is not sufficiently connected to the Italian main land.

A further option towards EU target compliance is given by the European RES directive, which enables Member States to deploy RES in other member States or third countries using comparative cost advantages, through so-called RES cooperation mechanisms. These allow trading RES credits between countries, which over fulfilled their targets already and countries, which have not deployed sufficient domestic measures to comply with their assigned targets.

This project will reveal the interaction of the described circumstances in more detail. Analyses of the energy sector in regards of its organizational structure, the supply and demand side as well as the flexibility and security of the system are conducted. Furthermore, the potential of RES technologies is evaluated in order to estimate the opportunities to transform the energy system towards decarbonisation. All gathered findings will be used as inevitable or variable input values for an energy system modeling.

The resulting output will be analyzed mainly in regards of its effects on system stability, Malta's country specific EU target compliance and the overall system costs. As a result, a comparison between several scenarios allows showing the impact of different energy system designs and, in conclusion, which energy system set up represents a good solution in compliance with system stability, target compliance and cost efficiency.

## 1.1. Guide through the project

The following illustration should help the reader to navigate through this project. It must be read from top to bottom. Firstly, the general approach comprising the problem formulation embedded in a certain theoretic and politic framework, as well as the delimitations are defined. The methodology applied to each chapter is not presented in one block before the main body of the project, but at the beginning of the specific chapters.

An energy concept of Malta must be closely drafted in accordance to EU ruling and decisions from the Maltese government, which are presented in the POLICY FRAMEWORK chapter. The context of stated prerequisites (externally by the EU and internally by Maltese Government) from the chapter helps classifying the status quo and the target for Malta's energy system. The existing characteristics of the Maltese energy system, its demand, its supplying infrastructure and technical or geographic restraints as well as the organisational set up are analysed in chapter DEMAND and chapter SUPPLY SIDE.

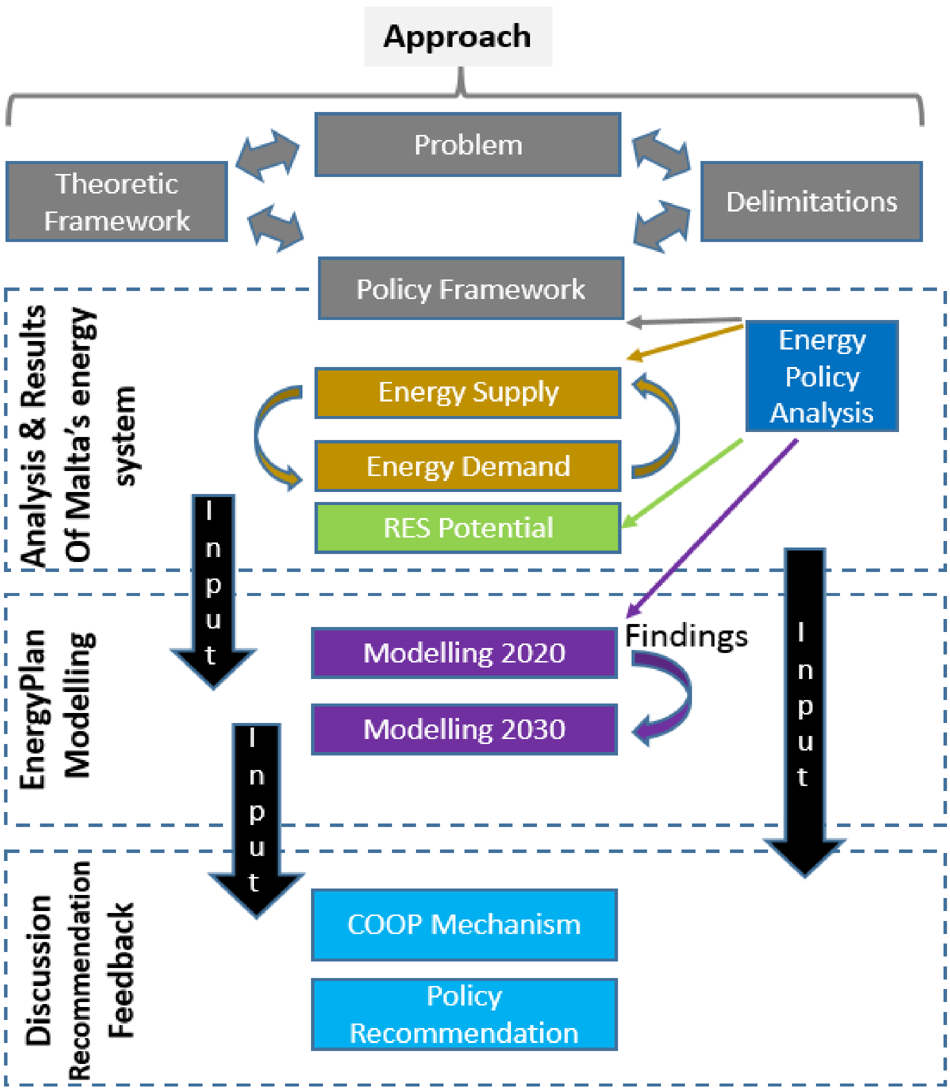



*Figure 2: Visual guide through the project*

Furthermore, the RES potential as the major modification parameter for the following Modelling section is analysed. All the gathered findings are used as input parameter in the modelling section. Some aspects, such as the organisational set up and energy policies will be taken up again as subject of discussion and recommendation in the end of this work. In the MODELLING MALTA'S ENERGY SYSTEM TOWARDS 2020 chapter, it is shown how Malta's energy system might look like in a forecasted 2020 business as usual or an innovative scenario based on the present situation and recent development in the years 2010-2014.

Besides, some technology specific effects of the system are analysed isolated so that a targeted modification of the energy system can be operated. The gained knowledge from the 2020 modelling results will be used in the MODELLING MALTA'S ENERGY SYSTEM TOWARDS 2030 chapter, where a further energy system evolvement is conducted.

POLICY RECOMMENDATIONS and alternative options or approaches will be given in the COOPERATION MECHANISMS AS ALTERNATIVE INSTRUMENT chapter.

In conclusion, general problems, alternatives and uncertainties of the project are discussed in the chapter REFLECTIONS ON THE PROJECT.

# 2. Approach

## 2.1. Problem Formulation

Malta's economy and population grew quite rapidly throughout the last 20 years, which obviously also affected its need to power the country sufficiently. Malta's energy system used to be a fully isolated island energy system with no access to other systems, relying exclusively on its ageing heavily pollutant domestic oil power plant fleet, depicting a strong oil lock in.

Firstly, that did create a high dependency on oil imports and secondly became a political conflict, since Malta joined the EU and since then has to obey to EU ruling, which is thriving towards a decarbonisation of the economy until 2050. Consequently, Malta has to reduce its $CO_2$ emissions, hence its major source of $CO_s$ pollution, its oil consumption. Additionally, an increase in the share of renewable energy sources (RES) on its final energy consumption must be achieved. In theory, there is plenty of sun resource on Malta, which could be utilized through PV and solar deployment and partly substitute electricity generation from oil products.

However, Malta faces a main problem with the deployment of RES in general. Malta is an extreme densely populated island with very little land resource. Additionally land resource is also the major economic factor for Malta's tourism sector and must be treated sensitively in regards of any environmental and visual impact to it. Therefore, the deployment of land resource with RES represents a strong land utilisation conflict. For that reason, wind power was already ruled out in former discussions about Malta's future energy system.

Since April 2015, the operation of an interconnector between Malta and Sicily connects Malta to the Italian market. A newly to be constructed advanced gas power plant and the discussed refurbishment to transform some of the oil consuming power plant units into gas fuelled ones constitute another option to decrease GHG emissions.

Assumingly the leading stakeholders of Malta's past and present energy system, running heavy fuel oil power plants to provide power to the island, are opposed to changes to Malta's energy system, since they have to fear for their business model. Hence, it has to be cleared if technical limits or economic and political obstacles are hindering the deployment of RES on the island.

***Facts:***

- Malta is obliged to fulfill the EU's 20/20/20 targets
- Strong oil (fossil fuel) lock in
- Organizational structure of the energy system is opposed to a transformation of the energy system
- Malta was a fully isolated power system until April 2015
- RES deployment almost nonexistent, despite assumingly good RES potential
- Natural RES potential is given, but strict land utilization conflicts (urbanisation, tourism and agriculture) arise when deploying RES

Malta's past and current power sector is operated by a single energy entity monopoly, Enemalta, which is opposed to major changes in the energy system, which are nevertheless imposed by the EU.

On the other side newly made investments are sank in the interconnector with Sicily and the entrance for an independent gas power plant producer is contracted in a power purchase agreement for the next 18 years leading to a system switch to gas and to specific restraints in the system operation. Furthermore, the utilisation of the Island's RES potential is discussed, as well as a possible implementation of RES cooperation mechanisms allowing to trade RES credits among EU member states in order to utilise comparative cost advantages. Considering all these circumstances, the authors pursue to answer the following question:

***"How could Malta's energy system look like in 2020?" when optimized under the premises of:***

***(1)Security of supply,***
***(2) Compliance to EU targets and***
***(3) Cost efficiency***

***The authors will also answer the question:***

***"How can the transformation of Malta's energy system be proceeded towards even higher RES penetration shares on final energy consumption until 2030?"***

## 2.2. Delimitation and Focus

### 2.2.1. EU Legislation

This master thesis is conducted parallel to an ongoing project, funded by the European Union, which was put out for tender by the government of Malta in September 2014 and was won by the Italian consultancy Nomisma Energia. The project is titled "An energy roadmap – towards achieving decarbonisation for the Maltese islands". The general delimitation of the project is to draft an energy concept, which allows compliance to the EU Directives addressing decarbonisation of Europe's economies. A major contribution to that must come from European power production, which must increasingly use Renewable Energies and cleaner fossil fuels like gas in order to decrease GHG emissions.

The first interim results will be checked upon by the EU in 2020, when specific targets concerning GHG emissions and RES share in final energy consumption have to be met by each Member State. Consequently, the considered timeframe of this report is set on an energy system scenario for 2020 as its first milestone, continued by a scenario for 2030, which outlines another interim target for the EU. Country specific targets for Malta are not yet defined beyond 2020 by the EU, which allows creating the scenario for 2030 more liberally. For the same reason of missing assigned targets and due to high uncertainties about Malta's energy consumption and technological advances beyond 2030, a scenario for 2050 will not be built and simulated.

### 2.2.2. Legislation from Maltese Government

Specific restraints on the expectation of this project are demanded by Malta's government itself, which assigns priority to the deployment of PV and waste to energy in order to achieve the target concerning the RES share, at least up to the first timeframe of 2020. Additionally, the instrument of cooperation mechanisms should be taken into account and analysed, since the Maltese government fears system problems when increasing domestic RES installations or is biased due to interest conflicts. The instrument of cooperation mechanisms should enable EU countries to trade RE-credits in order to achieve the national and European targets in 2020 cost efficiently.

### 2.2.3. Geography

Strict geographical constraints are given mainly by the scarce land area on Malta. Therefore, wind power is not only temporarily ruled out by politics, but also in the long term, it could be utilized only to a limited extent due to geographical constraints. In addition, the use of biomass produced inland, apart from biodegradable waste, is not possible for similar constraints. Due to the lack of rivers and mountains, possibilities of hydropower or hydro pumped storage are also not analysed.

The main focus of this project will be on pre-selected technologies within the electricity and heating sector. The transport sector will be touched only on the surface. However, since an integration of the heat and transport sector with the power sector seems inevitable for future energy system with low $CO_2$ emissions no topic will be excluded completely. However, that means also that extreme depths within each of the topics must sometimes be spared.

### 2.2.4. Further restraints

Further restraints are set by the authors in order to best focus on the research question and due to the availability of data and tools to conduct an energy concept for Malta within the limited time to finish this Master Thesis. Examples of what has been excluded is:

- Detailed analysis of technological innovation in the coming years;
- Quantitative evaluation of the effective impact of proposed polices;
- Energy policies and beyond 2020;
- District Heating and Cooling as a theoretic, but likely to be unrealistic option
- Detailed study on E-mobility

## 2.3. Theoretical framework

### 2.3.1. Choice Awareness and Lock-in Theory applied on Malta's power system

One approach applying theories to the transformation of Malta's energy system towards a higher penetration of RES and less $CO_2$ emissions can be found in the question of choice awareness. According to Lund[5], choice awareness deals with the question of how radical technological changes can be implemented at the societal level. The question of choice awareness is closely related to the collective (societal) choice perception. At this stage, the authors suggest combining the theory of choice awareness with "lock-in theories", since a lock-in describes a situation, in which no choice awareness seems to be perceived by society and alternative approaches to the current status quo are not considered. In Malta's case, one can consternate a heavy "oil lock-in" since the power generation has been exclusively based on oil for a long time (coal has been phased out in 1995[6]), despite the obvious potential of high solar irradiation, which seems to be a good technical alternative or at least a supplement to power production based on oil.

20 years ago the technical option of PV might not have been seriously considered in Malta since the technology was not yet a cheaper alternative than power production from fossil fuels, which made it not an economically feasible solution. Additionally the awareness for climate change and demand for energy sources was lower. Up to now, there used to be only one stakeholder, ENEMALTA, who is responsible for nearly 100 % of power generation. This stakeholder has obviously little interest to undergo a system change, particularly when that company is specialized in power production through fossil fuels. Additionally the institutional set up of Malta's authorities being 100 % dependent on ENEMALTA as the exclusive power producer and an important employer makes it difficult to raise direct criticism. One hypothesis claims that it takes external factors in order to initiate a radical change because the organizations (ENEMALTA), which have their business model optimized according to the status quo have no real interest to change it.

Because of all these factors, one can conclude that there was no true choice given to the people. According to AAU[7] there is a strategy set consisting of technical alternatives, economic feasibility studies, public regulations or democratic infrastructure in order to raise awareness. As described before, the institutional set up within Malta was not ideal in order to address the problem of a relevant change of the system by public regulation. However, an external stakeholder, the EU, imposed energy related directives on all EU member countries. According to the imposed *Directive 2009/28/EC,* Malta has to provide 10 % on its annual final energy consumption from RES within 2020. Additionally, one of the two major power plants on Malta is affected by *Directive 2010/75/EU,* which regulates industrial pollutions and has to be closed consequently.

Suddenly these ultimate external rulings initiate the kick-off for a radical change of Malta's energy system. The implementation of that change must now actively be addressed by Malta's authorities.

Referring back to the AAU strategies, technical alternatives within the RES sector must be found, feasibility studies must be conducted, possibly evaluating also the socio-economic impact of specific choices, as well as the democratic infrastructure must be developed, all framed by public regulations. Even though not all these strategies will be addressed specifically in this project, the theoretic context to raise awareness and implement a radical change of the Malta power system is closely related to the analyses conducted in this project. The analysis of Malta's RES potential and the power system modelling can be considered as part of strategies on alternative technologies and economic feasibility studies. Whereas, the proposal for policies in order to implement the necessary changes refers to the topics public regulation and democratic infrastructure.

One aspect of choice awareness is the discourse theory, in which all stakeholder discuss issues and options. The evaluation of environmental and visual impact studies on onshore and offshore wind power already lead to the authority's ruling that large-scale wind power technology will currently not be considered in Malta's future energy system. Such decision, as well as others, could be altered in the future though new discourses.

## 2.4. Project set up constellation

The Maltese government put out the need for EnergyPLANning consultation for tender in the end of 2014, since the EU, which is interested that each Member State manages to achieve its country specific targets towards a decarbonisation of the EU provided funds for such a project. Malta authorities granted the project to the private Italian energy consultancy Nomisma Energia. Hence, the direct business relationship consists of those two stakeholders, Nomisma Energia and the Ministry of Energy and Health on Malta. Direct cooperation is hold during the whole duration of the project.

One can assume that the Maltese authorities are divided between two interests. On one side there is the economic interest to support conventional power, since this is the core business of the partially government owned utility company Enemalta, on the other side there is the need to comply with the EU requirements towards decarbonisation. An increase of RES installations most likely means an increase of energy production outside of the monopolistic jurisdiction.

Since these conflicting interests could lead to compromises, which do not optimize the available potential of the country, the authors of this project find important to conduct this project autonomously.

## 2.5. Policy Framework

Since over two decades, Europe is discussing about climate change and is setting in place measures and directives addressing the issue. Member States had to adapt to these given guidelines and regulations concerning the energy and environmental sector mainly.

FIGURE 3 gives an overview of the legislative framework in which the evolution of Malta's energy system is embedded. The EU committed itself in the Kyoto Protocol, which demanded a greenhouse gas emission (GHG) reduction of 8 % below levels from 1990 until 2008. In 2009, the EU provided itself with a directive (2009/28/EC) to continue the trend and achieve a further reduction of 20 % by 2020. In 2011 also a longer-term target was set, i.e. the decarbonisation of the EU area towards 2050, known as the energy roadmap 2050, which aims at a reduction of 80-95% of the GHG emissions.

Since Malta's accession to the EU in 2004, the country is obliged to EU Directives as well and must contribute to the EU's overall targets.

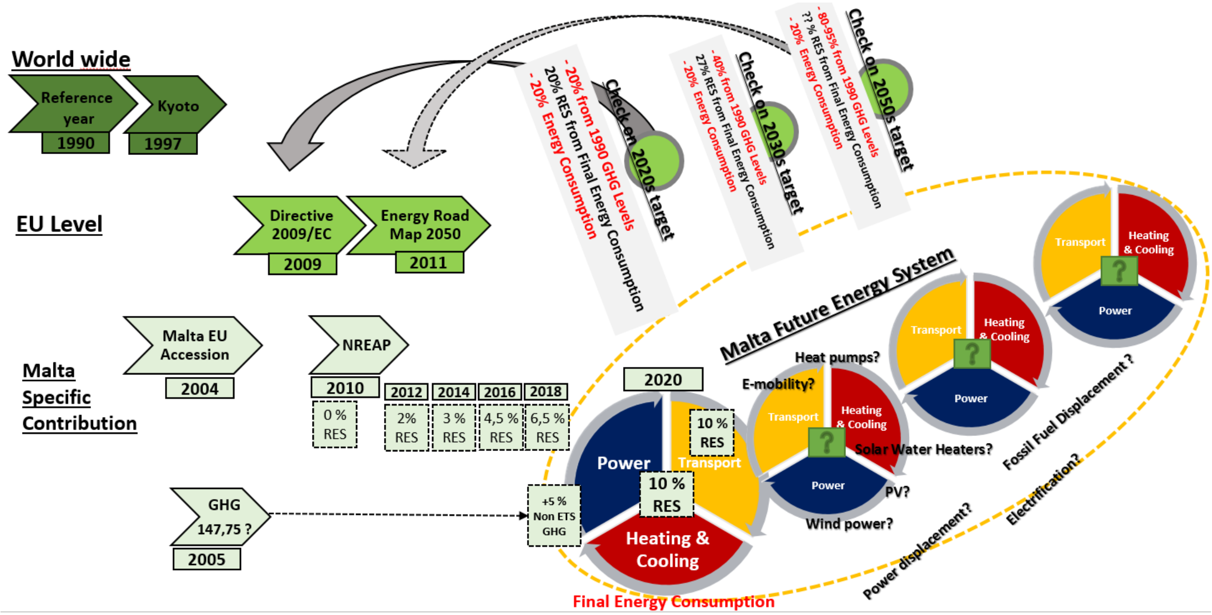



*Figure 3: Policy Framework for Malta*

The "20-20-20 goals" from Directive 2009/28/EC (Renewable Energy Directive, RED) will be the legislative ignition for this project. The following goals are stipulated by the EU until 2020:

- A 20% reduction in EU GHG emissions from 1990 levels;
- A 20% share of energy from renewable resources on EU's gross final energy consumption (with a 10% share in the transport sector);
- A 20% saving of energy consumption compared to a reference scenario, by means of increased energy efficiency.

The first two goals are legally binding for all EU member states, although with diversified contributions within them. The last goal is not binding.

Under the 2020 climate and energy package, a specific share of the target was assembled to each of the European member states according to their different starting points, renewable energy potential and economic performance[8]. As a result, shares of RES in final energy consumption ranging between 10 (Malta and Luxembourg) and 67,5 % (Norway) were assigned to the EU Member states.

Malta is categorized in the low contribution range and has to cover 10 % of its final energy consumption from RES by 2020. Additionally 10% of the transport sector final energy consumption has to be covered by renewable sources, i.e. biofuels or e-mobility. Furthermore, Malta is expected to increase its GHG emissions, which do not underlie the emission trading system, by no more than 5% until 2020 (compared to 2005) and to reduce its primary energy consumption by 22%, compared to a reference scenario, i.e. presenting a final energy consumption of 0,493 Mtoe (5,732 TWh) in 2020[9].

In its 2010 National Renewable Action Plans (NREAPs), each Member State had to provide a concept showing how the assigned contribution to the "20-20-20" targets would be achieved.

In 2011, the EU drafted an Energy Roadmap to 2050, in order to frame and organize the transition to a low carbon economy. An intermediate goal of a 40 % GHG reduction by 2030 is aimed, while further emission reduction by 80 to 95 % until 2050 is issued.

### 2.5.1. Energy Policies on Malta

All mentioned political circumstances could be treated as external legislation imposed on Malta. However, one can also see some inherent motivation from geopolitical and economic aspects for Malta. The major effect when obeying to EU legislation would be a decrease of the energy import dependency for Malta.

In 2004, after the accession to the European Union, the Maltese Government has published a policy document to drive the first measures in the energy sector and use the first flows of European financial resources. In this document[10], the Government has emphasized the need to invest in the renewables sector, in order to exploit the huge potential of clean energy generation of the Maltese islands. This led to the first grant schemes, partially financed by the ERDF (European Regional Development Fund), supporting the deployment of PVs.

In April 2009, the Ministry for Resources and Rural affairs proposed an Energy policy for Malta[11], which has been finalized in 2012.[12] Quoting the incipit of the document itself, it "outlines Government's energy policy, the priority areas and the overall goals and objectives for the development of the energy sector. These can be summarised as: security of supplies, environmental protection and competitiveness."

The main areas of intervention for Malta are outlined in this policy document and are recalled in the National Renewable Energy Action Plan 2010 (NREAP). The following main topics are defined as goals for Malta's energy policy.

- Energy efficiency: encourage and support efficiency in power generation and distribution, as well as in the energy end-use;
- **Reducing reliance on imported fuels: support the sustainable development of sources of renewable energy**, while continuing to provide opportunities in oil exploration;
- **Stability in energy supply: seek diversification of the energy mix through renewable energy, power interconnection to Sicily, introduction of natural gas in the system**;
- **Reducing emissions from the energy sector**;
- Delivering energy efficiently and effectively: **open the energy market for competition, according to its limits, and introduce a variety of options as energy sources for specific needs** to enhance the delivery and quality of the services;
- Supporting the energy sector: create synergies between energy and fiscal, education and research policies.

Excluding the points concerning energy efficiency measures and cross-sectoral synergies, these aspects and issues are also the focus of this project.

### *Support for Renewable Energy Sources*

Concerning the support for sources of renewable energy, the incentives for PV installations, as well as the introduction of grant schemes for solar water heaters are eminent on Malta. PV installations have been supported by both grants and feed in tariffs (FiTs) in the past. Presently the FiT amounts to 15,5 cent EUR/kWh after several lowering (from 24 cent EUR/kWh in 2010)[13]. The FiTs are granted for 20 years but capped at 1600 kWh/year for each $kW_p$ PV installation. The next figure shows a clear correlation between monetary incentives (red line) and installed PV capacity in the residential sector.

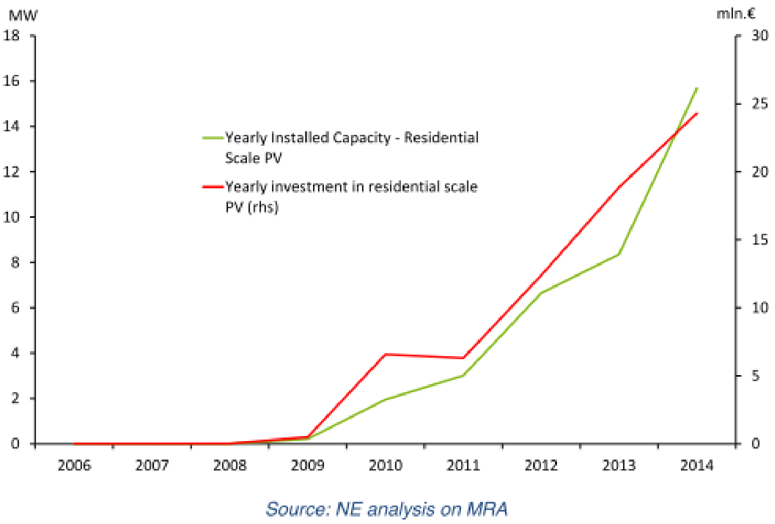



*Figure 4: Correlation between incentives and investment behaviour for PV installations*

Given the strong land constraints to which Malta is subject, the policy vision of the Maltese Government demands that a prospective growth of PV generation capacity may not occupy new lands[14]. Therefore, PV are incentivized exclusively if developed on rooftops and brownfield lands, such as former quarries or dumpsites.

Furthermore, during the period 2011-2015 SWHs are awarded a grant covering 40% of the investment cost up to 400 EUR[15]. Representatives of the Maltese government also discuss measures to support the use of heat pumps for heating purposes.

### *Transportation*

In the transport sector the reduction of $CO_2$ emissions and of fossil fuel import dependency is targeted through the scrappage scheme, i.e. the financial support to the car owners, which switch to newer and less pollutant vehicles.

### *Funding*

All the initiatives towards sustainability are funded through European programs and the national budget. Since the present government reduced the residential energy bills in 2014 and there is the political commitment to maintain the prices at that level until 2019, it is not possible to burden the end consumers with shares on the costs related to the support schemes for renewable energy installations. Hence, the monetary measures for energy related incentives are relatively constrained for the Maltese government.

### *Priorities*

It can be noted that the three parameters system stability, EU target accordance and cost efficiency used in this project in order to prioritize the EnergyPLANning choices towards 2020 and 2030 are comparable to the conditions under which interventions in the energy system should be orientated according to Malta's Energy Policy guidelines and circumstances.


*Figure 5: Priorities for Malta's energy system modelling*

# 3. Demand

## 3.1. General Demand Methodology

Before starting the analysis of the energy demand on Malta, it is highlighted that energy employed in a system can be categorized as primary energy supply, final energy consumption and end user demand, as represented in FIGURE 6.

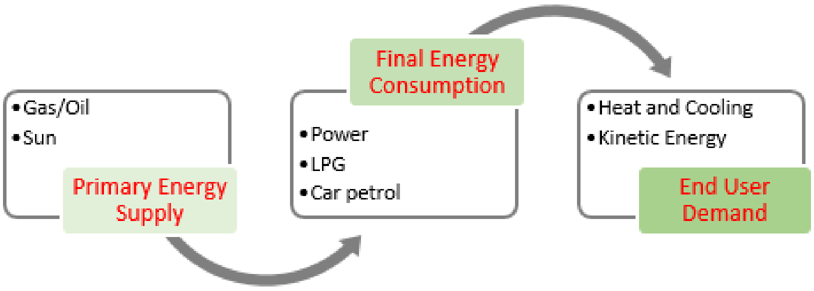



*Figure 6: Correlation between the energy categories*

*Primary energy is the energy, which is extracted or captured from sources, whose physical and chemical characteristics are not changed during the process*[16]. According to this definition gas, oil, coal and sun are included in the category. Final energy consumption is the energy, mainly power and refined oil products, which is used as an input fuel in specific technologies (for instances in car combustion engines, heat pumps and individual LPG heaters) in order to cover the end user demand.

The end user demand is the produced energy output resulting from the transformation process of final energy consumption. It is subject to energy losses according to the efficiency of the technology specific transformation process. The final end user demand can be heating and cooling for buildings and kinetic energy in the transport sector for example.

In some cases primary energy supply and final energy consumption coincide (oil in transport or in the residential sector for example), as well as final energy consumption and end-user demand coincide when the final process efficiency equals 100 %.

In particular when discussing about the heating sector, the authors will stress the difference between the consumption of primary and final energy. In fact, a reduction in final energy consumption does not necessarily mean a reduction in primary energy consumption (for example in case of switch from fossil fuels to electricity).

## 3.2. Gross and final energy consumption

### 3.2.1. Historical Gross primary Energy consumption

FIGURE 7 shows the development of Malta's final gross energy consumption from 1990 to 2013 for each sector. The overall consumption was 8,2 TWh in 1990 and rose by 24,9 % to 10,25 TWh until 2013. The biggest share of the consumption is represented by the thermal power plants, supplying Malta with electric power. In 1990 and 2013 fuel consumption for power generation were at the same level, although it presented much higher values in certain years in-between. However, the relative share decreased from 74,3 % in 1990 to 61 % of the total consumption, mainly due to the increasing weight of road transport since 2000. It must be kept in mind that this is gross energy consumption, meaning that final energy consumption should not be derived from this chart without care, since that correlates with the different efficiencies of the energy usage. The average efficiency of Malta's thermal power plants increased from 19 % (1990) to 31 % in 2011[17] mainly due to the mothballing of coal power production in 1995, while distribution losses increased from 10 to 15 % in the same period.[18]

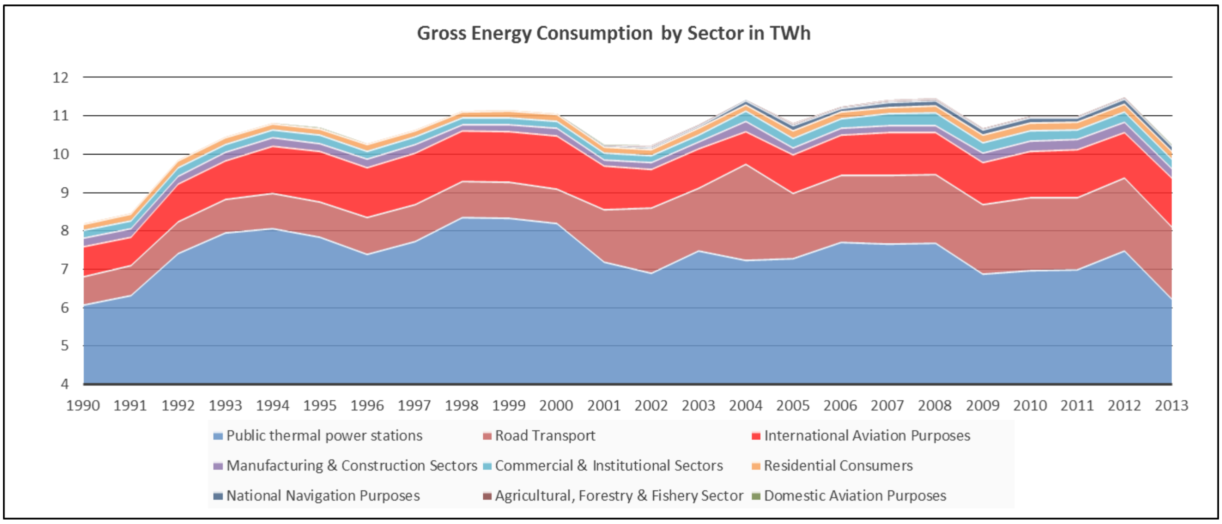



*Figure 7: Malta's Gross Energy Consumption by sector [19]*

The biggest increase in total consumption happened in road transport (+160 %) to 1,89 TWh and a relative share of 18,4 % in 2013. It is followed by international aviation business increase (60,1 %) to 1,26 TWh, equaling a relative share of 12,3 % of the overall consumption.

### 3.2.2. Final energy consumption 2013

The most recent data on final energy consumption refers to the year 2013. Such information is provided by the Maltese Ministry of Energy and Health. The overall final energy consumption amounted to around 6,34 TWh. However, one must consider that due to statistic measures from the EU[20], the energy demand for aviation of Malta cannot exceed 4,12 % of the overall final energy consumption, hence its registered value must substantially be lowered from the real value and is separated from road transport energy consumption. As a result, a reduced final energy consumption of 5,33 TWh was registered in 2013. The major share (FIGURE 8) is coming from electricity demand, which amounts to 2,17 TWh (43 %), followed by road transport, representing another 1,86 TWh (37%). Road transportation is almost exclusively based on oil products, with only 1,6 % of the energy consumption represented by biofuels[21], against the aim of the EU to have 10 % of the fuel for transport represented by biofuels in 2020. Fossil fuels, which are used for heating, cooking and industrial purposes, are mainly constituted by oil products. Most of the registered 0,79 TWh of fossil fuel is LPG (40%), which is followed by diesel (24%), gasoil (19%) and fuel oil (14%)[22]. The former is mainly employed in the residential sector, while the other fuels are found mainly in industries.

According to Eurostat, the end user energy demand (i.e. the denominator when calculating the RES share in the system, amounts to 5,74 TWh in 2013.[23]

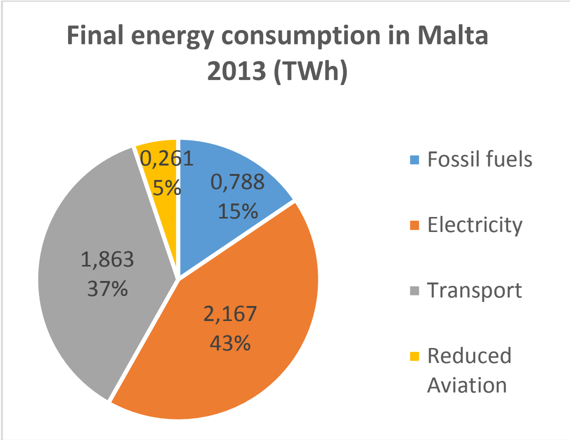



*Figure 8: Final energy consumption in Malta 2013* [24]

The authors base their estimates about the specific destination of final energy on aggregated data and on own assumtions. Also the situation in 2020 is forecasted on these premises. However, as for the level of final energy demand, the data provided by Eurostat for 2013 is taken as the reference on which also the EU target compliance for 2020 is measured.

## 3.3. Power Demand

### 3.3.1. Structure of power demand

In order to best assess the evolution of the power sector, the authors will differ between:

- Overall power demand
- Power demand for heating and cooling
- Remaining power demand

The overall power demand consists of power demand for heating and cooling purposes and the remaining power demand, which is not used for cooling and heating purposes.

That differentiation makes it easier to understand the parameters, which interact with the future power demand.

The overall power demand in 2013 is the only certain number (1. in FIGURE 9), if the data provided by Enemalta is to be trusted. According to little research data and own assumptions, estimates on the used heat and cooling technology are made. That is set fix as an internal default (2. in FIGURE 9). The thermal demand can partly be derived from the identified heating and cooling technologies, respectively the heating and cooling habits on Malta (3. in FIGURE 9). Only few surveys based on limited samplings regarding heating and cooling habits exists for Malta, which is why the authors also took own assumptions based on weather and housing conditions as well as personal living experience from hot countries into account, when defining the thermal demand.

The difference between the overall power demand and the assumed power input for heating and cooling as well leads to the remaining power (4. in FIGURE 9). Since there is no available data, which can confirm or contradict the assumptions taken, both the destination of the power in the system and the resulting thermal demand and composition is set as fixed for this project.

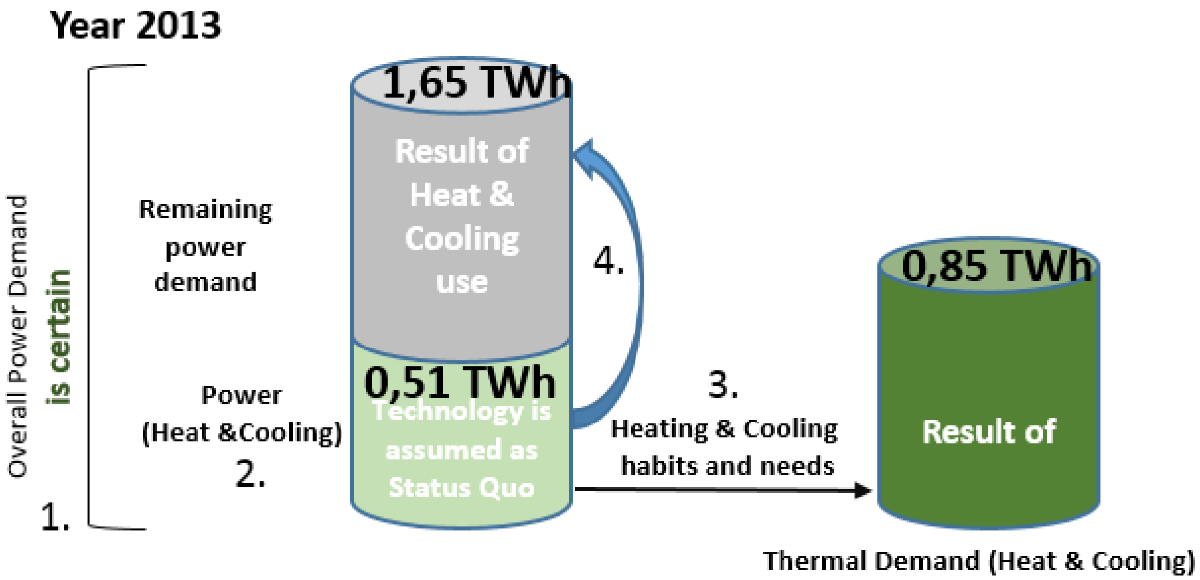



*Figure 9: Accounting Malta energy demand in 2013*

### 3.3.2. Development of power demand

*Major parameters influencing energy consumption on Malta are identified and set in context to their historical growth trend.*
*Based on the parameters, which are identified as the key causes for the past evolution of Malta's final energy demand, assumptions on the evolution of the final energy consumption and power consumption in particular are made. The correlation between the key causes and the energy forecasts is evaluated qualitatively rather than quantitatively. The forecast of Malta's future energy consumption will start from the reference year 2013.*

The total final power demand grew from around 1200 GWh in 1990 to about 2200 GWh in 2014 (FIGURE 10), which corresponds to an average annual growth rate of 2,55 %[25]. However, growth characteristics are better represented, when pointing out that in the 13 years from 1990 to 2003, the growth rate was even higher at 5 % annually and dropped to a negative rate of -0,4 % from 2003 to 2013. Since the biggest drop is registered in 2009, this negative growth is most likely imputable to the European crisis. Despite the recently negative or stagnating power demand, Enemalta[26] projects an increase from about 2,2 TWh in 2014 to roughly 2,6 TWh in 2030, representing an annual growth rate of around 1,1 %.

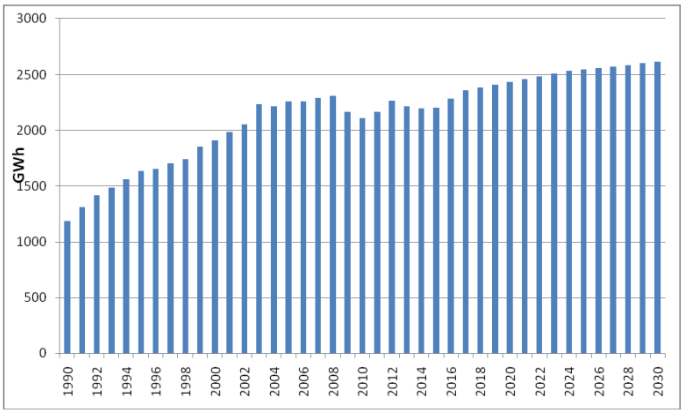



*Figure 10: Historical and Forecasted Power demand on Malta*

The authors disagree with Enemalta's power demand forecast and assume the following main reasons for the past and future development of power consumption.

- Population Growth and Energy intensity per capita
- Economic Development
- Tourism
- Technology Use

### *Population Growth and Power per Capita*

Numbers from the World Bank[27] show the high population increase from 1980 to 2000 and a flattening curve since then, with projections reaching a population of 438.000 people in 2030.

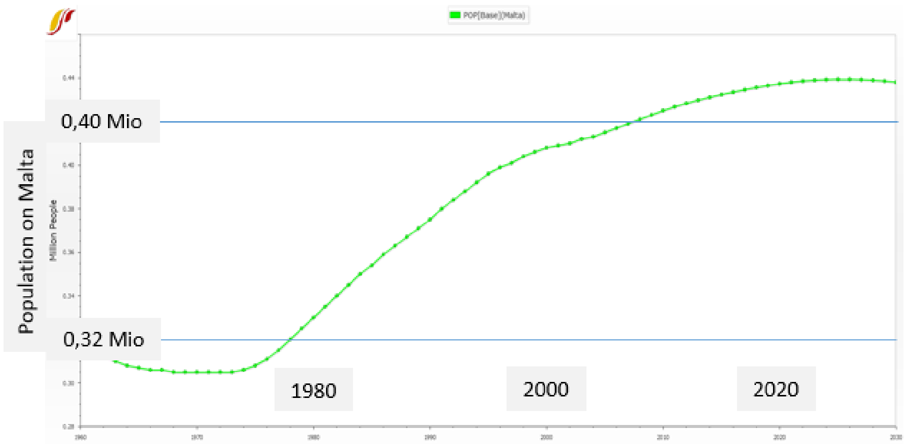



*Figure 11: Historical and Forecasted Population growth*

FIGURE 12 shows the annual population growth rates on Malta from 2000 to 2012 in more detail. A reduction in the population growth trend is characteristic.

| Country | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Malta | 0.74 | 0.74 | 0.73 | 0.73 | 0.42 | 0.42 | 0.42 | 0.41 | 0.41 | 0.4 | 0.39 | 0.38 | 0.36 |

*Figure 12: Historic Population Growth on Malta [28]*

The authors assume that the annual increase of population is fluctuating around +0.4% until 2020.

The electricity/capita ratio, calculated as the power demand divided by the population on Malta, increased from roughly 5000 kWh/capita in 2000 to roughly 6200kWh/capita in 2014, which reflects an annual growth of almost 1,6 % from 2000 till 2014. This trend is assumed to end and stagnate instead, since energy consumption awareness grows and a decoupling of GDP growth and power consumption becomes more characteristic.

### Economic Development

According to World Bank data[29] a rapid development of Malta's GDP from around 2,6 billion US dollars to 9,64 billion USD took place from 1990 to 2013 with an average annual growth rate of almost 6 %. Compared to the growth rates of other European Countries, this development was extremely positive. Furthermore, GDP growth rates tend to decrease and stagnate in already developed economies. Therefore, the authors assume that Malta's GDP will grow much slower in the future and will not have a big effect on power demand in contrast to the past.

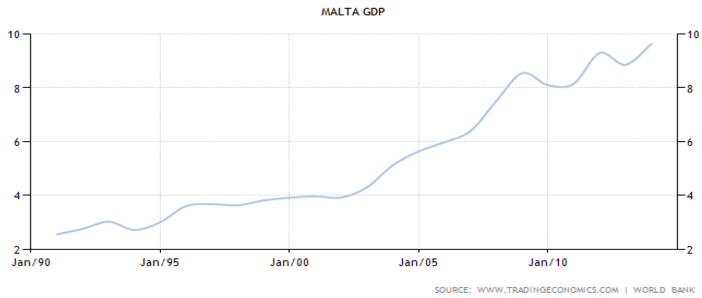



*Figure 13: Historic Development of Malta's GDP from 1990 to 2010 [30]*

### Tourism Growth

Tourism on Malta grew from levels of 0,5 million tourists/year in the end of the 1980s[31] to about 1,7 million in 2014.[32] The authors assume that this number is not growing further in the years until 2020.

### Technology Use

It can be assumed that the GDP growth also led to higher living standards, which also changed the habits of technology use. Therefore, the installations of air conditioners can be mentioned among the drivers for growing power demand in the past as well. Whereas, the increasing trend of using air conditioners for heating as well and the use of solar water heaters can lead to electricity displacement.

### Power demand forecasts

A positive correlation between Malta's power demand and the economic as well as demographic development is obvious according to historical data. However, the Island of Malta is geographically restrained by its small land area and urbanization has already reached high levels. Additionally, a further increase of population and tourism at the same time would sabotage each other due to severe land utilization conflicts and gentrification processes through urban development. Population growth already shows signs of a slowdown. It is assumed that the present growth rate of population of +0,4% per year is maintained until 2020, while tourism and commercial activities remain stable until 2030.

- ➔ Thermal (heating and cooling) demand and remaining power are assumed to increase through the growing population of 0,4% annually, which is forecasted from 2013. (1. & 2. in FIGURE 14)
- ➔ However, overall power input demand for heating and cooling in 2020 could decrease nevertheless if the technology mix in the heating sector leads to electric displacement. Since the exact technology use is uncertain and will be varied in this project's modelling phase, the needed input power for cooling and heating varies. (3. in FIGURE 14)
- ➔ The variation of the technology use in the heating sector leads also to variability of the overall power demand. (4. in FIGURE 14)

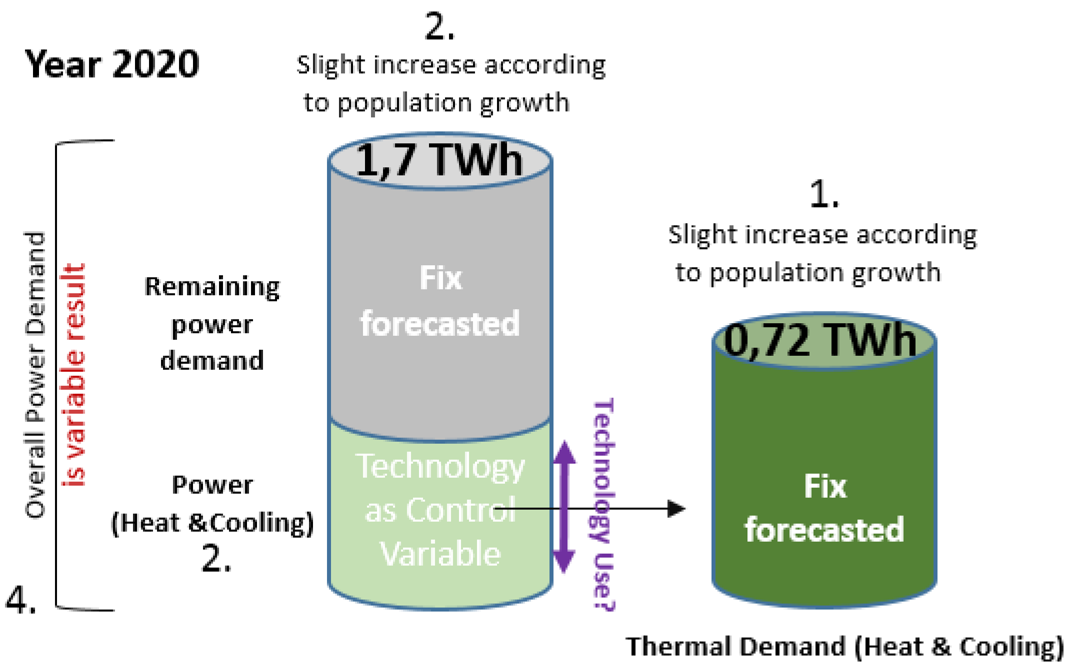



*Figure 14: Accounting Malta's Energy Demand in 2020*

Hence the question whether an electrification or a displacement of power will take place in Malta's future energy system is raised.

### 3.3.3. Hourly Power Distribution

A yearly power distribution, as required in input by the modeling software EnergyPLAN, consists of 8784 hourly values (leap year). Malta authorities provided the hourly data of system load for 2012, 2013 and 2014 and the average daily profile of electricity demand on a seasonal basis in the years 2010 to 2014. Astronomical seasons are considered, hence profiles are provided for the periods:

- 21st December to 20th March,
- 21st March to 20th June,
- 21st June to 22nd September,
- 23rd September to 20th December.

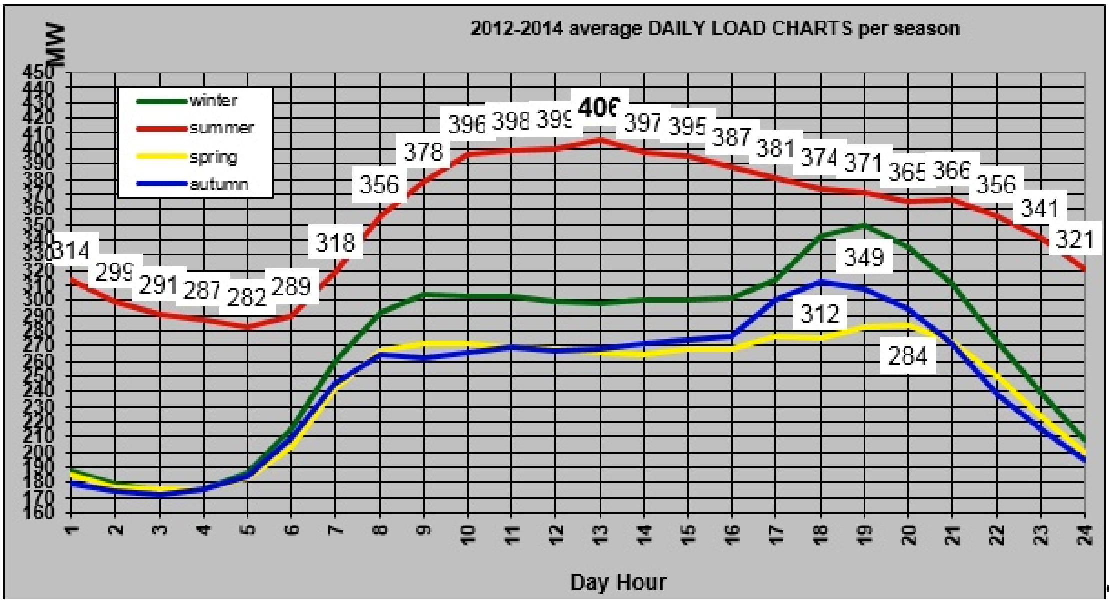



*Figure 15: Seasonal average Daily Load charts 2012-2014[33]*

Available data on the system load are provided by Enemalta, hence they refer to the supply side and not to the demand side. Being Malta an isolated system, in which Enemalta has the monopoly of the generation and distribution, generation and consumption shall coincide. It has to be noted, however, that the increasing PV power generation (strong increase from 2012 to 2015) is not accounted for at the Enemalta generation side. Furthermore, PV peak generation and peak demand on Malta coincide. Therefore, the data provided by Enemalta shows a decreasing trend in the peak demand between 2012 and 2014. Since in 2012 PV generation accounted for only 0,60% of the power demand, it is assumed that the impact on the power demand profile was limited. Hence, the hourly load data of 2012 is taken as a reference and used as power demand distribution in the EnergyPLAN model. It is evident that in certain hours, the system load was affected by supply shortages or system failures, displayed by sudden drops. Therefore, minor adjustments are operated on the available data, in order to have normalized profiles. The resulting 2012 power generation profile has a peak of 429 MW, occurring on the 9th August at 1 p.m. Since the reference year is 2013, the peak is scaled according to the power demand registered in 2013 and results in a peak of 408 MW.

The authors also evaluate the seasonal data provided for the years 2012, 2013 and 2014. The profiles enable a good overview of the seasonal features of the Maltese electricity system. For example it can be seen how the maximum electricity demand in summer occurs due to the overpopulation through tourism, causing high cooling demands in particular. That is also reflected in the peaks occurring in July and August, and relatively high demand in winter due to heating needs. Spring and autumn are taken as starting point to evaluate the impact on electricity demand of cooling and space heating in the two other seasons respectively, as explained later.

The power demand profile, built according to the present section, is applied to all the modeled scenarios.

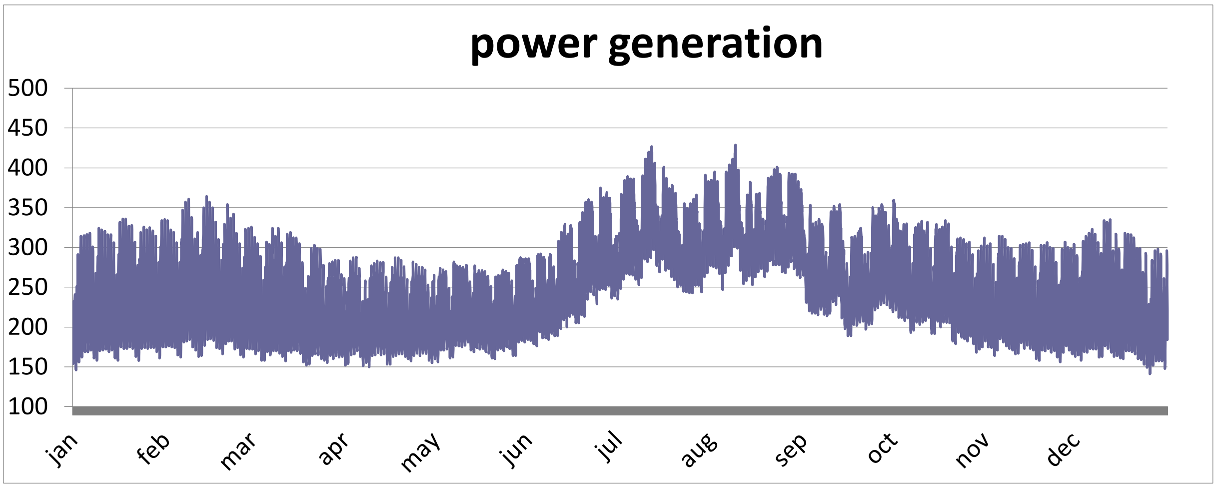



*Figure 16: System load profile (based on data from Enemalta referring to 2012)*

## 3.4. Heating and cooling demand and technology in 2013

*The assessment of the typical technology use for heating and cooling purposes in Malta is based on a few information from studies[34], as well as on assumptions based on Malta's economy and its climate. There is little data available for the electricity consumption dedicated to heating and cooling on Malta. According to the Maltese Census[35], in 2011 just over 152.000 dwellings were permanently occupied. The NSO Census 2011 also found out that around 50% of the occupied dwellings have at least one air-conditioner installed, which can serve both the space heating and cooling scopes. Malta officials stated that air conditioners are mostly air-to-air reversible type, and that it is intended to further promote their use for space heating, since only the cooling function is commonly used yet. In addition to this measure, also the use of solar water heaters for the production of warm water should be better supported in order to displace electricity consumption in electric water heaters.*

*In 2010, Said[36] undertook a survey trying to highlight the final destination of the electricity in households, which accounts for around 35% of the national demand. In winter months, it was found that water heaters represent the biggest single power consumption source. No specific data is provided for summer, but it is stressed that a large amount of energy is dedicated to air conditioning.*

*A survey conducted on 300 households by the University of Malta[37] in 2013 gives additional information concerning heating and cooling processes.*

*Based on the above stated statistics, which however rely only on relatively limited samplings and present partially different results, the structure of the heating sector is defined. Specific values are assigned to the heating and cooling demand, based on few given numbers and own elaboration on them.*

### 3.4.1. Heating

*Hot water*

Based on the provided surveys, it can be said that presently 80 % of the final energy required for hot water generation is provided by electric heaters, 12 % by SWH and 8 % by fossil fuel based technologies. In addition, according to the energy balance sheets provided by Eurostat for 2013[38], around 0,046 TWh are produced by solar thermal technologies in the form of heating.

*Space Heating*

According to the survey run by the University of Malta in 2013[39], space heating is necessary only in two to three months of the year and it is mainly operated by fossil-fuel-based heaters. This technology is followed by the use of air conditioning, in form of heat pumps, which is the most efficient solution, and of electric resistance heating.

It is assumed that 70 % of the space heating demand is covered by fossil fuel based devices with an efficiency of 85 %. Another 10 % is matched by resistance heating with an efficiency of 100 % and the remaining 20 % is covered by heat pumps, the most efficient technology, presenting a COP 3.

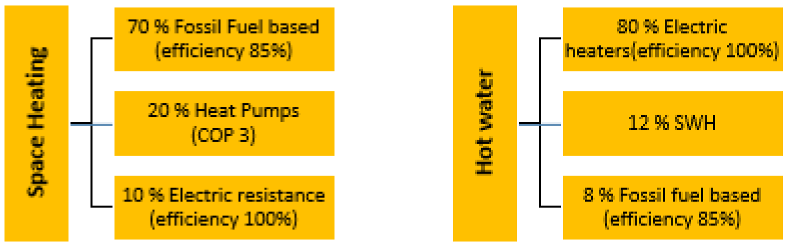



*Figure 17: Technology use for space and hot water heating*

It is also reminded that at least 50 % of the households already own a heat pump, which can be used for both heating and cooling purposes, but is presently mainly used only for cooling purposes. In case of a shift in technology use, where HPs are also used for heating, investment costs do not have to be considered twice for heating and cooling. Based on the oil balance by sector provided by the Maltese authorities, it is estimated that a certain share of the fossil fuel consumed in each sector is dedicated to heating purposes (see FIGURE 18). As a result, it is estimated that the heating sector employs around 0,3 TWh of fossil fuels.

| | fossil fuel (TWh) | heating | others |
|---|---|---|---|
| residential | 0,2 | 60% | 40% |
| commercial&services | 0,25 | 50% | 50% |
| industry | 0,28 | 20% | 80% |

*Figure 18: Fossil fuels in heating per sector*

According to available information on the fossil fuel employed in the heating sector and on the amount of solar water heaters in place in 2013[40], specific numbers are derived and assigned to the single technology shares, as specified before. It turns out that 0,36 TWh of electricity is required for heating purposes, more than 85 % of which are for the production of hot water.

| | 2013 | | | |
|---|---|---|---|---|
| | technology | demand share | input energy consumption (TWh) | final heat generation (TWh) |
| water heating | SWH | 12,0% | | 0,046 |
| | fossil fuel | 8,0% | 0,036 | 0,031 |
| | electric | 80,0% | 0,306 | 0,306 |
| | | | | **0,383** |
| space heating | fossil fuel | 70,0% | 0,265 | 0,225 |
| | electric | 10,0% | 0,032 | 0,032 |
| | HPs | 20,0% | 0,021 | 0,064 |
| | | | | **0,322** |
| | el input | | 0,360 | |
| | fossil fuel input | | 0,301 | |

*Figure 19 Energy input & output for heating technologies in 2013*

### 3.4.2. Cooling

*Space cooling is employed for 3 months or more from the majority of the residential participants in the surveys. Only electrical devices are deployed for this scope, namely air-to-air reverse heat pumps with a COP of 3, as derived from an analysis of the technologies on the market. Unlike all other European countries, Malta has a higher demand for space cooling than for space heating[41]. According to numbers provided in the Maltese census, there are about 2,9 people per dwelling (2011)[42]. According to surveys about cooling devices and behaviour[43] about 50 % of Maltese residents use cooling regularly. Those references are used as an orientation for the authors' assumptions.*

It is assumed that a cooling device, in form of a reverse heat pump with a nominal cooling capacity of 3 kW, which could theoretically be used both for cooling and heating, is installed in every second occupied household. Therefore, 76.000 devices are installed. The authors analysed the weather conditions on Malta and took own experience about cooling needs in hot countries (Malta, Italy, Crete and Australia), which they lived in or visited, into account in order to quantify the use of air conditioning into account as well.

The hottest temperatures occur in the months July, August and September on Malta. In that period of 90 days, it is assumed that intensive use of air conditioning is prevailing with air conditioners in full use for about 8 hours a day. The 8-hour timeframe consist of two hours during the day around lunchtime or whenever the household is occupied by its inhabitants and 6 hours at evening / night-time.

Additionally it is assumed that in the months of May, June and October a moderate use of two hours air conditioning per day occurs in every second household.

➔ That results in a cooling output of 0,2 TWh for the permanent residential sector in Malta every year.

In 2013 about 1,7 Mio tourists and 13,5 Mio overnight stays on Malta were registered. That equals about eight nights for each tourist. The authors split the tourists over the whole year as additional stable population. First, the night stays are distributed over the whole year (365/8=46). Then, the total number of tourists is divided by 46, which results in a permanent tourism population of around 37.000 on Malta over the year. Since tourism peaks are within the second and third quarter of the year[44], the authors distributed the number of around 37.000 equivalent stable tourists in season and offseason population. There are about double the tourists from April until October (49.800) than during offseason (24.900).

Then it is assumed that 1,5 people share a hotel room on average and that a small air con of 1,5 kW is installed in every room. Since tourists usually are less aware about energy savings (and related costs) and are more sensitive to hot temperatures, it is assumed that they use 8 hours of air con for the whole high season from April until October.

- ➔ That results in a cooling demand of around 0,07 TWh due to hospitality infrastructure

As for the services sector, in 2013, there were roughly 175.500 people employed on Malta[45]. Summing together all employment, which usually takes place indoor as a white-collar job and is therefore subject to conditioning the working areas, around 84.000 employees fall within the category. This embraces public and professional administration, financial sector & insurances, information &communication and other services. It is estimated that half of the considered workforce enjoys cooling devices. An air-con of 5 kW is installed for 6 employees and operated 90 days a year for 8 hours every day.

- ➔ As a consequence, over 0,02 TWh cooling output is generated and consumed mainly in offices.

In wholesale and retail, transportation, accommodation and food service there are about 50.175 employees. This category is listed separately since the sector includes large costumer areas, hence higher cooling demand. A bigger device of 6 kW is installed every 6 employees.

- ➔ As a result nearly 0,04 TWh cooling output are generated and consumed in commercial buildings.

As for industry, it is assumed that 5% of total electricity consumption (which, according to Eurostat, amounts to 0.513 TWh) is dedicated to cooling, required all over the year.

- ➔ As a result, the cooling output required in the industrial sector is nearly 0,08 TWh.

The resulting number are shown in FIGURE 20. The numbers for 2020 are slightly higher due to an increased residential population (same growth rate of +0,4 % per year).

| TOTAL | 2013 | |
|---|---|---|
| Input | 0,153 | TWh |
| output | 0,458 | TWh |
| | 2020 | |
| Input | 0,157 | TWh |
| output | 0,471 | TWh |

*Figure 20 Total Energy Input/ Output in 2013 & 2020*

### 3.4.3. Conclusion

The electricity employed in the heating and cooling sector, as it has been assumed for 2013, represents around 24 % of the total electricity consumed. The split between heating and cooling purposes is 70 % for heating and 30 % for cooling. A major share, amounting to over 70 %, in the heating sector is used for water heating.

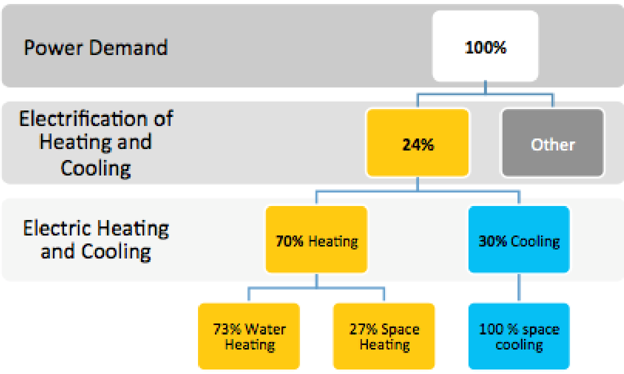



*Figure 21 Structure of power consumption by end use*

## 3.5. Development of heating sector to 2020

*It is expected that the heating sector structure evolves towards 2020, in particular the weight of SWHs and HPs will increase. Such technologies are expected to become cheaper in time and better known as a choice of usage. According to the statistics previously mentioned, investment costs for heat pumps must not even be considered, since a great number of heat pumps is already in place. However, the correct use of that technology is still not well established within the Maltese population.*

*A premise is necessary when discussing about the heating sector's technology development. It is recalled that the distinction between primary and final energy is relevant when comparing technologies. Final energy consumed in the heating sector is represented by electricity, fossil fuels (mainly LNG) and renewable resources (sun, air). However, they are not comparable, since electricity is not primary energy, hence primary energy savings can be evaluated only if the process to produce electricity is considered. For this purpose, it is considered that the electricity on Malta is produced mainly by fossil fuels and that, given the coming developments of the sector, the process efficiency is 50%. The production of electricity from RES, which interacts with the efficiency of the heating sector, will be considered in a second step.*

*The use of heat pumps and solar water heaters leads to several results. First, shares of the RES target can be covered by other sources than PV. Secondly, both technologies imply primary energy reduction to produce the same amount of heat. Finally, the electrical demand and the consumption of excess power production is affected. Both SWHs and HPs are electricity displacers, since they substitute first the worst technology for hot water or space heating generation, i.e. electric water heaters and electric heaters respectively.*

*This will necessarily affect the weight of the heating sector in the total electricity consumption, which will slightly decrease to a ratio dependent on the specific design of a model scenario. Furthermore, the increase of population, although relatively restricted, will directly lead to an increase in the demand for heating, if no consistent energy efficiency and energy saving measures are considered. It is estimated that the growth of the heat demand is almost parallel to the electricity consumption growth, hence around 0,4 % per annum.*

*The input parameters for two specific scenarios, a business-as-usual and an innovative evolution of Malta's energy system will be forecasted by the authors for 2020.*

*In order to consider both a shift in technology use and the overall heating demand growth, the evaluation of the upcoming heating infrastructure is run in two steps. In a first step, shift in technology use is applied to the existing heating demand. In a second step, the heating demand is scaled up to be consistent with the assumed growth for thermal demand, i.e. around +2,8 % over the period 2013-2020. In this second phase, it is assumed that every new occupied household will have an heat pump installed, which provides both heating and cooling and that the new hot water demand is covered for over 50% by SWHs and for the remainder by fossil fuel based devices, while electric heaters will not expand.*

### 3.5.1. Technology Status Quo in 2020

*Business as Usual scenario 2020*

The number of SWHs increased by around 600 new installations per year on average from 2009 to 2013[46], adding up to a heat production of 0,046 TWh in 2013[47]. In a conservative scenario, a continuing annual growth trend of 600 SWH, substituting existing electric heaters, is foreseen until 2020.

At the same time, it is expected that the weight of heat pumps in the existing space heating demand increases by 50 %, displacing less efficient electricity based technologies. As a result, the business as usual heating technology scenario in the first step looks as in FIGURE 22, with HPs covering 30 % of the space heating demand and 14,9 % water heating due to SWHs. In comparison, the same technologies had shares of 20 % and 12 % respectively in 2013.

| **Business as Usual heating** | | | | |
|---|---|---|---|---|
| | | demand share | input energy consumption (TWh) | final heat generation (TWh) |
| water heating | SWH | 14,9% | | 0,057 |
| | fossil fuel | 8,0% | 0,036 | 0,031 |
| | electric | 77,1% | 0,295 | 0,295 |
| | | | | **0,383** |
| space heating | fossil fuel | 70,0% | 0,265 | 0,225 |
| | electric | 0,0% | 0,000 | 0,000 |
| | HPs | 30,0% | 0,032 | 0,097 |
| | | | | **0,322** |
| | el input | | 0,328 | |
| | ff input | | 0,301 | |

*Figure 22: Energy input & output for heating technologies in a business as usual status quo*

*Innovative scenario 2020*

In the innovation-oriented scenario, a consistent shift in technology use due to raise of choice awareness is registered, hence the capacity of SWHs in occupied dwellings increases by 100% (doubling between 2013 and 2020) adding up to 0,09 TWh, substituting 0,046 TWh of heat produced through electric heaters before.

Furthermore, it is assumed that in 2020 all the households owning heat pumps use them also for space heating purposes and not only as air conditioners in summer. The increased use of HPs displaces the whole electricity used for space heating and a relevant share of fossil fuels previously employed in the sector. These technology switches result in the system represented in FIGURE 23.

| Innovative heating | | | | |
|---|---|---|---|---|
| | | demand share | input energy consumption (TWh) | final heat generation (TWh) |
| water heating | SWH | 24,0% | | 0,092 |
| | fossil fuel | 8,0% | 0,036 | 0,031 |
| | electric | 68,0% | 0,260 | 0,260 |
| | | | | **0,383** |
| space heating | fossil fuel | 50,0% | 0,189 | 0,161 |
| | electric | 0,0% | 0,000 | 0,000 |
| | HPs | 50,0% | 0,054 | 0,161 |
| | | | | **0,322** |
| | el input | | 0,314 | |
| | ff input | | 0,225 | |

*Figure 23: Energy input & output for heating technologies in the innovative scenario*

### 3.5.2. Heat Demand Upscaling to 2020

As already mentioned, it is expected that heating demand will increase at a rate of 0,4 % annually due to a slight increase in the population, as well as in the national GDP and consequently in the comfort standards (i.e. not all dwellings have an heating system in place at the moment). Such heat demand increase will be covered by installations of fossil fuel based heaters and SWHs in regards to the hot water production and by heat pumps for space heating purposes.

It is expected that 50% of the additional demand for water heating estimated for 2020 will be covered by SWHs. It is reminded that SWHs cannot provide more than 70 % of the overall energy required for water heating. Furthermore, all new occupied households will employ an HP for both heating and cooling purposes

#### *Heat demand upscaling Business as Usual*

Given the premises, the heat production from SWH would increase by 35 % compared to 2013, adding up to 0,06 TWh in 2020. This represents a displacement of around 0,015 TWh of electricity (0,016 TWh electric water heaters displacement + 0.001 TWh electricity consumption of the newly installed SWH). Furthermore, a reduction of electricity consumption for space heating purposes from around 0,05 TWh to 0,03 TWh occurs. In total, power consumption in the heating sector is reduced by nearly 0,04 TWh.

In FIGURE 24 the result of the technology shift and of the up scaled heating demand of the business as usual scenario are reported.

| Business as Usual heating 2020 | | | | |
|---|---|---|---|---|
| | | demand share | input energy consumption (TWh) | final heat generation (TWh) |
| water heating | SWH | 15,8% | | 0,062 |
| | fossil fuel | 9,1% | 0,042 | 0,036 |
| | electric | 75,0% | 0,295 | 0,295 |
| | | | | **0,394** |
| space heating | fossil fuel | 68,1% | 0,265 | 0,225 |
| | electric | 0,0% | 0,000 | 0,000 |
| | HPs | 31,9% | 0,035 | 0,106 |
| | | | | **0,331** |
| | el input | | 0,331 | |
| | ff input | | 0,308 | |

*Figure 24: Energy input & output for heating technologies in a business as usual status quo in 2020*

### *Heat demand upscaling innovative*

In the innovative scenario, the heat production from SWH would increase to almost 0,1 TWh in 2020, displacing 0,048 TWh of electricity (0,051 TWh electric water heaters displacement – 0,003 TWh electricity consumption of the newly installed SWH). Instead, the demand of electricity for space heating purposes slightly increase, since HPs also replace part of the fossil fuel based heaters. In total, power consumption in the heating sector is reduced by 0,044 TWh. In table FIGURE 25 the result of the technology shift and of the up scaled heating demand from the innovative scenario are reported.

| Innovative heating 2020 | | | | |
|---|---|---|---|---|
| | | demand share | input energy consumption (TWh) | final heat generation (TWh) |
| water heating | SWH | 25% | | 0,097 |
| | fossil fuel | 9% | 0,042 | 0,036 |
| | electric | 66% | 0,260 | 0,260 |
| | | | | **0,394** |
| space heating | fossil fuel | 48,6% | 0,189 | 0,161 |
| | electric | 0,0% | 0,000 | 0,000 |
| | HPs | 51,4% | 0,057 | 0,170 |
| | | | | **0,331** |
| | el input | | 0,317 | |
| | ff input | | 0,232 | |

*Figure 25: Energy input & output for heating technologies in innovative scenario in 2020*

## 3.5.3. Hourly heating and cooling

From the seasonal hourly distributions, seasonal space heating and cooling demand distributions are derived. Spring and autumn are taken as baseline, in which little space heating and little cooling are operated. An average distribution for spring and autumn is built as middle point reference.

In order to build the cooling demand distribution, the hourly difference between the reference distribution and the summer distribution is considered. The resulting profile is applied to the 3 summer months. It is assumed that in spring, there is an increasing cooling demand and in autumn a decreasing cooling demand and that a little constant cooling demand is required all over the year, supposing it is employed in the industrial sector.

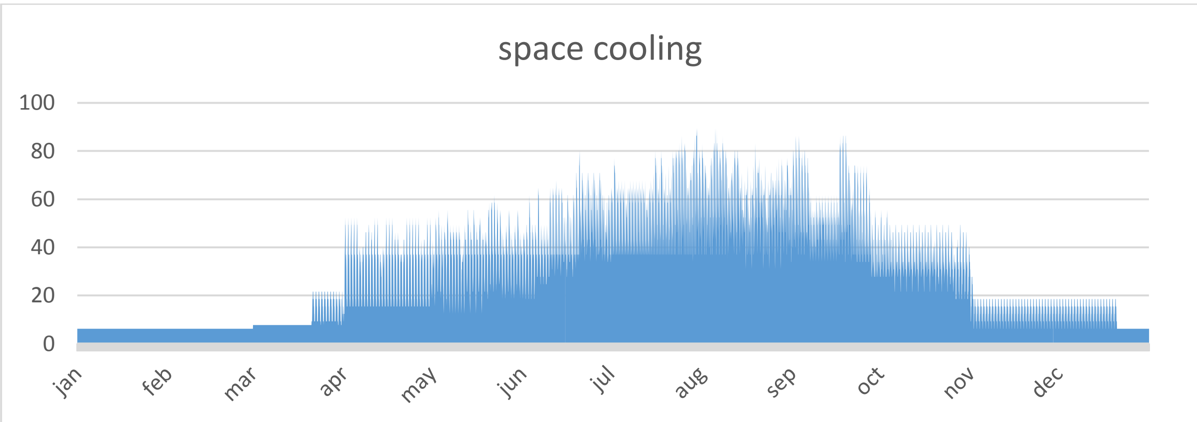



*Figure 26: Yearly hourly distribution of Cooling Demand on Malta*

Water heating demand is supposed to be a constant over the 8784 hours, with a slight increase in July and August due to the great touristic affluence. For the construction of the space heating demand distribution, it is assumed that it is required mainly in the winter months, while it is minimal in spring and in autumn.

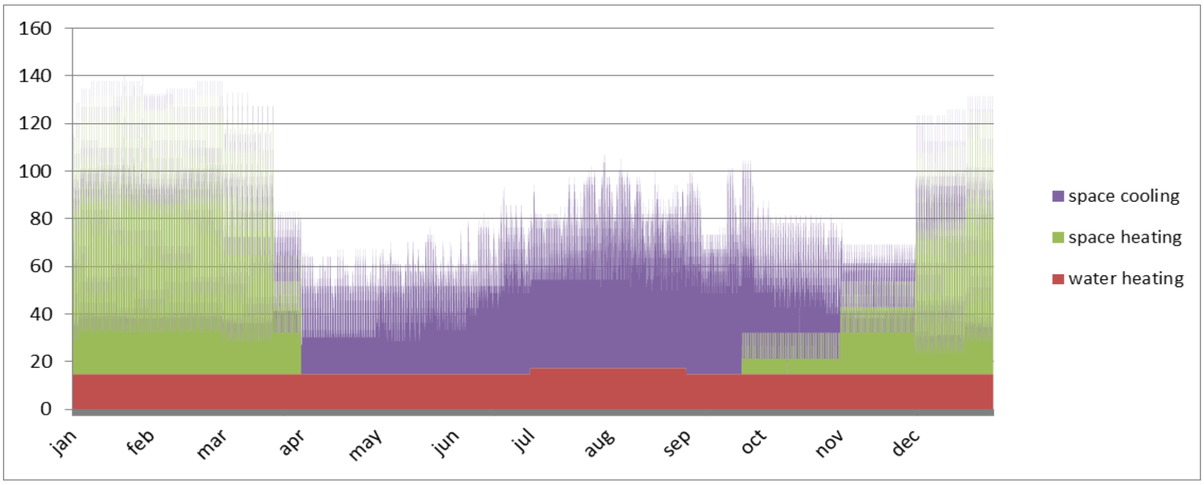



*Figure 27: Yearly hourly distribution of Water and space heating and space cooling*

According to surveys[48], most households indicated their heating period as 2 to 3 month (typically December to March). However, the analysis of the average temperatures on Malta supposes that a little space heating may be necessary also in October, November and March. The winter profile of space heating power demand is isolated as the difference between the winter and the reference distribution. Proportional distributions are provided for March, October and November. These normalized profiles are obtained by the manual adjustment of the profiles, keeping in mind that the given proportion between the heating demand for water and for space heating has to be respected.

The cooling and heating demand profiles are compared to the power demand profile. The difference between the power profile and the energy deployed for heating and cooling purposes, which is referred to as the remaining power profile, is examined. Hence, low peaks and high peaks of heating and cooling demand are manually normalized in order to obtain a realistic daily distribution and a relatively constant remaining power profile over the year, though considering seasonal features such as increased population in the summer months and less hours of light in winter

## 3.6. Final Energy Demand in 2020

The parameters power demand and heating demand have been already analyzed and it is assumed that they do not change dramatically until 2020, except for a small increase of 2,8% in heating and cooling demand, as well as in the remaining power demand. Another important factor on final energy demand are energy efficiency measures, which will not be considered in this project. That leaves the transportation sector, which can be split between road transport and aviation. One must consider that due to statistic measures from the EU[49], the energy demand for aviation of Malta cannot exceed 4,12 % of the overall final energy consumption, hence its registered value must substantially be lowered from the real value and is separated from road transport energy consumption. Despite the historical increasing trend of energy demand for road transportation, it is assumed that energy demand in transportation decreases by an average annual rate of 0,5 % until 2020. The reasons for a decrease are foreseen in technology advances and stricter regulation on emissions from cars leading to purchases of more efficient vehicles. Another reason is the saturation of demand for cars (number of cars already increased at a high rate in the past years) which has risen. Hence, it is supposed that the energy demand for transportation from 1,86 TWh at an annual rate of 0,5 % to 1,8 TWh in 2020. The same trend is expected until 2030, leading to a final demand in the energy sector of 1,71 TWh. A slow penetration of electric vehicles (between 2020 and 2030 mainly) and better use of public transportation in the near future are further factors, which could change the development more radically, if e-mobility is set as a serious goal.

In conclusion, the slight increase in heating and cooling, as well as in remaining power is partly compensated by the decrease in final energy demand for transportation. Hence, the same final energy consumption of around 5,74 TWh as in 2013 is used also for 2020.

# 4. Supply side

## 4.1. Organisational set up of Malta's power market

With Enemalta, there is only one large vertically integrated entity stakeholder, which is licenced to supply power to end-customers on Malta. Enemalta is also power producer and grid operator. That organisational structure opposes to EU directives for unbundling of the power sectors. However, Malta was granted derogations in regards of its power market organisation, due to its belonging to the category of "small isolated systems", as defined in the European Directive 2003/54/EC. Malta didn´t have, until April 2015, grid bound access to other energy markets and its system is too small to deliver economies of scale and effective competition. Malta is not expected to grant third party access to the transmission and distribution systems and is not required to set a liberalized market and to grant independence and unbundling of the TSO from the other system functions.

Given the premises, Malta does not have a wholesale market in place and the balancing between generation and demand is carried out by Enemalta PLC, which also sets the end-consumers price. This must be approved by the Malta Resource Agency (MRA), which underlies the Ministry of Energy and Health. The marginal price of the power production is determined by Enemalta ex ante, based on the foreseen generation mix in the next year or years. Until the beginning of 2015 this price was at the level of 0,11 € cent/kWh.

In 2014, the Chinese company Shanghai Electric Power purchased a 33 % stake in Enemalta. The remainder of 67 % stake is owned by the Ministry of Energy and Health. Hence, the interests of the Maltese government mostly coincide with the ones of Enemalta. A limited amount of renewable energy is produced by small independent electricity producers. Their production is either self-consumed or sold to Enemalta PLC.

## 4.2. Current Supply Side of Malta's energy system as in 2014/2015

Up to now power production from Malta has relied on the two power stations, Marsa and Delimara, whose characteristics are specified in FIGURE 28. Both plants are operated by the monopoly entity Enemalta and both plants are running on heavy fuel oil (HFO) and Gasoil. The running units of the two plants combine a nominal capacity of 583 MW and used to generate nearly 100 % of the power consumed on Malta. Marsa power plant has already been partly decommissioned while a remaining capacity of 130 MW is finally going to be decommissioned by the end of 2015.[50] Enemalta has already been fined by the European Commission, since the outdated power plant, whose $CO_2$ emission intensity exceeds 950 kg $CO_2$/MWh, was not allowed to run more than 20.000 hours between 2008 and 2015 according to the EU's large combustion plant directive (LCP Directive 2001/80/EC).[51]

The Delimara 3 unit is planned to be refurbished to run on natural gas in the future. Delimara 1's steam turbine with a capacity of 120 MW is planned to be mothballed as soon as enough alternative capacity is available.

| Power Station | Technology | Gross supply capacity (MW) | Fuel | Efficiency | year of commission |
|---|---|---|---|---|---|
| **Marsa B 7-8** | 2x STG | **130** | HFO | | 1964-1987 |
| **Delimara 1-ST** | 1x STG | **120** | HFO | 29,70% | 1992 |
| **Delimara 2A-GT** | 2x GT | 74 | Gasoil | 20% | 1996 |
| **Delimara 2B** | CCGT-2y GT, 1x ST | 110 | Gasoil | 37,90% | 1998 |
| **Delimara 3** | 8x Internal Combustion Engines | 149 | HFO | 47,40% | 2012 |
| **Total** | | **583** | | | |

*Figure 28: Malta's power plant fleet (old status quo)*

FIGURE 29 shows Malta's rising power production (red bars) from roughly 1.700 GWh in 1995 to 2.216 GWh in 2013[52]. The blue line shows the related $CO_2$ emission factor per MWh which decreased from approximately 1,1 tons $CO_2$ / MWh to almost 0,7 tons $CO_2$ / MWh in 2013. This number is comparatively high, when considering that the EU registered a $CO_2$ emission factor of 0,46 tons $CO_2$/MWh in 2010 on average[53].

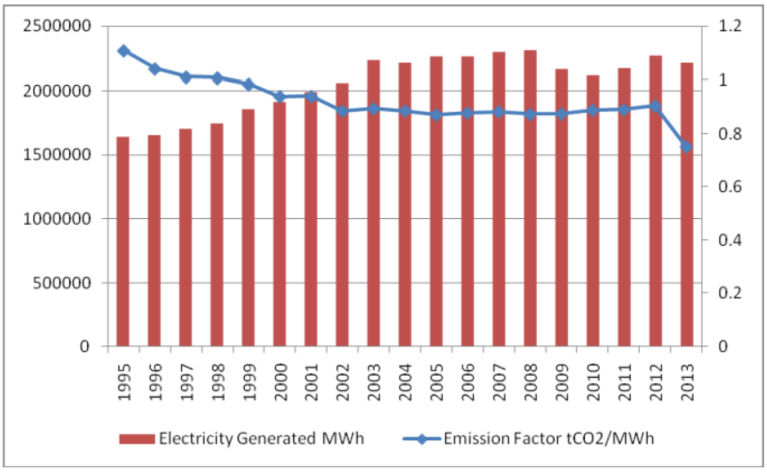



*Figure 29: Historic power generation and related emission factor [54]*

### 4.2.1. GHG Emissions

In FIGURE 30[55], Malta's GHG emissions per sector are compared with the EU average (2011). It becomes obvious that major GHG savings can still be achieved in the power industry, accounting for almost two thirds of the total 3,1 Mt $CO_2$eq registered in the country in 2011.

| GHG emissions per sector | Malta | EU average |
|---|---|---|
| Energy/Power industry | 64% | 33% |
| Transport | 19% | 20% |
| Industry | 7% | 20% |
| Agriculture | 3% | 12% |
| Residential & Commercial | 3% | 12% |
| Waste & Others | 4% | 3% |

*Figure 30: Comparison of GHG emissions per sector between Malta and EU*

Among the other big GHG contributors, Malta's transportation has about the same share as in the EU average, whereas industry, agriculture and residential and commercial sectors have a quite little share in comparison to the EU. This is due to little presence of activity in the primary and secondary economic sectors and to the fact that Malta presents one of the lowest energy consumption rates per household in Europe[56].

## 4.3. Future Capacity of Conventional Power Production as from 2016

FIGURE 31 shows the future conventional power production capacity, as it is already planned and financed, which will also be modelled by the author's 2020 energy system scenarios. The negative capacity difference of 250 MW deriving from the shutdown of Marsa B 7-8 and of Delimara 1 ST will partly be compensated through the Sicily-Malta Interconnector coming online in 2015, theoretically adding 200 MW to the system.

The Maltese power plant fleet will be enforced by private investments from the ElectroGas Malta consortium, a German, Azeri and Maltese joint venture, which won the independent power producer (IPP) tender opened by Enemalta in 2014[57] and will construct a 215 MW advanced combined cicle gas turbine. An 18-year power purchase agreement (PPA) between the consortium and Enemalta, who will distribute the power, was agreed on from 2016 on. The PPA price is 95,99 EUR/MWh[58] , including the option of negotiating the technical and economic conditions (quantity and price of the delivered energy) every 5 years.

The 149 MW Delimara 3 unit will be refurbished to run on natural gas as the new CCGT capacity is commissioned and a floating LNG storage and a regasification plant are built under the agreement between Enemalta and ElectroGas. A gas supply agreement (GSA) is included in the deal, which secures gas supply for Delimara 3.

The specific conditions of the agreement have not been disclosed entirely, but it seems that both price and quantity of the delivered energy are set, at least to some extent, in advance. This makes the presence of a PPA a limiting factor to the development of the rest of the system, in particular of renewable electricity sources, since a consistent share of the supply will be locked, without possibility of displacing it with a more effective alternative.

| Power Station | Technology | Gross supply capacity (MW) | Fuel | Efficiency | year of commission |
|---|---|---|---|---|---|
| Delimara 2A-GT | 2x GT | 74 | Gasoil | 20% | 1996 |
| Delimara 2B | CCGT-2y GT, 1x ST | 110 | Gasoil | 37,90% | 1998 |
| **Old capacity** | | **184** | | | |
| Delimara 3 | 8x Internal Combustion Engines | 149 | Natural Gas | 47,40% | 2012 |
| IPP Advanced CCGT | | 215 | Natural Gas | 50 % ? | 2016 |
| **New capacity** | | **364** | | | |
| **Interconnector** | | 200 | | 95,4 | 2015 |

*Figure 31: Malta's upcoming conventional power supply*

Conventional production capacities on Malta will add up to 548 MW, split in 184 MW of old gasoil plants, maintained as back up capacity, and 364 MW of new natural gas power generation. When including the 200 MW interconnector capacity, a total conventional capacity of 743 MW will be registered on Malta in the future. This capacity is more than sufficient to cover the peak electricity demand, registered as just above 400 MW in the Maltese system.

It can be expected that the 184 MW of oil-fired capacity will not be needed on a regular basis, except for backup capacity in emergencies. In theory, it can be expected that an increased PV capacity, whose influence is discussed afterwards and the IPP will be almost the only players on the supply side in Malta and will increasingly push the conventional power generators out of the merit order. The price setting technology will be the gas-fired power plant. However, Malta does not present a liberalized market, hence the dispatching of the different sources is not always market driven, but first needs to provide security of supply and comply with long-term agreements (natural gas plants CCGT and interconnector with Sicily).

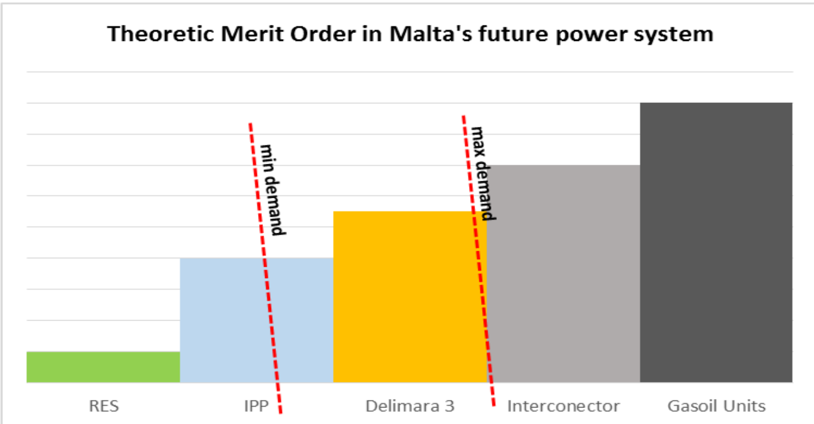



*Figure 32: Theoretic merit order in Malta's future power system [59]*

The anticipated merit order supposes opposition from the established monopoly entity Enemalta towards a more sustainable energy system with RES.

## 4.4. Production from RES

**PV**

Since the most updated data concerning PV installations and generation refer to 2014, it has been chosen to stick to these most updated numbers, although the reference year is 2013 for most of the system elements.

On Malta, the production of electricity from RES is almost completely imputable to PVs. The production from PV systems rose from 530 MWh in 2009 to 38.255 MWh in 2013[60][61]. Starting from 2010, PV generation increased by 54% to over 100% every year. The share of electricity from PV to the overall power production in 2013 amounted 1,74 %.

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|
| Capacity (MW) | - | 0,742 | 5,340 | 15,928 | 27,325 | 50 |
| Production in MWh (cumulative) | 530 | 1.730 | 8.430 | 13.620 | 38.255 | 70.735 |
| Power Demand in GWh | 2.167 | 2.113 | 2.168 | 2.268 | 2.167 | 2.200 |
| Share of power from PV | 0,02% | 0,08% | 0,39% | 0,60% | 1,77% | 3,22% |
| W/capita | 0 | 1,74 | 12,55 | 37,44 | 62,24 | 118,78 |
| Population | | | | | | 425.384 |

*Figure 33: Development of PV production on Malta*

By the end of 2013, 27,33 MW installed PV capacity with a production of 38.255 MWh were registered in Malta. Considering the already approved proposals for PV systems in 2013, the authors assume that around 50 MW must have been installed by the end of 2014. That figure would equal 119 W/capita of PV installations on Malta. For a comparison, it is reported that in Germany, given an installed capacity of 38.500 $MW_p$[62] and a population of 80 million inhabitants, that W/capita ratio corresponds to 481 W/capita. Given the much higher population density in Malta, the lack of open area PV systems and a quite recent introduction of incentives for PV installations that number can be considered a big success already.

**Other RES**

No relevant wind power capacities are installed. Micro scale wind turbines produced only around 14 MWh in 2013. 1,9 MW of Biogas plants were installed at the end of 2013[63]. Actual production numbers are not known. Assuming 6000 load hours for the biogas plants, some 11.400 MWh were likely been generated. Waste to energy technologies also produce variable amounts of energy, which partially account for renewable energy, but play a negligible role in the system.

No further power production from RES is evident. The overall RES share was registered as 2,26 % of the power consumption in 2013[64] and assuming the recent trend a further growth is foreseeable.

## 4.5. Grid Stabilization Share and technical flexibility of the system

The increasing penetration of variable RES in a power system leads to the issue of system balancing and of security of supply. Major solutions to the issue are flexible power plants, sufficient interconnection capacity with other countries providing diverse load profiles, enough back up capacity, storage technologies and demand side management. There is no univocal answer to the question of the maximum share of electricity that can come from fluctuating RES in an energy system, without endangering system stability. In fact, the specific features of the considered system, in particular its flexibility have to be taken into account[65].

In a relatively well-integrated system, it is generally considered that up to 70% of the demand can be covered at any time by variable RES, without causing specific troubles to the frequency and voltage of the grid. That would translate into a 30 % minimum grid stabilisation share, i.e. the requirement that at any time minimum 30% of the demand is covered by firm capacity (conventional power plants which can provide the ancillary services of system stabilisation). 30 % is also the default value assigned to the parameter in EnergyPLAN. In case of an isolated, badly interconnected or poorly differentiated system, this maximum penetration share of renewables could also be considered lower or particular attention has to be paid.

On the contrary, a well-integrated and flexible system can also bear higher penetration of fluctuating RES generation. Although Malta has just lost its historical isolation thanks to the start of operations of the interconnector to Sicily in 2015, the system remains delicate, since the flexibility of the system gained through the interconnection is only partial. In fact, the interconnection is in place only with Sicily, an Italian region, which is hardly interconnected to the rest of the continent and has a fragile electrical system itself. Furthermore, the operation of the cable is subject to a bilateral agreement between Italian grid operator Terna and Enemalta, which limits the operational schedule of the interconnector and privileges the import of power to Malta and not the export.

In addition to that, it is relevant to evaluate how many separate units compose the conventional capacity, which is an indicator of flexibility. The future Maltese power system is based on a reduced number of only two major power plants. However, the Delimara 3 plant consists of 8 internal combustion machines adding up to a capacity of 149 MW. Hence, combustion units are smaller than 20 MW on average. As for the new gas fired power plant, no specification is available but it is likely that its 215 MW capacity is divided in smaller separate units. This factor is positive in regards of the flexibility of the system. RES penetration from PV will be the only significant fluctuating source to the energy system. On advantage, fluctuations in power production from PV on Malta are rather low due to the relatively constant clear sky weather conditions, leading to sufficiently precise generation forecasts. For all mentioned characteristics, it is chosen to work with a value of minimum 30% grid stabilisation share. This factor will influence the operation of the system, hence the feasible structure of the system and in particular the PV penetration. Hence, an evaluation of the possible system setup, when introducing more flexibility in the system and reducing the minimum grid stabilisation share, will be operated.

# 5. RES-e potential

As already mentioned, Malta is characterized by a small territory and a high population density. As a result, available land area is very scarce and intense competition in utilization of the latter exists. 33 % of Malta's land coverage[66] is sealed by constructions (buildings, roads, artificial area), compared to EU's average of 5 %. Consequently, land is extremely valuable, which makes its availability seem to be the biggest constraint to the expansion of RES installations, rather than resources availability itself.

FIGURE 34 gives an overview of the technologies with the best potential for RES power production on Malta, which are wind power, solar and biomass. Solar energy is circled to show that the utilization of that energy source is politically prioritized, since it can be utilized with the least land consumption and less environmental impacts through PV rooftop installations. It is expected to have the highest potential among various RES. Waste to Energy can only be a minor contributor due to the limited amount of waste, biodegradable waste in particular.

Wind energy is sharply debated due to its high environmental impacts and therefore currently officially not considered to be utilized in the near future due to strong interference with restrictions and rules in Malta's land planning and fauna protection (negative outcome of the environmental impact assessment). Nevertheless, the technology is not dismissed completely in this paper since planning restrictions can change with political decisions and more ambitious targets towards a sustainable energy system in the long-term.

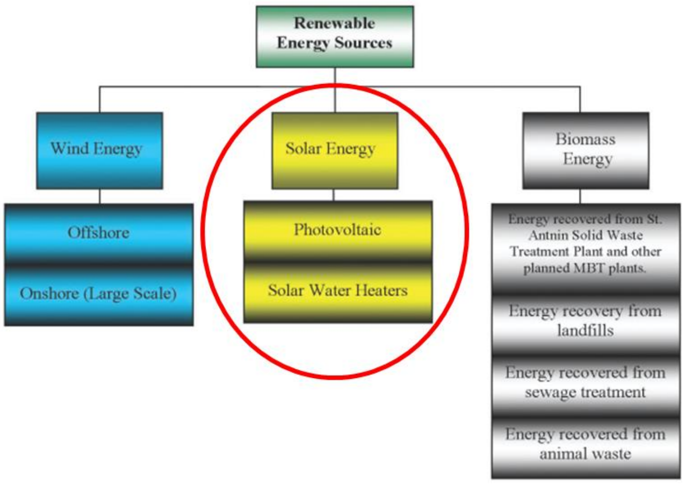



*Figure 34: Focus of RES technologies for Malta* [67]

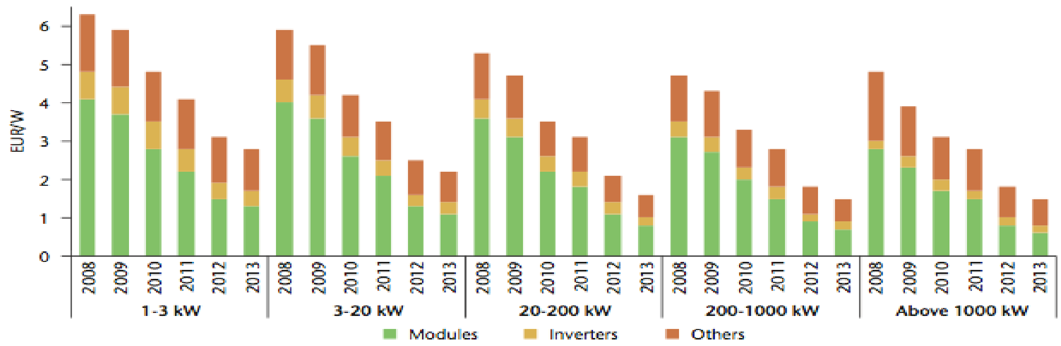
In the following, the conditions for PV on Malta in regards of the resource availability and of its land consumption and environmental impacts are analyzed. Wind power is briefly examined afterwards.

PV panel installations will be the main driver towards Malta's 2020 RES targets and most likely beyond that time horizon. Malta presents the best solar resource in the EU and PV power peak production on Malta coincides rather well with the yearly peak loads during summer middays, when the demand for cooling is high and the Island is overpopulated with tourists. Hence, also some technical principles for that technology are explained and a detailed methodology about the assessment of its potential is provided.

## 5.1. PV - Technical background

The tremendous price falls for PV modules is not expected to stop[68], as well as technology advances, which will further increase economic feasibility of PV. Solar photovoltaic (PV) cells are semiconductor elements, which generate direct current electricity through the direct conversion of sunlight. The technology underwent a major development in the past decade, both performance and price wise. In FIGURE 35 the decrease for prices of PV systems on the Italian market is shown from 2008 to 2013. System prices decreased by almost one third over that period, with major reductions coming from the price drops of the PV modules.

Until 2050, prices are expected to continue to follow a similar learning curve as the one experienced until now, hence a fall of prices around 20% for every doubling of installed capacity[69].




Source: Gestore dei Servizi energetici (GSE) (2014), *PV in Italy: Generation Costs and Value Chain*, May, Rome.

*Figure 35: Decrease in PV installations price in Italy between 2008 and 2013 according to the size of the installation*

At the same time, while prices are dropping, technological improvement brought the efficiency of the most common technology, i.e. crystalline silicon panels, to an average of 16% in 2013[70]. The best performing commercial technology reaches the efficiency of 21 %, while commercial thin film technology presents an efficiency of up to 14 %. This factor, namely conversion or nominal efficiency, is defined as the ratio between the produced electrical power and the amount of incident solar energy per second.

The nominal efficiency relates to the power generated under the so-called "standard test conditions" (STC), i.e. module temperature of 25°C, vertical irradiance of 1 000 $W/m^2$, air mass of 1,5 and a specific irradiance spectrum.

For the upcoming calculations, the efficiency of 16% is taken as baseline, with possibility of an improvement at a speed slightly slower than in the past decade (flattening of learning curve). According to the latest study of Fraunhofer ISE on behalf of Agora Energiewende, a famous German think tank in the energy sector, the conversion efficiency of crystalline modules is expected to increase by 150% to over 200%, reaching values of 24% to 35% in 2050[71]. In the worst case of the achievement of an efficiency of 24%, a constant growth rate of 1,2% p.a. is assumed, which will bring the PV conversion efficiency to 17% in 2020 and to 20% in 2030.

Another factor influencing the energy outcome from solar panels is the performance ratio (PR), which is related to the whole balance of system, e.g. panels, inverters, transformers, wiring and monitoring equipment. This factor is due to the deviation from the standard conditions, on which the nominal efficiency is calculated (temperature and incident radiation) and on losses in the transmission and conversion (wiring and inverter). PRs can reach up to 90%, but in the following, a conservative performance ratio value of 75% is considered, mainly due to the high temperature on Malta.

Hence, the overall transformation process efficiency is given by (nominal efficiency)*(performance ratio). It is reminded that the former is given by technological limits, while the second is related to the specific installation features and external effects from the environment, like temperatures.

### 5.1.1. Alignment to the sun

The energy output of PV modules depends also on parameters, which are related to the specific installation settings. First, the location of the installation is fundamental, since the global irradiation on a horizontal surface, i.e. the energy of the sun reaching an area on the ground, expressed in kWh/m$^2$, varies with the latitude. The global irradiation does not present the maximum value on a horizontal surface though. The energy gain is maximal if the solar direct radiation is incident with an angle of 90 degrees to the surface of the PV modules. Given the rotation and revolution movements of the Earth around the sun, the maximum energy output is achieved on a surface, which adjusts inclination every hour during the day and every day during the year, according to the sun' s altitude (expressed in degrees). The sun altitude variations across the year in Malta, at a latitude of around 36°, is represented in the polar diagram in FIGURE 36.

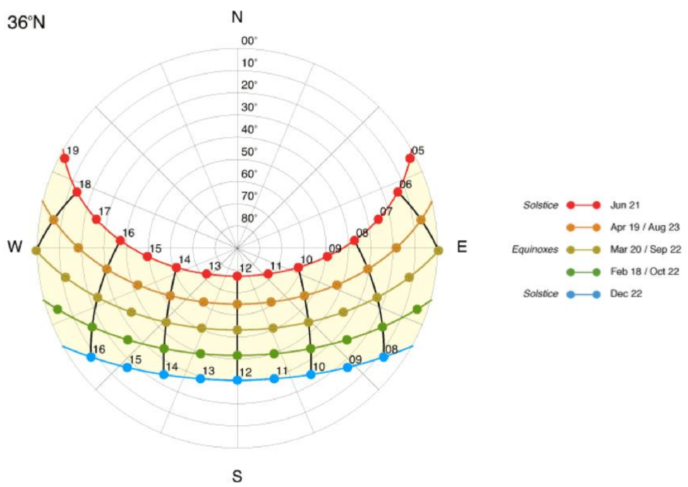



*Figure 36: Polar diagram for a latitude of 36°, representing the solar altitude at any point of the year*

At any point, the optimal inclination of the PV panel is calculated as (90°-sun altitude). Furthermore, sunrays reach a surface directly from the south only at midday, while during the rest of the day they reach the ground from east, southeast, south-west and west. However, only the options of fixed tilt angles are considered in the following, since tracking structures always facing the sun are expensive and they consume themselves energy.

### 5.1.2. Optimal tilt angle for Malta

If the option of tracking structures is excluded (green line in the chart in FIGURE 36), the tilt angle of the PV installations can optimize either the winter output (purple line), the summer output, the seasonal output by manual adjustment or the yearly total output. It is decided that the main interest on Malta is to optimize the overall energy output from RES installation, hence it is discussed what is the optimal tilt angle for this purpose, according to the geographical location of the island.

Malta is located at a latitude around 36° north. Referring to Landau[72], at latitudes between 25° and 50°, the exact formula, which maximizes the energy gain over the year and over the day is

$$0{,}76 * latitude + 3{,}1°$$

This formula takes the maximization of the daily output over the year into account and does not focus on the midday maximum output only. Hence, in Malta the optimum tilt angle, which enables to gain the maximum yearly energy output from a PV installation, would amount to 30,5°, according to this methodology. This formula, applied to a latitude of 40°, provides the blue curve in the graph of FIGURE 37. Mott Mc Donald, who conducted two studies on the PV potential on Malta, in 2005 and 2009 respectively, on behalf of MRA takes 30° as optimal tilt angle.

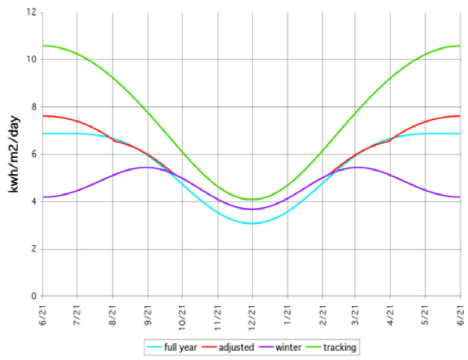



*Figure 37: Energy output over the year, given different installation settings of the PV panels* [73]

In contrast, according to the tool PV GIS[74] and other field studies, the optimum fixed tilt angle in Malta, which enables the maximum gain of energy is 32°. This value is generally agreed on and optimizes the energy output at midday over the year. Hence, by applying this tilt angle the peak is maximized, but not the yearly production sum.

In the following, an optimum tilt angle of 32° is considered, since the greatest set of data employed in the project calculations come from the PV GIS database. In any case, minor variations of the tilt angle around the value of 32° or 30,5° do not relevantly change the outcome.

On a panel optimally inclined, although not tracking the sun, the global irradiation is higher than on a horizontal surface. According to the European Solar database PVGIS[75], in Malta an horizontal surface receives an annual irradiation between 1805 and 1959, with a country average of 1913 kWh/$m^2$, while a 32°-inclined surface reaches an average of 2155 kWh/$m^2$ per year, representing an increase of 12,6%.

### 5.1.3. Ground Coverage Ratio

Assuming flat rooftops or fields, as it is the case of Malta, the installation is not constrained by architecture and the optimum tilt angle can be applied through the employment of inclined supports. Another parameter is strictly intertwined to the choice of the tilt angle: the ground coverage ratio. This is the area of the PV modules divided by the available area for the PV system's installation, which depends on the installation setting and on the shading elements. This factor is particularly relevant in case of the expensive and/or limited land resource in Malta. The GCR must be decreased when the tilt angle increases to avoid shading since, when PV panels are inclined, shading from adjacent panel rows occurs if the proper distance in between is not respected. FIGURE 38 shows that lower inclination angles require less spacing, hence allowing higher GCRs without shading.

A choice between optimum tilt angle and maximum GCR shall be discussed in a context of limited available area for PV installations. Furthermore, the minimum distance between panel arrows, in order to avoid shading, differs between winter and summer and it can be chosen whether to avoid shading only at midday or for longer periods of the day. Hence, the installation can be optimized in order to avoid shading at midday of the winter solstice (recommended), or it can be preferred to increase the GCR, although this implies higher shading in certain periods of the year (e.g. winter time and morning/afternoon) or decrease the GCR to avoid any shading, although this requires more area for the same installed capacities.

The choice of the GCR for the installation of PVs in Malta will be discussed in more detail later on in this chapter.

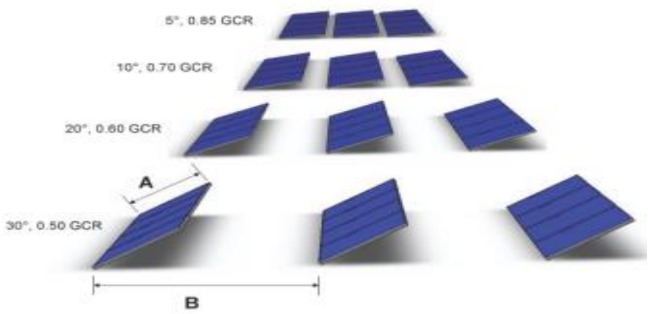



*Figure 38: Relation between inclination and ground coverage ratio [76]*

Hence, the actual energy output of a solar module depends on the technology employed, and on the setting of the installation (location, tilt angle and shading), on the system performance and on the solar resource availability (irradiance and meteorological conditions).

## 5.2. Methodology PV potential calculation

The PV potential on Malta is calculated on the two parameters of solar resource availability and the availability of land resource or respectively the available roof top area.

The solar resource is evaluated through the data of maximum solar irradiance (W/m$^2$) and yearly global irradiation (kWh/m$^2$), which are provided by the Joint Research Centre of the European Commission[77]. For a better understanding, Malta's PV potential will be categorised in a European context first. In studies after Suri et. al unconstrained irradiation, land resource and demand for power are set in relation to each other in order to define the hypothetic potential for PV. Afterwards the specific potential according to land resource constraints on Malta is analysed.

*The unconstrained land resource is simply the land area of Malta. The constrained land resource is the overall land area subtracted by all areas, which are not to be deployed with PV installations. The availability of space for PV installations, mainly rooftops and brownfields, is assessed based on literature studies and of an analysis led by the authors, whose specific methodology will be explained within the section* PV POTENTIAL ACCORDING TO LAND RESOURCE*.*

### 5.2.1. PV Potential according to solar resource

As already mentioned, Malta has a yearly average sum of global irradiation of 1913 to 2155 kWh/m$^2$ at horizontal and optimally inclined surface respectively, according to the data provided by PV GIS. The geographical distribution is illustrated in FIGURE 39.[78] It is not only the high overall solar irradiation, but the relatively constant solar irradiation during the year due to the low latitude and the frequent presence of clear sky, which makes conditions on Malta favourable to operate PV systems. 62,6 % of the year weather conditions are characterized by clear or very clear sky[79], which makes the forecast of the hourly power production from PV and its integration in the system easier.

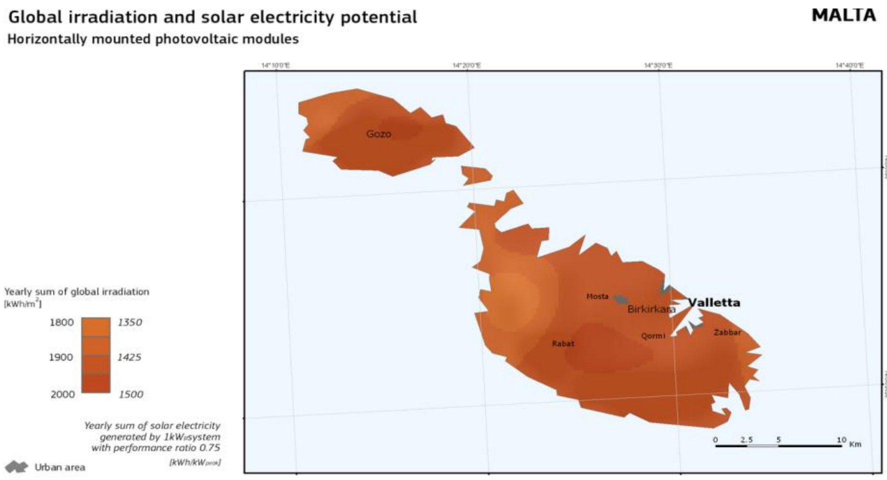



*Figure 39: Global irradiation on Malta* [80]

Malta has the highest potential for power generation from PV in regards to its nominal energy yield per square meter in comparison to all European countries, as represented in FIGURE 40. Hence, the same amount of power produced from PV would require less land consumption than anywhere else in Europe.

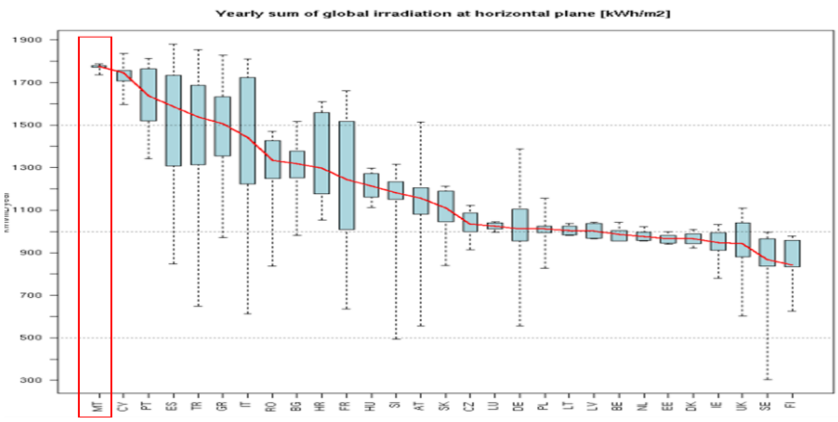



*Figure 40: Yearly global irradiation at horizontal plane in all the European countries. The red box highlights the position of Malta[81]:*

Hence, also the ratio of $kWh/kW_p$ is the highest in Europe, reaching values around 1650 $kWh/kW_p$ given a PV panel efficiency of 16 % and optimal tilt angle. That is equivalent to a capacity factor of 18,8 % (~1650 hours/year) for PV systems on Malta.

### *Calculation of the maximum capacity per square meter*

To derive the maximum PV capacity, which is installable on a given area, the potential maximum peak per square meter is calculated by the following formula:

$$A= (B*C)/1000$$

A= PV installation $kW_p/m^2$ B= maximum clear sky irradiance ($W/m^2$) C=PV module efficiency

Maximum irradiance of 980 $W/m^2$ occurs on Malta, according to the European Commission Joint Research Centre.[82] Given a module efficiency of 16%, the value of 157 $W_p/m^2$ is found, meaning that the installation of 1 $kW_p$ requires an area of 6,4 $m^2$, if ground coverage ratio is not considered.

### *Calculation of PV power output*

The annual energy output from a unit of PV installed capacity ($kWh/W_p$) is calculated by applying the formula:

$$E=n_p*G_{i,h}/A$$

Where:

*A= Maximum capacity per square meter* ($W_p/m^2$),

$n_p$ = *(system efficiency PR)*(module efficiency)*

$G_{i,h}$= *annual sum of daily global irradiation on the panel* ($kWh/m^2$)

The maximum value is achieved in case of an installation at optimal inclination, which faces true South and avoids shading, for which the value of $G_{i,h}$ amounts to 2155 $kWh/m^2$. In case of horizontal installation, this number amounts to 1913 kWh/m$^2$. This leads to a generation of 1647 and 1462 kWh/kW$_p$ respectively. Once the surface potential for PV installations on Malta is assessed, these numbers will be employed to evaluate the maximum potential installed capacity and the energy output from the installations.

### 5.2.2. PV Potential according to land resource

FIGURE 41 shows how much of a country's surface must be utilized by PV installations in order to hypothetically cover the country's power demand, given the electricity consumption of 2005 and an efficiency of PV modules around 12%. Despite being one of the European countries with the highest irradiation levels, Malta would have to utilize the largest share of its land area (3,55 %) for PV installations among all European members, since its overall surface is so small. In the case of Malta a land area of 11,22 km$^2$ had to be sacrificed, meaning around 28 square meters per capita. However, the Netherlands and Belgium are not far from this share, due to the relatively limited area and the much lower irradiation level than on Malta. Bear in mind that only the overall sum of production from PV but not the right match of supply and demand was considered in this example.

Given relatively stable electricity consumption in the past decade and an increase in the PV efficiency, a new calculation with updated values would lead to a value of around 8,5 km$^2$ in case of optimally inclined surface and neglecting the ground coverage ratio or 9,6 km$^2$ in case of horizontal installations

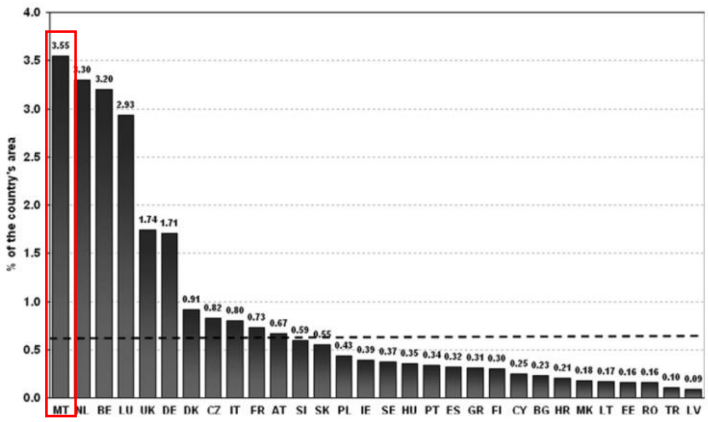



*Figure 41: Land area needed for PV to cover a countries power demand* [83]

Another interesting calculation run under the same study of 2006 points out that Malta would have to utilize 0,28 square meter per capita in order to cover 1 % of the country's electricity consumption with PV power (FIGURE 42). The dashed line indicates the average size of TV satellites to give an easier grasp of dimensions. Assuming Malta wants to cover 10 % of its electricity consumption by PV in 2020 and considering the efficiency improvement of the technology, just 2,8 m$^2$ per capita of PV panels are needed. Assuming 3 people per household on average (2,9 in 2011 according to Eurostat statistics[84]), each household would have to sacrifice less than 6,84 m$^2$ for a PV installation, if only residential areas are considered for the scope. According to the calculations operated before in this chapter, that portion of area is sufficient for a crystalline PV module installation of 1kW$_p$ with an efficiency of 16 %[i].

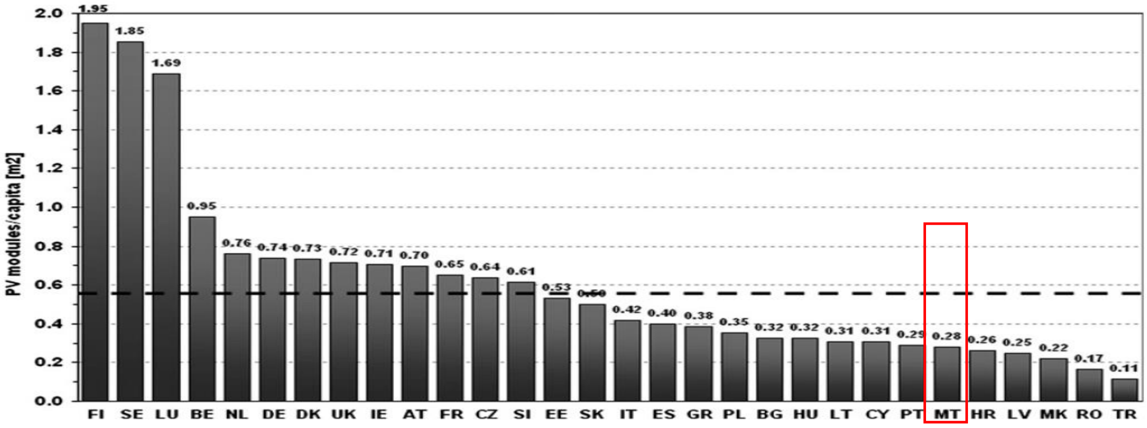



*Figure 42: Area per capita needed to cover 1 % of a countries' power demand* [85]

The evaluation of the available area for the installation of PVs by 2020 is considered crucial to define the potential and the limits of the Maltese power sector, though no updated data are available on that. Based on literature studies and on an analysis led by the authors, numbers are provided. The authors have defined an own methodology and the calculated outcome will be the starting point for the PV potential assessment. It is considered that the only available area for PV installations is constituted by rooftops and brownfields for Malta, which will be assessed in the following. Analyses of the residential and industrial sector available rooftop area are run separately.

### *Roof top area for Malta's Residential sector*

The available roof top area of residential buildings is constrained by several criteria, which are summarized in the chart below and explained in the following.

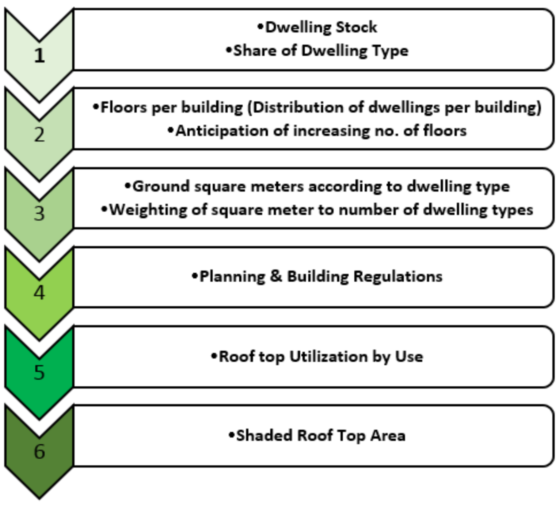



*Figure 43: Constraining parameters for PV roof top area*

[i] With irradiation of 980 (W/m$^2$)

*Building stock and dwelling type*

In order to calculate the rooftop area for the Malta's residential areas, one must identify Malta's building stock.

Data on the residential building stock was available from a census in 1995, which was already used in older studies[86]. However, that is hardly accurate enough due to the rapid growth in population and economy on Malta since that time. A new census from 2011 provides data about the number of dwellings in different housing categories on Malta. One can generally differ between single household and multi household building types.

Data for the building stock is taken from the Census of Population and Housing 2011[87]. As already anticipated when discussing the energy demand evolution, population growth is expected to be much weaker than in the past years, hence only a moderate growth in the dwelling stock is foreseen.

The next table shows the development of the building/dwelling stock from 2005 to 2020, as assumed in this project. Whereas the data for 2005 and 2011 is certain, the numbers for 2020 are results of an extrapolation of the anticipated remaining growth characteristics from 2005 to 2011. One can generally differ between single household and multi household building types.

| | 2005 | Share in % | 2011 | Share in % | 2020 | Share in % |
|---|---|---|---|---|---|---|
| Single household buildings, SUM | 65.614 | 47,1 | 63.020 | 41,3 | 58.000 | 37 |
| Multi household buildings, SUM | 72.729 | 52,3 | 89.064 | 58,3 | 98.500 | 62,7 |
| Maisonettes | 40.160 | 28,9 | 44.145 | 28,9 | 45.500 | 28,0 |
| Flat / Apartment / Penthouse | 32.569 | 23,4 | 44.919 | 29,4 | 53.000 | 33,8 |
| Other | 835 | 1,0 | 686 | 0,4 | 500 | 0,3 |
| TOTAL | 139.178 | | 152.770 | +18,5 | 157.000 | |

*Figure 44: Malta's building stock 2005 to 2020*

In 2005, there were 139.178 occupied dwellings registered, from which 47,1 % was single household buildings and 52,3 % was multi household buildings. In the updated census of 2011 the overall number of the occupied dwelling stock rose by roughly 10 % to 152.770. In 2011 the share of single household buildings decreased to 41,3 %, while the share of multi household type increased to 58,3 %. The authors expect the characteristics of the development from 2005 to 2011 to continue until 2020, although with a slower growth rate. Hence, a growth of only 2,8 % (in 9 years) resulting in a building stock of around 157.000 is assumed for 2020 with the major share of 62,77 % coming from multi household buildings.

*Floors per building*

Although data is available only for the number of overall dwellings, it must be considered that some buildings have multiple floors vertically stacked, meaning that not every ground square meter of a dwelling can be counted as roof top area. Data concerning the number of floors was taken from previous studies[88] and slightly corrected upward, since it is expected that the building stock of Malta will rather grow vertically in the future, since ground space is already quite exhausted. That assumption is already backed by the fact that the share of single houses decreases, in favour of multi household buildings, as reported by the Censing Report on Housing for the period from 2005 to 2011, and is assumed continuing also until 2020.

The number of floors for multi household buildings was calculated as 1,5 floors for maisonettes and three floors for flats & apartments in studies published around 2005[89]. As more and more new buildings are constructed as multi household buildings containing various households to use land more efficiently, there is less roof top space available per household. The number of floors averages four floors for newly built flats/apartments/penthouses from 2005 to 2011 and two floors for maisonettes[90]. The number of floors of maisonettes are expected to stay at two floors. The number of floors of the roughly 8.000 flats / apartments / penthouses, which are going to be built between 2011 and 2020, is assumed to increase to five floors. If the evolution of the construction standards is taken into consideration, flats / apartments / penthouses will present on average 3,5 floors each by 2020.

### *Roof top area*

In the next step, the average ground area of households is defined. Exact data from primary sources for the ground area was not available for all types of buildings or dwellings. Averages range from 74 and 80 $m^2$ and were mentioned in former studies.[91] The author's assigned surfaces ranging from 74 $m^2$ to 150 $m^2$ weighted by the number of dwelling types, resulting in an average ground floor area of 78 $m^2$ per dwelling.

For simplicity, it is assumed that they are households with 8,83 m length and 8,83 m width. It is assumed that flat rooftops on Malta exceed the ground floor area by half a meter to each site, since the roof also covers the outer walls of a building, even exceeding them little for rain and sun sheltering. That increases both sides by one meter (length 9,83 m & width 9,83 m) resulting in a roof top area of 96,6 $m^2$.

Not all of the roof top area can be used for PV installations. One depreciation of the roof top area is due to planning and building regulations, which regulates that any installation on the roof must maintain a minimum distance of 2 meters to the front and backsides. [92] Hence, the roof top suitable for PV installations decreases to 57,3 $m^2$ (9,83m*5,83m). That decreases the roof top potential by roughly 40 %.

### *PV roof top function (30 %)*

Since there are various elements competing for roof top area in Malta, e.g. TV antennas, laundry rooms, terrace, solar water heating, cold-water storage tanks, air conditioning, the actually usable space for PV installations must be decreased from the previously calculated one. Hence, a PV roof top function ratio is taken into account, which expresses the percentage of roof top area, which can be used for the purpose of PV installation. According to Farrugia et al.[93], 30 % of the estimated rooftop area can be used for PV. Since the authors have neither other reference data, nor the possibility to calculate a PV roof top function ratio, the same value is used in this project. It can be expected that a change in the usage of rooftops, i.e. the reduction of the use of verandas, could offset a higher PV roof top function ratio.

### *Shading (10 %)*

Parts of the roof might be shaded too strongly by other buildings; hence those areas are not suitable for PV. That problematic can occur in particular in densely urbanized areas, in which Malta's building stock is typically located. No specific data on that criterion was available to the authors. The authors assume that 10 % of the free roof area cannot be deployed with PV installations due to shading.

### *Roof top area for Malta's Industrial sector*

A similar, but simplified methodology is used to calculate the PV roof top potential for other building categories, which underlie fewer restrictions than the residential sector. The data for industries is taken from the State of Environment Report for 2002[94], which indicates the overall designated industry area for Malta. No more recent data was available. In the study from MMD, the same data was taken, but forecasted in a 40 % growth until 2020. The authors take the same forecasted number in this project. As for the commercial sector and the public buildings, partly unconstrained raw data on the roof top area is taken from Mott MacDonald's study in 2005, as well.[95]

The raw data is constrained differently according to the planning area category. The industry area will be depreciated by 50%, since it is assumed that only 50 % of the designated industrial areas are covered by buildings, hence roof tops. In the commercial and public building sector 100% of the already given rooftop area can be used since not the raw designated planning area but the area of buildings / roof tops was taken as a reference. In general bigger PV roof top function ratios (from 50 to 70 %) are taken, since roof utilization conflicts are assumed smaller on industrial-, commercial- and public buildings than on the residential rooftops.

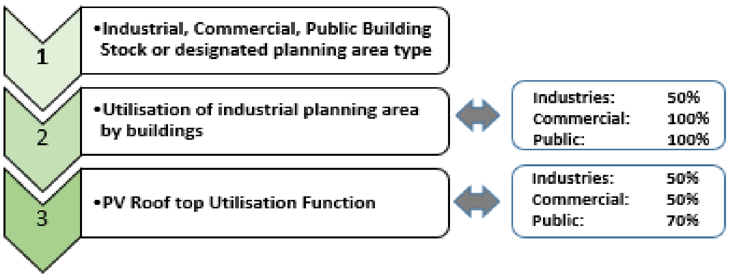



*Figure 45: Roof top constraining parameters*

### *Brownfields*

Data, in which the brownfield areas of Malta's airport, landfills, quarries, carparks and decommissioned power plant areas were analyzed, is taken. These data are partially issued by the Ministry of Energy and Health, which conducted internal studies, and are partially taken from the Solar Farm Policy[96], a document published by the MEPA (Malta Environment and Planning Authority) in 2014. The document provides guidelines for large-scale PV installations in Malta based on expressions of interest of industrial entities and quarries owners regarding the installation of PVs on their brownfields. No specific factor is assumed to the given area, since it is assumed that calculations on the effective available area for PV installations have been already operated.

### 5.2.3. Results

*Residential Buildings*

The calculation of the roof top area in the residential sector on Malta, which can potentially entirely be covered by PVs, looks as follows:

$$\boldsymbol{building\ or\ dwelling\,\frac{stock}{number}\,of\ floors * ground\ square\ meter}$$

$$* \, x \, \% \, building \ regulations \ * x \, \% \, \text{PV roof top function ratio} * x \, \% \, shading$$

As a result, a roof top area of 1.623.000 m$^2$ can potentially be deployed with PV panels on Malta, given the estimated dwelling stock for 2020.

*Industrial-, Commercial- and Public buildings*

Similarly, the available rooftop area of non-residential buildings is calculated applying the restraints discussed before (FIGURE 46).

$$\boldsymbol{Designated\ Industrial\ Area\ or\ Commercial\ and\ Public\ roof\ top\ area}$$
$$\boldsymbol{* \, x \, \% \, building\ utilization * \ \% \, PV\ rooftop\ function\ ratio}$$

| | Designated planning area or unconstrained roof top area in m2 | Utilisation with buildings | PV Roof Top Utilisation Factor |
|---|---|---|---|
| **Industrial Area** | 4.928.580 | 2.464.290 | 1.232.145 |
| **Commercial Area** | 1.811.263 | 1.811.263 | 905.632 |
| **Public** | 208.800 | 208.800 | 146.160 |

*Figure 46: Roof top area according to constraints*

### 5.2.4. Results, installation design and sensitivity analysis

*Ground coverage ratio*

The trade-off between maximized installed PV panel area per square meter and the most efficient energy yield (through minimized shading) per square meter is highly dependent on PV module prices, which must be expected to shrink further in the future. Since area, respectively roof top area on Malta is of high value a compromised GCR must be found, which prevents too high losses from shading, but at the same time does not consume too much rooftop potential.

One major study on roof top potential from Mott MacDonald (referred to as to MMD in the following)[97] used a GCR of 37 %, based on a 15° sunangle in December on Malta. Due to the fact, highlighted by Culligan[98], that the shading losses grow exponentially having a much higher effect within higher GCR regions, and because of shrinking module costs and the high value of land in Malta, the assumed GCR seems too low. Other sources, i.e. the assessment of Farrugia et al., supposes that a less conservative GCR of 60 % is sufficient to avoid consistent shading. In a context, in which the lack of available space is the main constraint to the deployment of PV, a GCR of 60 % is taken in this project as well. However, further studies on the optimal GCR, which is dependent on the tilt angle and the overall PV system's cost, could suggest different GCRs.

In FIGURE 47, the starting data and the parameters applied to the residential sector are summarized.

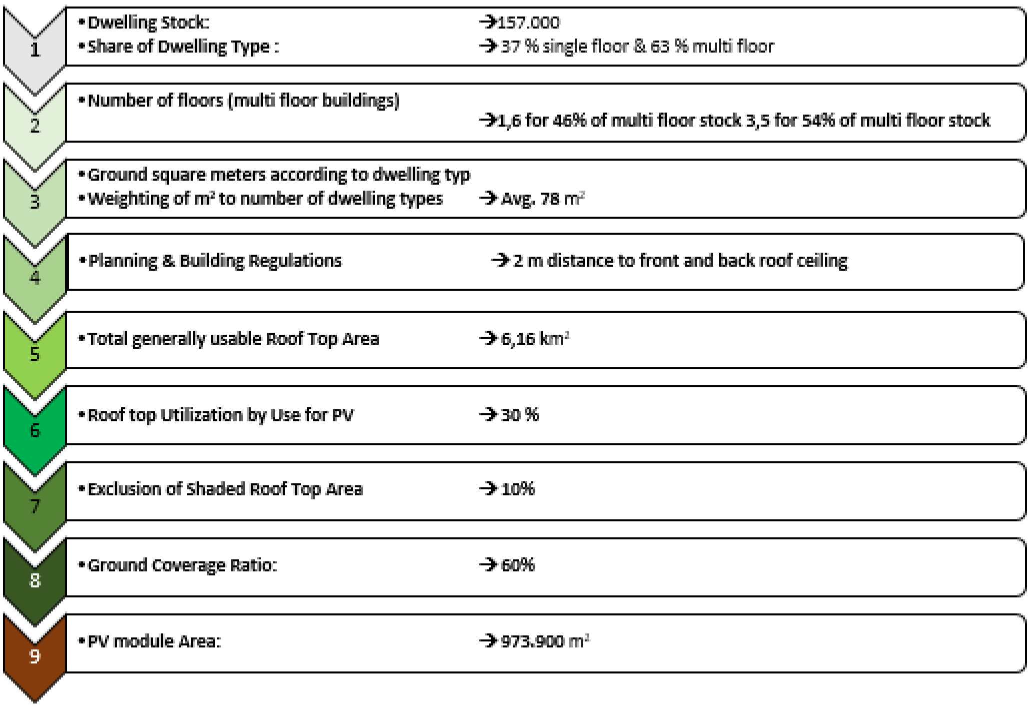



*Figure 47: Constraining Malta's residential roof top area*

When developing possible scenarios for the Maltese energy system in the following, the occupied area by certain installations will be considered excluding the ground coverage ratio, i.e. the term of comparison will be the discounted available area of 973.900 m$^2$ for the residential sector.

As already calculated, considering a nominal PV panel efficiency of 16 %, it takes 6,4 m$^2$ to install 1 kW$_p$. As a result, 152 MW$_p$ could be installed on domestic rooftop areas.

| | | |
|---|---|---|
| Residential roofs | 152 | MWp |

The same calculation, also with a ground coverage ratio of 60%, applied to the industrial-, commercial and public sector leads to a total discounted area of 1.370.300 m$^2$ and to the following PV capacity potentials.

| PV Potential on non-residential roofs in 2020 | | |
|---|---|---|
| Industries | 116 | MWp |
| Commercial | 85 | MWp |
| Public Buildings | 14 | MWp |

*Figure 48: PV potential (MW$_p$) on non residential roof tops on Malta in 2020*

When adding brownfields, such as the airport, landfills and quarries to the picture a further potential of 68 MW$_p$ is offset.

In total, 434 MW$_p$ PV can be installed under the current legislation and building stock in 2020. When applying less strict constraining parameters, some 114 MW$_p$ extra could be offset.

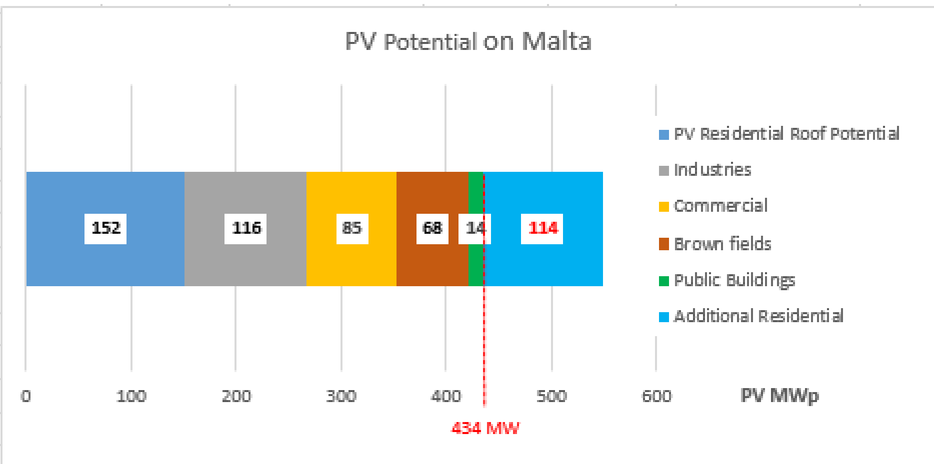



*Figure 49: Overall PV potential (MW$_p$) on Malta in 2020*

*Results and sensitivity on constraining parameters*

Some 114$MW_p$ could be offset when applying the following sensitivity parameters.

| Residential roof PV capacity in 2020 | | | |
|---|---|---|---|
| | PV Residential Roof Potential | 152 | MWp |
| Sensitivity | half the building restriction | 30 | MWp |
| | 1/4 less floors | 8 | MWp |
| | PV function ratio + 10% points | 51 | MWp |
| | GCR + 10% points | 25 | MWp |
| | Optimistic PV Residential Roof Potential | 266 | MWp |

*Figure 50: Sensitivity on residential roof top potential on Malta*

Building restrictions

The building restriction to maintain 2 m distance from the roofs' front and back ceilings decreases the actual gross roof space of an average building on Malta by 41 %. Hence, by cutting that restriction in half demanding only for 1 m distance to front and back ceiling would gain 20 % roof top area back, some 30 $MW_p$ capacity could be offset.

Floors

If the assumptions concerning the increase of height of buildings towards 2020 were wrong, the change in the number of floors from 3,5 to 2,5 in the flat/apartment/ penthouse dwellings would offset roof area equivalent to 8 $MW_p$.

PV Utilisation Function on roofs

The increase of 10 % points in the PV utilisation rate would lead to an overall increase of 33 % of the available rooftop area for PV installations, i.e. the space for additional 51 $MW_p$ capacity.

GCR

The increase of 10 % points in the GRC would offset 25 $MW_p$, although the power output per $MW_p$ would decrease due to shading effects.

In total, a 114 $MW_p$ higher PV installation potential could occur, without even tapping the assumption of a building average ground (roof area) of 78 $m^2$. All that makes clear how sensitive these roof top area analyses are on Malta. It is anyway evident that the development of the PV installed capacity is not only dependent on the maximum available space on rooftops, but also on the cost efficiency of the installation, on the willingness of the inhabitants to purchase such investments and on the policies in place and affecting both elements previous mentioned.

Of course, the output of the installations is also sensitive to the specific installation setup and to the technology specifications as discussed in the section PV - TECHNICAL BACKGROUND.

### 5.2.5. Discussion of Results

This project's results concerning the potential for PV installations on Malta are discussed in comparison to the other studies concerning the PV potential, i.e. MMD and Farrugia et al., since many parameters underlie a lot of uncertainty and are sensitive to different assumptions.

There are three main studies on Malta's roof top potential for PV. Two studies from the energy consultancy Mott Mac Donald (MMD), one published in 2005 and a second version, which based on parts of the first study's findings, published in 2009. Both studies were ordered by the Malta Resource Authority. Another important literature source is the paper of Farrugia/Fsadni/Yousif from Malta's university published in 2005.[99]

In order to reference this project's results, a comparison to the two other studies from Farrugia and MMD is shown.

| PV Capacity Potential in MW (year 2020) | | | | |
|---|---|---|---|---|
| | MMD (GCR 37 %) | MMD (GCR 60%) | Farrugia (GCR 60%) | Own Calculations (GCR 60%) |
| Residential | 160 | 259 | 213 | 152 |
| Industry | 285 | 462 | 26 | 116 |
| Commercial | 105 | 170 | - | 85 |
| Public buildings | 12 | 14 | 1,4 | 14 |
| Brownfields | - | - | - | 68 |
| **Total:** | **561** | **904** | **240** | **434** |

*Figure 51: Comparison of PV potential studies*

The total difference between the calculation from MMD (normalized 60 % GCR) is about 3,8 times higher than the most pessimistic calculation from Farrugia et al. and twice a high than this project's calculations. Even, when taking the original GCR of 37 %, the study from MMD still indicates 21 % more PV capacity than this study.

The main reason for this discrepancy is that different assumptions on the dwelling stock growth have been taken, furthermore it can be noticed that MMD did not differentiate between occupied and unoccupied dwellings, while the exact methodology applied by Farrugia et al. is not cleared.

For the industrial sector the installed capacity discrepancy, which in MMD's study is almost 6 times higher than in the other studies, seems rather stunning. The data employed by MMD was taken from the State of Environment Report for Malta 2002[100]. One explanation for the high number could be that the entirely designated land area for industrial purposes was considered as covered by buildings, which seems rather unrealistic in the authors´ opinion. The authors of this paper took the same source for the raw data but assumed that only 50 % of the industry area is occupied by buildings, hence representing area for roof top installations.

The authors will use the results of the own calculations as a reference for the energy system modelling in this project. As the discrepancies between the above compared studies show, exact numbers must be dealt with carefully. The authors do not claim having the ultimate results but found it important to present a methodology and to emphasize how crucial calculations for utilisable roof top area on Malta are. The following figure shows the potential maximal production of PV according to the findings about Malta's roof top potential. Just above 30 % of the power supply could be covered through PVs, if no further technical constraints are considered. That would be sufficient to reach Malta's 2020 goal of a 10% RES share.

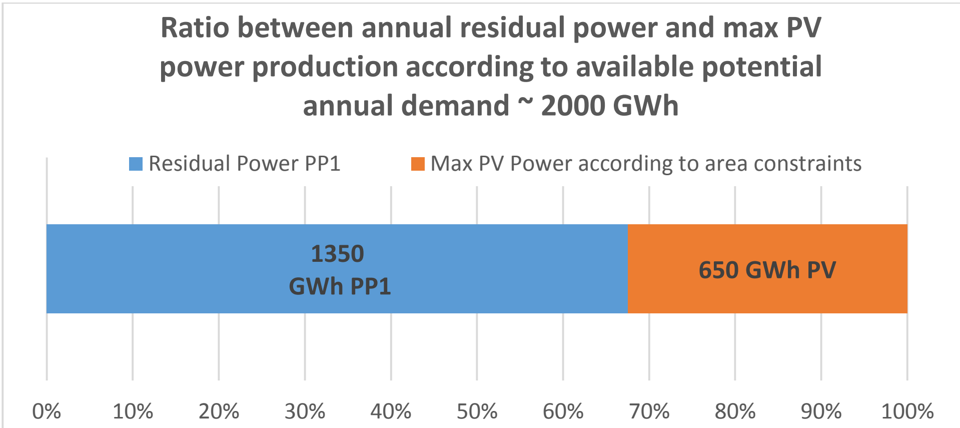



*Figure 52: Maximal PV production on Malta*

As discussed afterwards, PV installed capacity and power production could theoretically be increased, when PV panels are set up differently.

### *Discussion on Ground Coverage Ratio*

When discussing the maximum potential of PV, it has been chosen to start from the hypothesis that all PV panels are installed with an optimum tilt angle, hence a ground coverage ratio < 100 % had to be considered in order to avoid shading, since increasing the tilt angle decreases the possible ground coverage ratio. Hence, less PV panels can be installed on a given fixed area, if they are expected to produce at their maximal potential, with optimal tilt angle and ground coverage ratio avoiding most of the shading. Alternatively it can be chosen to increase the overall energy production (given a fixed area), while decreasing the specific productivity. In practice, this means that PV panels can be installed parallel to the roofs, e.g. horizontally in most cases, and GCR can be considered close to 100%. Given the relatively high solar irradiation on Malta, a horizontal setup of PV installations would decrease the specific energy output only by around 15 %[101]. In a situation with lack of land or expensive land and reduced area availability, it can be an option to reduce the installation specific performance but to generate a higher total energy output through a higher overall installation capacity.

In case of horizontal installation of PVs, the incident global irradiation is reduced, while the performance ratio is slightly increased due to avoided shading between panel rows, as presented in FIGURE 53.

| | | |
|---|---|---|
| PV conversion efficiency | 16 % | 16 % |
| irradiation ($W/m^2$) | 980 | 980 |
| PR | 0,8 | 0,75 |
| angle | horizontal | 32° |
| GCR | 100 % | 60 % |
| Annual global irradiation ($kWh/m^2$) | 1913 | 2155 |
| $kW_p/m^2$ | 0,157 | 0,157 |
| $m^2/kW_p$ | 6,4 | 6,4 |
| $m^2/kW_p$ (including GCR) | 6,4 | 10,6 |
| Energy output ($kWh/m^2$) | 245 | 259 |

*Figure 53: Comparison of Ground Coverage Ratios*

Given the calculated available area in the residential sector, a horizontal setting could enable the installation of 254 MW instead of only 152 MW. The two alternative settings are compared in an installation using the maximum potential of a standard residential rooftop, measuring 9,83*8,83 $m^2$, of which 57,3 $m^2$ can be covered by PV panels. Neglecting the modularity of PV panels, a calculation of the installable capacity, its costs, its energy output and its payback time is operated.

| | optimal tilt angle | horizontal |
|---|---|---|
| cost €/kWp | 1800 | |
| available area m2 | 57,3 | |
| FiT €/kWh | 0,15 | |
| GCR | 60% | 100% |
| installable capacity kWp | 5,4 | 9,0 |
| investment cost € | 9716 | 16193 |
| annual energy output kWh | 8891 | 14031 |
| annual earnings € | 1334 | 2105 |
| amortization time | 7,3 | 7,7 |

*Figure 54: Results comparison of ground coverage ratio*

The comparison shows that the horizontal installation enables more installed capacity, which leads to higher investment costs but also higher overall energy output, which is rewarded with the FiT. The amortization time is slightly higher for the horizontal than for the optimal tilt angle (less than half a year), but it is clear that the overall earnings will be higher over the whole lifetime of the installation, since more electricity is produced every year.

If the priority is to deploy the maximum available area with PV installations in order to produce the maximum power, while also maximizing the return for the investor, horizontal installations should be taken into consideration. The optimization of PV installations towards a maximal total energy yield can be expected to be even better, when prices for PV panels drop further.

## 5.3. Potential for Wind power on Malta

If in a first step, the wind resource in itself is excluded from the analysis of Malta's RES potential. One will typically identify countries with low population densities and vast rural areas as suitable for wind power installation. Good examples are Denmark, Germany, Spain, Portugal and Ireland. On the contrary, Malta does not fall under that category of countries. The land scarcity in combination with high colonization leads to a high population density. As a result, environmental and visual impacts from wind power projects could not be buffered by vast land space, consequently opposing a major problem for the development of wind power projects on Malta.

On the other side, Malta is qualified for wind power by sufficient wind resource, as it will be assessed in the following. The options for wind power can be categorized by location, onshore or offshore and by the size of its turbine installations into micro scale, medium scale and large scale. Firstly, the onshore wind potential is analyzed.

### 5.3.1. Onshore wind conditions for Malta

The following map shows a variety of sites, from which wind data was gathered. All measurements are concentrated around the west coast of the country.

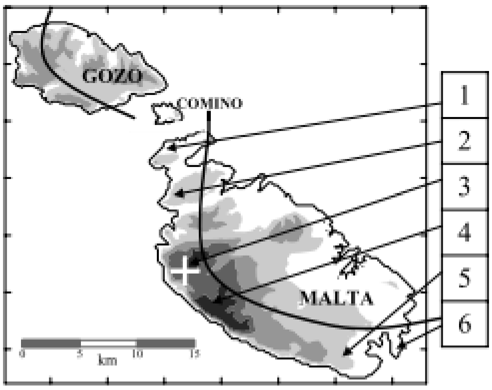



*Figure 55: Wind measurements on Malta[102]*

The next graph shows the mean monthly wind speeds and mean monthly energy yields for a medium sized wind turbine 45 m above ground level, at site number3.

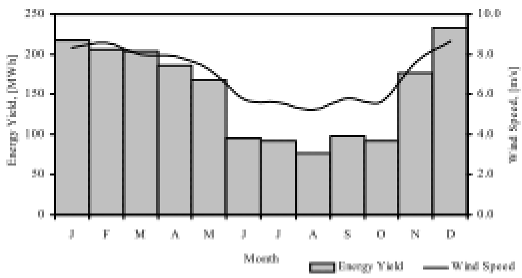



*Figure 56: Mean wind speed (m/s) and energy yield (MWh)[103]*

During summer season until October, the wind speeds are just below4 m/s and in winter around 8 m/s. In regards of the whole power system, that characteristic is positive considering that PV peak production peaks during summer season. The prevailing wind direction comes from North West. The wind measurements embraced 36 consecutive months.

### *Energy yield per square meter*

Assuming a standard air density of 1,225 kg/$m^3$ and a Rayleigh distribution[104], average power density is around 350 to 400 W/$m^2$ at 45 m above ground level.[105] The collected wind measurements were used to model a wind resource maps in a WAsP model. Average power densities of 300 W/$m^2$ are considered suitable for wind power generation itself. According to that precondition, a cumulative area of 153 $km^2$, almost half of Malta's land area is theoretically suitable for wind power generation, if sufficient wind resource were the only source.

### *Wind power potential constrains according to land resource conflicts*

The Environmental Report 2008 indicates the land usage on Malta. It becomes clear that the northwestern part of the main Island has the best potential for wind farm planning, since agricultural and flora areas are dominating the land, while the east of the Island is densely urbanized. This factor makes clear, why the wind measurements were also concentrated in the western part of the main Island.

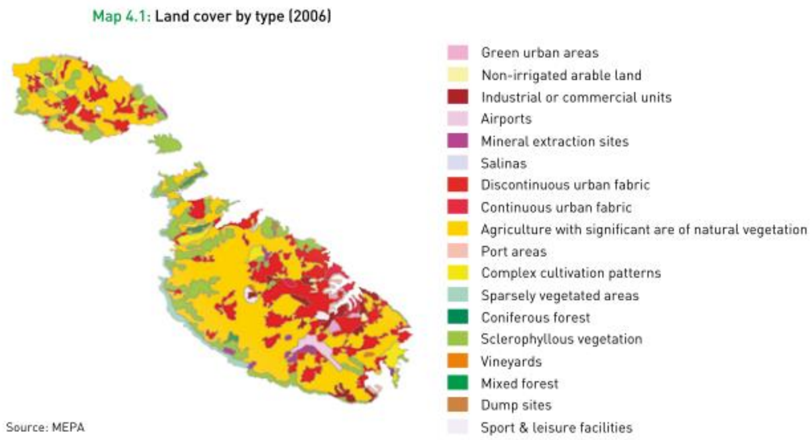



*Figure 57: Land Coverage on Malta [106]*

Consequently, it is only the western parts of the main Island, which would be suitable for medium or large-scale wind power installations, without disturbing life for inhabitants too much. However, as it can be seen on the next map, the northwestern area of Malta is also subject to nature conservation to protect biodiversity of the Island, which should not be neglected since tourism is a major economy on Malta. Studies from EWEA[107] assume that only 4 % or 6 $km^2$ of the area presenting good wind potential (153 $km^2$) could be utilized according to practical constraints on Malta. When considering spacing restrictions between wind turbines, one can calculate the land consumption per installed capacity for wind power. As a rule of thumb, the spacing between wind turbines is measured in 8 to 10 times the rotor diameter of a turbine in main wind direction and 5 times the rotor diameter in minor wind direction.[108] EWEA calculated a land consumption of 0,136 $km^2$ for a 1 MW turbine with 55 m rotor diameter. That translates into 7,4 MW/$km^2$ or 45 MW in total, which could be installed on Malta. Never the less, the practical constraints considered previously refer only to technical issues of wind turbines itself and not to the environment of Malta.

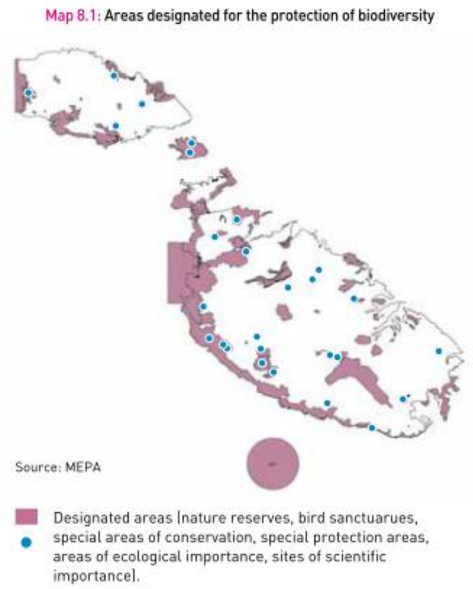



*Figure 58: Areas of Nature Conservation [109]*

Studies from consultancy Mott McDonald conducted in 2005[110] and 2009[111] considered constraints according to the environment and planning policies on Malta. Firstly, an unconstrained maximum potential of 230 MW for onshore wind power on Malta is given. FIGURE 59 shows how the potential shrinks by certain constraints. The parameter "Interference with airport" cuts numbers in halves. This is followed by restraints due to lack of road access for the construction phase, to grid stability issues and to visual impact, leaving a potential of 15 to 25 MW on the Island only. However, one should bear in mind that new roads can be built and that visual impacts do not necessarily have to prevent wind power development if the concern is eased by authority's regulations.

| **Maximum Capacity Unconstrained** | **230 MW** |
|---|---|
| **Cumulative impacts of constraints** | |
| Interference with Airport | **114 MW** |
| Lack of Road Access | **82 MW** |
| Electricity system stability | **40 MW** |
| Visual impact | **15-25 MW** |

*Figure 59: Wind power restraints on Malta [112]*

### 5.3.2. Offshore wind Regime on Malta

Wind data from the National Center for Atmospheric Research [NCAR][113] and the European wind atlas[114] can be analyzed as an indication of the general wind regime in the Malta region. Mott McDonald[115] evaluated 3 NCAR data sets from offshore measurements (120 south-east, 200 km south-west and 200 km north-west from Malta) which show a range of 5,75 m/s to 6,0 m/s wind speed on 10 meter height. The European Wind Atlas gives a range of 5,5 m/s to 7,0 m/s at 50 m and 6,0 m/s to 7,5 m/s at 100 m height in the Malta region. The wind speeds are not competitive to the offshore wind speeds in the typical offshore area in the Northern Sea. However, they would be efficient for the deployment of an offshore wind power. In the other side, most of the offshore locations are deemed to be unsuitable to wind installations due to conflict with navigation routes, aviation security, environmental protection areas and too deep waters[116].

*Offshore sites*

In its first study, MacDonald[117] identified 8 suitable sites for offshore wind power projects in shallow waters (<30 m). The Sikka Il-Bajda site, located on a sandbank about 2 kilometers northeast of Malta was identified as the most feasible location. A more detailed study to develop that site was published in 2009.[118] Three different project set-ups with different turbine types and spacing models were shown, resulting in roughly 86 MW installed capacity, producing 157 to 227 GWh in a closer spacing model and 132 to 190 GWh with around 70 MW installed capacity.

Early studies by Farrugia identify an overall area of 13,5 km$^2$ with water depths not exceeding 20 m. When using 2 MW turbines with 75 m rotor diameter 7,9 MW/km$^2$ could be installed, accumulating to 14 MW installations in those water depths.[119] Nowadays it is possible to install offshore wind turbines in deeper waters, which can partly explain the discrepancy to MMD's study. In the end, it is a question of costs, which are higher when utilizing sites with deeper water depths.

### 5.3.3. A Political Status Quo

As shown, the wind resource itself on and around Malta is sufficient for a decent installation of wind power. However, due to the high environmental conflict and to the extreme land scarcity, the development of wind power on Malta is treated very sensitively and rejected as a viable option in the short term. The capacity potential ranges from 15 to 230 MW onshore and 14 to 86 MW offshore, according to the methodological restrictions applied. Nevertheless, the realistic capacity can only be relied on Malta's land planning policy and the timing of actual wind power installations, since especially wind power offshore technology was still at the beginning of its learning curve, when the studies were conducted.

# 6. RES-h potential

## 6.1. Solar water heaters (SWH)

The thermal demand for water heating is expected to amount to 0,394 TWh in 2020. At present it is provided mainly by electric heaters (see demand chapter), but a relevant share of them could be replaced by solar water heaters (SWH), which provide an almost completely renewable output. Only a minor share of electricity, accounting for 5 % of the energy output, is required for the technical functioning of the SWHs.

It can be assumed that up to 70 % of the total thermal demand for water heating can be covered by SWHs on Malta (i.e. 0,276 TWh). Due to solar resource unavailability at certain times and heat storage limits, SWH always need a backup heater, since it is not possible for them to match 100% of the thermal demand profile at competitive price.

It has to be noticed that heating is not a transferrable energy, unless a district heating network is in place, which is not the case on Malta. Hence, demand and supply have to be located in the same place. In addition to that, the use of SWHs only, without backup technologies, implies the installation of big-sized heat storages, which are feasible only on the large scale (i.e. solar district heating). Hence, it is preferable that SWHs are located on the rooftop of the building requiring the warm water, are coupled with small heat storages and are always backed by other technologies, i.e. electric of fossil fuel based heaters. Hence, the investment cost of the traditional heater is not saved, but most of the cost of the electricity previously consumed in electric water heaters or of the fossil fuel is.

In case the maximum potential of SWHs is deployed, the system would evolve as reported in FIGURE 60.

| **hot water 2020** | | | |
|---|---|---|---|
| | | **input energy consumption (TWh)** | **final heat generation (TWh)** |
| **Old Technology Status Quo** | **oil and gas** | 0,038 | 0,032 |
| | **electric resistance** | 0,306 | 0,315 |
| | SWH | - | 0,047 |
| | **Total** | | **0,394** |
| **Max SWH** | **SWH** | | **0,276** |
| | 5 % electric heating | 0,054 | 0,054 |
| | 5 % oil and gas heating | 0,064 | 0,059 |
| | 5 % SWH electricity consumption | | 0,014 |
| | **Electricity Displacement** | | **0,250** |

*Figure 60: Supply of hot water on Malta*

### 6.1.1. Area consumption through SWH

Given the hypotheses of employment of flat solar collectors with a yearly efficiency of around 50%, installation at optimal tilt angle without shading losses and a global irradiation of 2133 kWh/m$^2$, SWHs can gain up to 1066 kWh/year of thermal energy per $m^2$ of installation. Hence, the energy required for matching all displaceable water heating demand by solar thermal collector installations would cover a total net area of 258.910 $m^2$. Some 43.150 $m^2$ of area is already deployed by solar collectors (0,046 TWh)

As already discussed for PV installations, also solar thermal collector installations are subject to space constraints on Malta. The two technologies can be considered in competition for the use of rooftop available surface, hence the maximum installable potential of the two technologies is interconnected and it might not be possible to deploy the maximum potential for both PV and SWHs, which is why the benefits of both technologies are evaluated and compared in the modelling section.

*Discussion on conflicted areas*

In the roof top area calculation for the potential of installing PV, a usable roof top area of 1.037.000 $m^2$ in the residential sector was calculated. In that calculation, it was already considered that not all of the roof top area could be used for PV installations exclusively, but also for SWH installations. The assumed PV roof top function ratio of 30 % does consider that a certain share of the roof area is used for other purposes than PV installations, including the use for SWHs. However, it can be argued that only SWH installations accounting for the generation of about 0,046 TWh were included in the calculation, since that is about the current production from SWH and the order of magnitude of the 30 % PV roof top function is even referenced to earlier studies. Therefore, it could be reasonable to deduct the area needed for the remaining installation equivalent to reaching the full SWH potential capacity, which lead to an energy generation of 0,276 TWh. Therefore, the additional area of 215.720 $m^2$ potentially needed for new SWH installations would have to be deducted from the available area for PV installations, which amounts to over 2,34 $km^2$, when residential and non-residential available rooftops (excluding brownfields) are considered. Consequently, the potential for PV installation would be reduced by 34 $MW_p$. Hence, the total PV potential would decrease from 434 $MW_p$ to 400 $MW_p$.

## 6.2. Heat pumps (HPs)

Heat pumps are devices, which transform renewable energy from air, ground or water to heat. Some input energy, either electricity or gas is needed to run the compressor and the pumps within the cycle. A heat pump system consists of a heat source, the heat pump unit and a distribution system. A refrigerant fluid transports the heat from a low-energy source (i.e. the renewable energy source) to a higher temperature energy sink (the space to be heated). This cycle can be reversed, transferring heat from the space to be cooled to an external energy sink, so the same infrastructure can be used for heating and cooling purposes, giving an additional economic advantage in cases where both services are needed.

In the case of Malta, it is assumed that electricity driven heat pumps with a COP of around 3 can provide both space heating and cooling. Due to the mild and relatively constant temperatures all over the year, air-to-air devices provide sufficient efficiency and no back up technologies are required. It is assumed that heat pumps are mainly installed individually in the residential sector and not as centralized technologies.

The utilization of heat pumps is a way to reduce the primary energy demand for heating purposes first of all. Also in case electricity comes from natural gas based power plants, given a power plant efficiency of 50% and a COP of 3 for the heat pump, the overall efficiency would be 50%*300%=150%. Alternatively, oil boilers have an efficiency of 85 % and electric heaters an overall efficiency of 50%*100%=50% (when considering both the electricity production process and the device itself).

Hence, HPs can be a good alternative to the conventional technologies in any case, but especially if RES electricity is used to supply them, so that the total process can achieve higher efficiency. HPs can be an even better solution, when surplus power production deriving from renewable sources can be used.

As for the investment costs, it is reminded that a high number of heat pumps is already in place and mostly utilized in reverse mode. Therefore, their utilization also for heating purposes would not add up further investment costs for over 50 % of the occupied households.

As shown by the efficiency comparison, it is worth substituting both fossil fuel and electricity-based heaters with heat pumps. This would result in the following system:

| space heating 2020 | | | |
|---|---|---|---|
| | | primary energy consumption (TWh) | final heat generation (TWh) |
| Old Technology Status Quo | oil and gas | 0,273 | 0,232 |
| | electric resistance | 0,033 | 0,033 |
| | HPs | 0,022 | 0,066 |
| Max HP | HPs | **0,110** | **0,331** |
| | Fossil Fuel Displacement | -0,273 | |
| | Additional power Demand | +0,055 | |

*Figure 61: Supply for Space Heating*

The choice of employing heat pumps would benefit the energy efficiency and the environmental impact of the heating sector, but also contribute to the achievement of the EU 2020 target.

The fact that heat pumps produce a certain share of renewable final energy is recognised by the Renewable energy directive 2009/28/EC, whose Annex VII[120] sets specific rules for the accounting of HPs renewable energy contribution. According to the directive, the share of RES from HPs is calculated as:

$$E_{RES} = Q_{usable} * (1 – 1/SPF)$$

Where:

$Q_{usable} = H_{HP}*P_{rated}$ = estimated heat delivered by HPs

$H_{HP}$ = equivalent full load hours of operation of HPs

$P_{rated}$ = nominal installed capacity of HPs

SPF = seasonal performance factor (an efficiency factor, which considers the COP and additional system losses)

The precondition for the heat to be accounted for as renewable energy is that SPF > 1,15* $\eta$ , where $\eta$ is the system efficiency (value of 45,5% agreed on at European level for the period 2010-2020). This means that only heat pumps with a SPF of 2,5 are accounted for as delivering a share of renewable energy. In the case of Malta, the assumed COP of 3 falls within the requirement and 66% of the heating output can be accounted for as renewable energy.

The Directive is followed by the commission decision of 1st March 2013 (2013/114/EU), which specifically provides guidelines for Member States to assess the necessary parameters ($Q_{usable}$ and SPF)[ii] and calculate renewable energy from heat pumps. The commission decision couples the registered installed capacity of HPs, the technology type and the Member State specific climate with the expected output of the devices. Furthermore, it recognises that heat pumps can be utilized also in reverse mode, but it does not mention the option that also the cooling output can contribute to the RES target.

The publication of such a document makes it evident, that the monitoring of the RES contribution from heat pumps is still at an early stage and needs to be implemented at national level, although this will require rather relevant efforts. In particular, the approach towards cooling generation and its accounting towards renewable energy seems to be still undecided. For this reason, 66% of the heat generation through HPs is accounted for as renewable energy, while the cooling generation is not accounted at all in this project.

[ii] The Directive is followed by the commission decision of 1 march 2013 (2013/114/EU), which specifically provides guidelines for Member States to assess the necessary parameters

# 7. Methodology for EnergyPLAN Modelling

## 7.1. What is EnergyPLAN?

EnergyPLAN was developed by a research group of sustainable EnergyPLANners of Aalborg University. The program was firstly developed by Henrik Lund in 1999 on an excel spreadsheet basis. It has continuously been extended and reprogrammed in order to supply a more user-friendly interface and more functions since that time. For this project, the latest version 12.0, issued in January 2015, is used.

EnergyPLAN is a deterministic model, which simulates the operation of an energy system based on input data for demand, supply, balancing & storage options and cost parameters on an hourly basis. Hence, the design of the model itself cannot be optimized but has to be provided by the user. The operation of the system, instead, is optimized from a technical or economical point of view by the software. EnergyPLAN is not a stochastic model, meaning that it bases its modelling on specific data and it does not deal with uncertainty related to unpredictability and fluctuations on the demand and supply side. Data used for the modelling are referred to a specific period and are normalized in order to eliminate or adjust values due to specific conditions.

## 7.2. Why EnergyPLAN?

The key objective is to model a variety of options so that they can be compared with one another to show limits and possible pathways for Malta's energy system, as well as costs, rather than modelling one 'optimum' solution solely based on defined pre-conditions. It is possible to illustrate a palette of options for Malta's energy system and compare them based on costs, environmental impact ($CO_2$ emissions), system stability (stabilization share and CEEP[c]) and RES target achievement using this methodology. This could classify EnergyPLAN as a 'simulation' tool rather than an optimisation tool, even though there is some optimisation within the model.

## 7.3. How using EnergyPLAN?

EnergyPLAN can be divided into:

- a primary input section;
- the simulation section;
- an output section.

The chronological order also reflects the chronologic steps, which are undertaken by the program, which simulates the given input data according to the predefined optimization strategy chosen by the user. The output section presents the outcome resulting from the optimized running of the system as

[c] Critical Excess Energy Production

it has been designed by the user. FIGURE 62 shows the progress in a graphical way and gives a quick overview about important parameters.

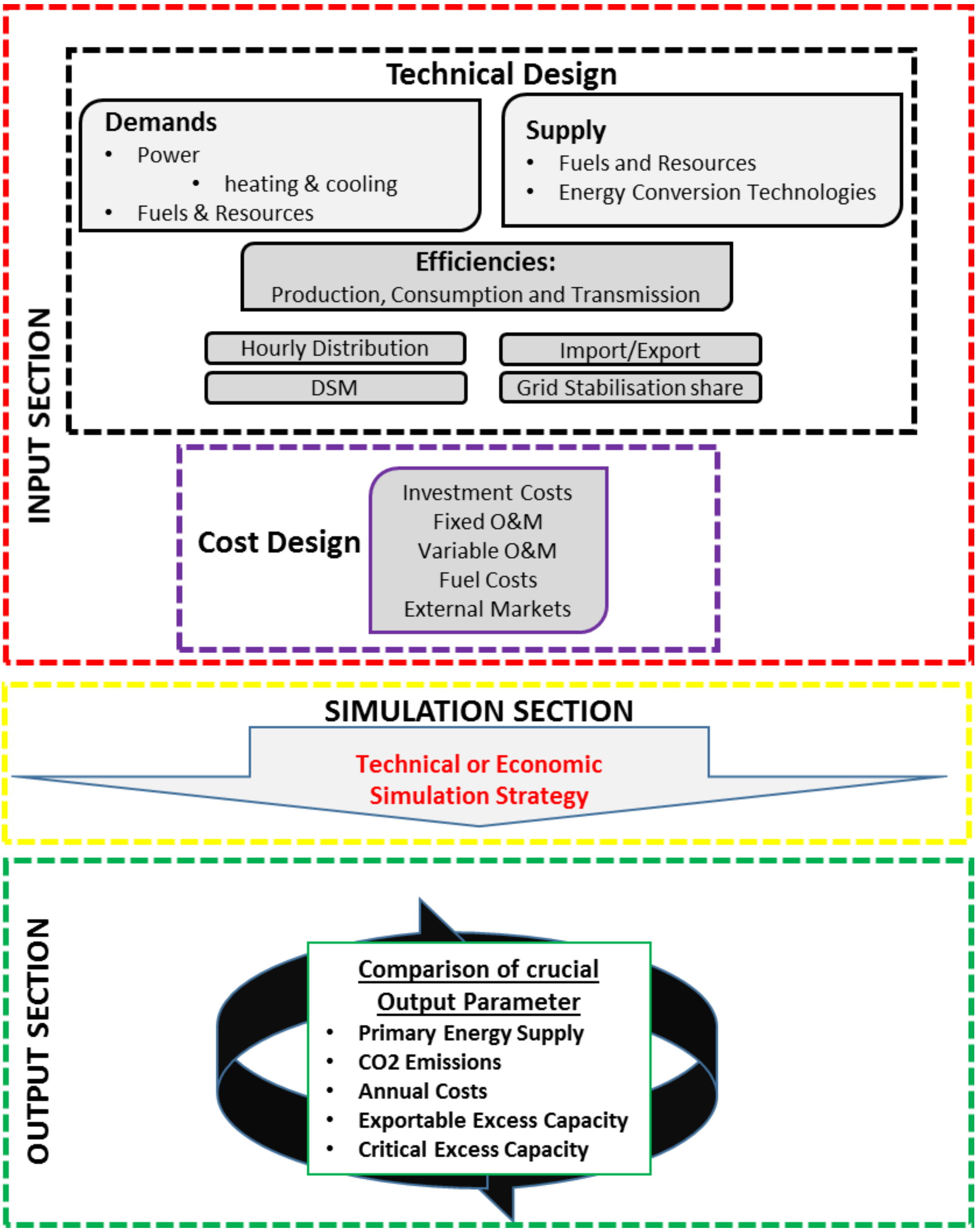



*Figure 62: Scheme of EnergyPLAN*

The input data concerning the system features, e.g. demand per sector and installed capacity, are provided by the user, together with the appropriate hourly distributions on the demand and supply side, when requested. A number of distributions is already available within the EnergyPLAN package, but it is preferred to build ad hoc distributions, which take the specificities of the Maltese system into consideration. Cost data are provided by the program, on the basis of the "Technology data for power plants" published by the Danish TSO Energinet.dk and the Danish energy agency[121]. It has been noticed that the Maltese system presents some specific features, which are far away from the Danish situation and will be discussed afterwards. For the heating sector completely new costs are set, while in the other sectors the Danish costs are taken and only minor adjustments are needed in order to fit the Maltese system.

In the optimization section, it can be chosen whether to run a market or technical optimization. The former identifies the most cost-efficient operation of the different energy technologies, according to the merit order. Hence, marginal costs on the supply side are optimized. The latter is more accurate in case of high shares of renewable non-dispatchable energies, since it aims at minimizing the consumption of fossil fuels, independently from the cost. In both cases, the operation of the system provided in input is optimized, while no optimization of the long-term (investment) costs and on the demand side can be operated by the software. When cost data are provided, the overall cost of the energy system can be assessed, but the investment costs are not a variable in the modeling.

All input categories are pre-defined by EnergyPLAN but must be quantified by the user. The input values for each parameter were identified by:

- General literature and data research on energy technologies;
- Literature and data research on Malta's current energy system;
- RES Potential Analysis for Malta;
- Assumptions about Malta's future energy system;
- Policies determining and restricting the future input to the energy system from a legislative angle;
- The author's suggestions how Malta's energy system should look like in the future.

## 7.4. How using EnergyPLAN? - The Input Section

### 7.4.1. Technical Data Input section

At first, the technical design of the energy system must be designed. In the following, the major parameters, which must be quantified by the EnergyPLAN user, are shown:

- Energy demand;
- Use of technology;
- Efficiency of the different technologies;
- Installed capacity of the different technology;
- Hourly Distributions;
- Grid Stabilization Share.

### *Energy Demand*

In the beginning the overall power demand is put in. The power demand also includes the heat or cooling demand covered by electricity consuming technologies.

The same applies for the fuel demand, which is assigned to heat or power supplying technologies specifically. As for fuel, either fossil and nuclear-based fuels or Renewable Energy Resources are used. Power can also be imported, if an interconnection to another market exists.

### *Use of Technology*

A variety of technologies to cover the energy system's demand can be used in EnergyPLAN. The software distinguishes between individual and large industrial technologies to cover the demand. The technologies use either primary fossil and renewable resources or secondary resources in form of power. In case of fossil fuel based technologies, the type of fuel they run on must be assigned. In addition, the overall installed capacity for each technology must be quantified, as well as the average energy transformation process efficiency. Such information is divided by sectors, i.e. electricity, individual heating (large centralized heating systems are not present in Malta) and transport.

### *Hourly Distributions*

Power, heating and cooling demand, as well as supply of fluctuating RES, must be assigned with an hourly distribution, representing a demand or supply profile for each hour of the year. Whereas for fossil-based capacities that is not necessary, since those power plants produce according to the residual demand (power demand – RES supply) and to their marginal cost. Each distribution must consist of 8784 hours (amount of hours during a leap year). The total values of the distribution itself are trivial since the distribution is indexed, meaning only the relative relation of all distributed values is relevant and once the yearly absolute value for the demand and the maximum achievable value for the RES supply is given. When the user varies the absolute input quantities in a category with an assigned distribution, EnergyPLAN would automatically distribute the absolute value in the ratio of the assigned distribution.

Data concerning the hourly and seasonal distribution of electricity demand are provided by the Maltese institutions, while the distributions of heating and cooling demand have to be built by the authors (see section HOURLY HEATING AND COOLING). When considering heating, it has to be considered that it is generated from both electricity and oil products, while cooling is totally produced through electricity.

The production data from all connected PV systems in Malta until 2014 was obtained from the Maltese authorities. The data sheet consisted of the monthly average PV production in 24-hour resolution. This results in an approximation of the PV generation profile, since daily fluctuations are not registered in the provided monthly averages. Nevertheless, the data was fed into EnergyPLAN. No correction factor had to be applied, since all PV system losses were already reflected in the production data.

*Grid Stabilisation Share*

The user can define a minimum grid stabilisation share in EnergyPLAN ensuring that enough firm capacity is present in the system at any time. As already discussed in the section GRID STABILIZATION SHARE AND TECHNICAL FLEXIBILITY OF THE SYSTEM, for Malta a value of 30 % is assigned to this parameter.

### 7.4.2. Economic Data Input Section

Costs in EnergyPLAN can be assigned to the technologies within the energy system's infrastructure and are constituted by:

- Investment costs, i.e. a price per capacity unit;
- Fixed Operation & Maintenance [O&M] costs as percentage of the related investment cost.

According to the technology lifetime and an agreed discount rate, the annual costs for each technology are derived. The program calculates the total investment costs and the annual investment costs considering the lifetime period and the discount rate, as well as the annual fixed O & M costs.

The following variable costs are calculated based on produced or consumed units.

- Fuel Costs and $CO_2$ Costs;
- Variable O&M;
- External power market prices;

An interest rate of 3 %, as often suggested for infrastructure projects of national economic importance, is used as EnergyPLAN's standard default. A major share of investments in this project comes also from individual residents, which usually have higher interest rates. However, the current European fiscal policy allows assuming such low interest rates also for individuals.

As a source for the cost input parameters, EnergyPLAN's 2020 cost database is used[122] only for large power plants. Despite the comprehensive content of EnergyPLAN's cost database, the authors trust their own data research, since in particular numbers for individual heating and cooling technology seem to vary substantially, depending on the specific destination and use of the technology in each country. That must be emphasized for Malta, since it is a small market and its climate environment differs substantially from Denmark, on which the costs of EnergyPLAN's database are focussed. As an example, given the mild meteorological conditions in Malta, heating systems are much less complex than in Northern Europe. Therefore, the costs for PV, SWH and heat pumps are directly taken from the online offers of the Maltese company Bajada New Energy.[123] Bajada New Energy is Malta's market leader in the renewable energy sector offering full service for PV, SWH and heat pump installations. The costs provided include installation costs. The size of the reference plants is for residential installations.

In the following, the most important cost parameters are explained in detail.

*Handling the costs from Malta's power plant fleet in EnergyPLAN*

Two of the four fossil fuel fired power plants (184 MW) will be operated exclusively as back up capacities in 2020. The two backup power plants are modelled as PP2 in EnergyPLAN, will already be paid off by 2020 and it is not planned to renew them at the end of their lifetime. The two operating power plants (364 MW), which are going to run on natural gas, are modelled as PP1 and treated as new investments.

In order to calculate the costs of Malta's energy system in 2020, the investment costs must be modified according to the above stated situation. EnergyPLAN does not offer separate cost reference windows for different large power plants. The input capacities for all large PP groups (PP1 and PP2) are automatically referenced to the large power plant cost window, see picture below. Therefore, the window indicates a capacity of 548 MW-e, which will be multiplied by the per MW unit cost.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Large Power Plants | 548 MW-e | 0,68 | 25 | 5,1 | 373 | 21 | 19 |

Since only the investment costs of 364 MW for PP1 should be included, the authors lower the cost per unit for large power plants to bypass EnergyPLAN's cost accounting limits. The following formula shows the arithmetic approach.

*Capacity Sum of PP1 and PP2 (MW) * x unit cost (EUR) = Investment cost of PP1 (MW)*

*Where:*

*Capacity Sum of PP1 and PP2* = 548 MW

*Investment costs of PP1* = 373 Million EUR

As a result, 0,68 million € /MW adding up to the investment costs of 373 million € distributed over a lifetime of 25 years. That sum equals the real full investment costs for the new 215 MW advanced CCGT with accounted investment costs of 0,87 million EUR/MW[124], plus the investment costs for the refurbishment of 149 MW Delimara gas engine plant (1,25 million EUR/MW). The two power plants will be the flagships of Malta's future fossil fuel power plant fleet.

The O&M costs are calculated in percent of total investment in EnergyPLAN. If sticking to the conventional rule of O&M costs accounting for 3,5% of the total investment as proposed in EnergyPLAN, the O&M costs would be lowered through the above-described methodology due to the effect that the investment costs only reflect the two new power plants. However, the O&M costs should not be lowered, since the 184 MW of PP2 capacity must be maintained as back up capacity. Therefore, the hypothetic investment costs for PP1 must be assumed. Assuming the same investment costs for PP2 as for PP1 they would add up to 190 million EUR, adding up to 563 million € PP1 and PP2 investment costs. Now the O&M share for PP2 can be calculated.

The O&M costs of 19,7 million € annually (3,5 % * 563 million € for PP1 & hypothetic costs of PP2) must equal 373 million € PP1 costs * x% O&M.
As a result the share of O&E will be increased from 3,5% to 5,3% in EnergyPLAN.

### *Interconnector Costs:*

EnergyPLAN cost database counts 1,2 million € as investment per MW unit of interconnector capacity, which actually comes relatively close to the costs of the Malta-Sicily interconnector, despite the fact that the length of an interconnector must also be considered. In this project the 1,2 million € per MW unit are lowered to 0,6 million € per MW unit, since the EU finances 50% of the project[125] and Italy will also take a share on the costs.

### *Costs for LNG*

The EnergyPLAN default price for natural gas is 9,1 EUR/GJ for 2020. According to World Bank data[126] prices for natural gas in Europe fluctuated around 9,3 EUR/GJ nominal prices from 2008 to 2015, while the 2014 annual price is 33 % lower than the historical price peak in 2008. In contrast, US gas prices dropped considerably (-51 % due to US fracking boom) in the same period, fluctuating around an average of 4 EUR/GJ and are expected to remain rather low.

However, Malta is not connected to any gas pipeline network. Hence, natural gas must be imported as LNG (liquefied natural gas). LNG prices are higher, since the supplier has to liquefy the natural gas first, ship the LNG to the consumer and regasify the fuel. According to Penn State University[127], the costs related to LNG processed in an average sized plant are structured as follows.[d]

| € / GJ | **low** | **high** | **average** |
|---|---|---|---|
| **Liquefying** | 1,3 | 1,7 | 1,5 |
| **Shipping** | 0,26 | 0,77 | 0,5 |
| **Regasifying** | | | 0,28 |
| **Total** | | | 2,3 |

*Figure 63: Costs for LNG processing*

It is assumed that in 2020 natural gas prices maintain the same average prices as in 2008 to 2015 and that a divergence between the US and European price is still. Depending on the regional supplier, prices for LNG vary. US LNG on average costs would amount to 6,3 EUR/GJ. European LNG would add up to 11,3 EUR/GJ, which is a much higher price although lower shipment costs are involved due to close proximity. The authors see the advantage of importing LNG from the USA, although they are aware that the gas, which will be employed on Malta is going to originate in East Europe, since the gas supply provider is Socar, an Azeri company extracting natural gas from that region[128]. Socar is part of the joint venture Electrogas, which contracted the construction of the new gas fired power plant and the gas supply to Malta.

### *Costs for individual heating*

The costs for individual heating technologies are calculated separately in an excel spreadsheet, because EnergyPLAN does not consider costs for cooling technologies and uses a different

[d] All prices are converted to € with currency data as in April 2015.

methodology to calculate the number of required units per technology, which adds up to the technology specific investment costs, when multiplying the number of units with the costs per unit.

EnergyPLAN calculates the number of used technology units by dividing the overall heat demand by the heat demand per building (kWh/year) which can be provided as an input to EnergyPLAN. In contrast to that methodology, the authors define a number of units combined with a certain capacity required for space heating, space cooling and water heating purposes, according to the specific needs and given assumptions. This is done individually for the residential, hospitality, commercial and industrial sector.

The base unit is a residential-equivalent device, i.e. a device providing space heating, space cooling or water heating with an average size for a single dwelling. In fact the costs are referred to domestic installations. Cooling devices have a reference size of 3 kW, which is the starting point for deriving the system cooling demand.

### *Number of Devices*

According to NSO Census 2011[129], the number of permanently inhabited dwellings amounts to around 152.000. Furthermore, given an increase of population of +2,8% until 2020, which distributes itself in new or presently not inhabited dwellings (3 inhabitants/dwellings), additional 4.000 units will be permanently inhabited. In is assumed that all these dwellings have individual infrastructure for space heating and water heating. Half of them have cooling devices installed. Most common cooling devices are reverse heat pumps. Hence, when the number of HPs used for heating purposes increase, the number of HPs used only for cooling decreases.

In the hospitality sector, the assumption that 1,5 tourists occupy each unit is maintained and it is supposed that each unit (hotel room or temporarily rented apartment) requires a water heater, a space heater (only for the offseason tourists population) and a cooling device. It is assumed that all three elements require a capacity, hence an investment cost, which is half the equivalent for a permanent household (1,5 kW).

As for offices, it is already cleared in the COOLING chapter that they employ 84.000 people. In 50% of the structures, every 6 employees there is an air conditioner with a capacity (and a relative investment costs) almost double as the ones employed in the residential sector. All offices have every 6 employees a space heater, which is 1,5 the size of household space heaters, and a water heater, which is half the size of household water heaters.

In retail and commercial infrastructures, 50.175 people are employed. For every 6 employees, a cooling device double the size as residential ones is installed, since the area which must be cooled or heated per person must be assumed larger than for offices. For space heating the devices are 1,5 the size of residential ones and a water heating device half the size of residential ones, since warm water must not be expected to be used much in retail and commercial infrastructure.

As for the industrial sector, very little data is available. It is assumed that cooling, consuming 5% of the sector power production, is produced all over the year for two shifts (16 hours) a day. This means that 4400 residential-equivalent devices have to be in place. It is also assumed that the same number of space heating devices and half the number of water heaters are installed in industries.

According to all the given information and assumptions made by the authors, a specific number of equivalent devices is provided for the three purposes (see FIGURE 64).

| cooling | | | |
|---|---|---|---|
| | size (kW) | amount | equivalent residential-size |
| residential | 3 | 76000 | 76000 |
| residential ext | 3 | 4000 | 4000 |
| tourism | 1,5 | 33533 | 16767 |
| offices | 5 | 7000 | 11667 |
| retail | 6 | 12544 | 25088 |
| industry | 3 | 4400 | 4400 |
| | | | **137.921** |

| space heating | | |
|---|---|---|
| | number | equivalent residential-size |
| residential | 152000 | 152000 |
| residential ext | 4000 | 4000 |
| tourism | 16533 | 8267 |
| offices | 14000 | 21000 |
| retail | 12544 | 18816 |
| industry | 4400 | 4400 |
| | | **208.483** |

| water heating | | |
|---|---|---|
| | number | equivalent residential-size |
| residential | 152000 | 152000 |
| residential ext | 4000 | 4000 |
| tourism | 33533 | 16767 |
| offices | 14000 | 7000 |
| retail | 12544 | 6272 |
| industry | 4400 | 2200 |
| | | **188.239** |

*Figure 64: Space heating, water heating and cooling devices*

The distribution of investment costs over the technology specific lifetime is handled the same as in EnergyPLAN. The results of the excel spreadsheet calculations are input under EnergyPLAN's additional cost tab sheet.

The number of devices is multiplied by the costs of the singles devices. The costs are mentioned in the following.

### *Costs for Solar Water Heaters*

A Novotherm 150 solar water heater at a current price of 1600 € , as it is purchased by Bajada New Energy, will be the reference for average SWH installations on Malta.[130] It has a 150 l water tank, which is recommended for households of up to 4 people. It is assumed that each building/dwelling using that technology has one Novotherm 150 installed. The minor share of costs, which are needed for an electric back up water heating are assumed to be included in the given costs. Since the market for SWH used to be a niche market on Malta, the authors assume that prices will go down by 10% in the next 5 years, which is why a price of 1.440 € will be taken for this project.

### *Costs for heat pumps*

It is assumed that each building/dwelling using heat pumps have a reverse air conditioner installed, which can be used both for cooling and for heating. The reference heat pump is the Hisense 12.000 BTU, which presents a COP just above 3 for both heating and cooling and an output capacity of around 3 kW. Its current cost is 560 € for the device, plus 156 € for the installation.[131] The costs for the device are expected to be 10% lower in 2020. As a result, a cost of 504 € for the device adds up to 660 € including the installation.

### *Costs for individual oil/gas boilers and electric resistance heating*

As cost references for space and water heating via oil and gas heaters or electric heaters, prices from the Maltese companies Attards[132] and TopChoice[133] are obtained. The companies sell household and electronic devices.

| | | System € | number devices | Installation € | Total € |
|---|---|---|---|---|---|
| **space heating** | **LPG (Oil & Gas)** | 150 | 3 | 0 | 450 |
| | **HPs** | 504 | 1 | 156 | 660 |
| | **Electric** | 70 | 3 | 0 | 210 |
| | | | | | |
| **hot water** | **LPG (Oil & Gas)** | 500 | 1 | 200 | 700 |
| | **SWH** | 1440 | 1 | included | 1440 |
| | **Electric Water** | 150 | 2 | 100 | 400 |

*Figure 65: Costs for individual heating devices*

### *Costs for PV*

According to Bajada New Energy's pricing, the cost for 1 $kW_p$ PV would currently amount to 1800€ including installation costs. That cost is indicated for PV installation < 5 $kW_p$, hence it is considered representative for residential households. Since the domestic PV sector on Malta just recently gained momentum, the authors assume a 20% price reduction (4,4% annually) within 2020. In comparison, prices for small scale roof top installations decreased much faster by 67% from 2006 to 2013 (14,6 % annually) in Germany.[134]

It is further assumed that 60% of installations will fall into the category > 5 $kW_p$. Therefore, costs of 1.440 EUR/$kW_p$ will be taken for 60% of the PV installations. The remaining 40 % of installation, expected to be larger than 5 $kW_p$, hence related to the commercial and industrial sector, will be cheaper due to economies of scale. While EnergyPLAN's cost database indicates 1300 EUR/$kW_p$ of PV costs for 2020, a study from Agora Energiewende & Fraunhofer[135] indicates 824 EUR/$kW_p$ for large-scale projects. Since no particular large projects are expected for Malta, the authors will compromise costs at 1300 EUR/$kW_p$ for installations >5 $kW_p$, sticking to EnergyPLAN's data base.

When weighting the costs according to 60% small-scale installations and 40 % large scale installations the average cost for PV installations in this project amounts to 1385 EUR/$kW_p$. It must be considered that the authors take the prices for 2020, as if all installations would take place in 2020 conditions.

| PV | System € /$kW_p$ | Installation |
|---|---|---|
| **< 5 $kW_p$** | 1440 | included |
| **> 5 $kW_p$** | 1300 | included |
| **Weighted Total** | **1384** | |

*Figure 66: Costs for small and large-scale PV installations*

### 7.4.3. Basic default input parameters for 2020 used in all scenarios if not stated differently within the scenario

*Transport*

Consumption for road transportation is 1,8 TWh in 2020. 10 % or 0,18 TWh will be covered through biofuels, with biodiesel amounting to 0,16 TWh (90% of biofuels) and bioethanol to 0,02 TWh (10% of biofuels). The split between diesel and petrol is 60 to 40 %, as in 2013, resulting in 0,97 and 0,65 TWh respectively. Electric vehicles will not play a significant role yet, hence they will not be simulated in the 2020 energy system. Costs for biofuels were not considered in the modelling, but since that is the case in all models within the project, relative changes do not occur.

*Heating*

When it comes to individual heating, an important element has to be noted. Space heating is operated mainly using portable LPG heaters on Malta. However, this option is not available in EnergyPLAN, therefore it has been chosen to use the tab referring to oil boilers instead. The relative investment cost has to be modified, reflecting the one of portable LPG heaters. The fossil fuel cost, instead, could not be adjusted, since the same tab would also refer to the fossil fuel employed in PP2, therefore specific calculations and a discussion on that will be operated in the chapter POLICY RECOMMENDATIONS.

Furthermore, in EnergyPLAN the heating demand for space heating and water heating cannot be separated. Therefore, some approximations will occur, in particular when the variable generation of solar water heaters, only providing hot water, has to be matched with the demand profile, including space heating and hot water generation. However, it is assumed that such approximation do not change the model outcome relevantly. With regards to costs, as already mentioned the devices providing space heating and hot water are calculated separately.

### *Large Scale Power Supply:*

The following table shows the input data of fossil power generation distributed on power plant group 1 running on fuel oil and an average efficiency of 49% and power plant group 2 running on gasoil and an average efficiency of 31%.

| Gas run Power Fleet | | | |
|---|---|---|---|
| **Year 2020** | **Capacity in MW** | **Efficiency** | **Fuel** |
| **PP1** | 215 | 50% | Natural Gas |
| | 149 | 47% | Natural Gas |
| **Sum or Average** | **364** | **49%** | |
| **PP2 (backup capacity)** | 110 | 38% | GasOil |
| | 74 | 20% | GasOil |
| **Sum or Average** | **184** | **31%** | |

*Figure 67: EnergyPLAN, Input for PP1 and PP2*

### *System Requirements and Options*

The following table shows the interconnector capacity to the external Italian power market, as well as the minimum requirement of 30 % firm capacity (namely minimum grid stabilization share) in the system. A maximum peak of 150 MW export capacity, equalling an annual maximum export trade volume of 0,24 TWh, is allowed.

| | | |
|---|---|---|
| **Interconnector** | 200 | MW |
| **Grid Stabilisation Share** | 30 | % |
| **Max Peak** | 150 | MW |
| **Annual Volume** | 0,24 | TWh |

*Figure 68: EnergyPLAN, Interconnector peak*

### *Distributions*

All distributions are used as produced by the authors according to the methodologies presented in HOURLY POWER DISTRIBUTION chapter section.

## 7.5. How using EnergyPLAN? -Simulation Section

It is possible to optimize the energy system with a technical or economic optimization strategy in EnergyPLAN. In the technical optimization energy is physically generated in the most efficient way (minimising fossil fuel consumption, independently from the costs), while in the economic optimization energy is generated in the most cost efficient way (minimising the systems operational costs).

### 7.5.1. Technical Optimization Simulation

There are four different main types of technical optimization in EnergyPLAN, which all relate to the operation of CHP plants. None of them perfectly fit the energy system of Malta, which does not have any CHP plant. Two of the technical optimization strategies specifically refer to features of the Danish system, hence are not even mentioned, while the other two are evaluated in relation to the Maltese energy system.

- **Balancing of Heat Demands:**

In this optimization, power plants producing also heat must operate according to the heat demand profile. Heat production is prioritized in the following order:

- Solar Thermal
- Industrial CHP
- Heat from Waste
- CHP Heat
- Heat Pumps
- Peak Load Boilers

Since there are no large-scale heat-producing units on Malta, the authors found this option not suitable to the Maltese system. Instead, the second optimization strategy will be used, when applying a technical optimization.

- **Balancing heat and electricity demands**

Connolly[136] explains that during times with excess electricity, an increase of electricity consumption through boilers and heat pumps is triggered before making the excess electricity available for export. Two choices can be operated in this regard:

  - Individual heat pumps and electric boilers can be optimised to utilise only critical excess production.
  - Individual heat pumps and boilers can be optimised to utilise all electricity export.

Condensing PPs will decrease power production in favour of CHPs, reducing the production of power in favour of the production of heat, which will be stored.

The optimization strategy practically works as illustrated in FIGURE 69. During low penetration of RES, in the example wind power, CHP plants run full load supplying power and heat. Excess heat is stored thermally. Whereas during high RES penetration CHP plants run only on partial load. Extra heat must be obtained from the thermal storage. That optimization does pretty much describe how the Danish energy system is optimized.

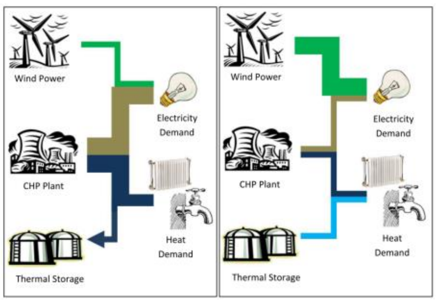



*Figure 69: Simplified comparison of EnergyPLAN's optimization strategy[137]*

Neither of the strategies can ideally be utilised by EnergyPLAN on the Maltese energy system since excess heat from Power Plants is currently not utilised and no centralized heating system is in place. Hence, CHP plants and large scale thermal storages are not part of the system, but a modulation of the output from conventional power plants, according to the RES production fed into the system, can be foreseen. In Malta, heating purposes are covered by individual means in each household. The presence of smart meters in most of the Maltese households could ease the consumption of excess electricity in heat pumps (flexible demand). Hence, the optimization "balancing of heat and electricity demands" is taken and adapted.

### 7.5.2. Economic Optimization Simulation

The market economic simulation strategy is based on a market set up like the NordPool market where the short-term marginal price is represented only by the variable costs of power production. Hence, the merit order applies. Malta is a rather isolated market, doesn't have a wholesale market and the system operation does not necessarily follow market criteria, since Enemalta set a fixed 18-year PPA with the independent power producer, which is going to run the gas CCGT starting from 2016. Also the interconnection with Italy won't necessarily work according to market rules, since a confidential agreement is in place between Enemalta and Enel Trade and Malta doesn't have a wholesale market and price to base on. Hence, an economic simulation makes little sense and will not be applied.

## 7.6. How using EnergyPLAN? - Output Section

Connolly stresses five major output parameters to be compared between different EnergyPLAN models.[138]

- PES (Primary Energy Consumption)
- $CO_2$ Emissions
- Annual Costs
- EEEP (Exportable Excess Energy Production)
- CEEP (Critical Excess Energy Production)

### 7.6.1. Energy System Priorities

When modelling Malta's energy system, the following three parameters are to be prioritized in the given order, according to the Maltese government's prerequisites:


*Figure 70: Priorities when modelling Malta's energy system*

- **Security of supply and system stability**

Demand for power must be covered by supply at all times. Eventual outages or fluctuations in demand and supply due to extreme weather situations must be backed by enough back up capacity, which makes the system able to overcome temporary failures and assure security of supply[139].

Referring to EnergyPLAN's simulation methods, security of supply is the first parameter, which EnergyPLAN tries to comply with, given the input data. However, EnergyPLAN is not able to influence the installed capacity but only its operation, hence operation and not long-term security of supply. In case of lack of sufficient installed capacity, EnergyPLAN cannot produce a system granting security of supply. Hence, the authors must provide sufficient installed capacity in input. Furthermore, EnergyPLAN does not simulate any system failure or plant outage.

However, it has been presented in the SUPPLY SIDE chapter that by 2020 and beyond more than sufficient capacity will be available on Malta to cover the demand, given the existing conventional units, the gas-fired power plant, which is constituted by small single units. The interconnector to Italy, which just started operations, can partially be considered as additional back up capacity and a source of supply security. Therefore, an assessment of security of supply, as it has been defined here, is not going to be presented to the reader in the models, since it is expected to be met at any time.

Instead, system stability needs to be verified and maintained in each of the presented scenarios. The main parameter to define in EnergyPLAN the system stability is the minimum grid stabilization share, which identifies the minimum share of production, which has to be covered at any time by firm capacity. Firm capacity is that capacity, which is available for granted at a given time, typically conventional generation capacity. A minimum grid stability share of 30 %, which is also the default value suggested by EnergyPLAN, is set as a requirement by the authors. Therefore, EnergyPLAN will operate PP1 at any time, despite sufficient production from PV power production in order to comply to the grid stabilisation share. As a result, excess electricity production can occur.

The fact that excess electricity production (EEEP) occurs is not seen as a problem to the system stability, since an interconnector is in place. Also the presence of Critical excess electricity production (CEEP), meaning that excess electricity production is larger than the amount, which can be exported through the cable capacity at certain times, is not a negative factor per se, since it can be chosen to reduce the generation from renewables or trigger more demand to overcome it.

- **Compliance to EU Targets**

By 2020, Malta has to meet the targets set by the European Union in regards of RES share in final energy consumption and of $CO_2$ emissions in the non-ETS sector. For Malta the targets are:

  - 10% of the final energy consumption covered by RES, including 10% of the transport sector covered by RES)
  - +5% of non-ETS $CO_2$ Emissions compared to 2005

EnergyPLAN does optimize towards the most efficient technologies, which means that RES are automatically deployed with priority. Nevertheless, EnergyPLAN can only work with the Input parameters provided by the authors, which is why feedback from a non-target sufficient output must be used in order to revise the input. Furthermore, EnergyPLAN shows only the RES share on the PES, therefore the authors calculate the RES share on the final energy demand for each scenario individually. The authors will also indicate the level of target achievement in each scenario and the contribution of the specific technologies and sectors towards the target.

As for the second target, EnergyPLAN provides the $CO_2$ emissions related to the energy sector only, while the European target is referred to emissions which come also from others sectors. Hence, minimization of the $CO_2$ emissions is aimed at in the modelling, but it is not possible to verify the target compliance.

- **Cost Efficiency**

As for cost efficiency, EnergyPLAN always performs simulations with the aim of minimizing the running costs of the system. Investment costs, though, cannot be optimized using the software. Investment options can be compared by giving different input data, in order to assess the best cost efficient and secure system.

Considering suitable technologies and the right capacity mix of several energy sources the authors try to identify the cheapest technology package, which is able to comply with the two previous requirements “System Stability “ and “Target Compliance”. That can be done through a first guess on the technology potential on Malta and will be refined by several outputs from EnergyPLAN, which indicate to change particular Input parameters until the best model is found.

## 8. Scenario Approach

When building the scenarios for the Maltese energy system, three kinds of input data can be differentiated. There are external defaults like costs of the different technologies as well as legislation and obligations prescribed by external stakeholders like the EU. These parameters can hardly be adjusted in the modelling.

Furthermore, there are internal defaults, which are already characteristic of the energy system or already set in motion by the actions of the Maltese stakeholders. For example, certain recent sunk investments or decisions and contractual bindings in the energy sector, as well as energy planning legislation on Malta. The impacts of these predefined choices on the system are evaluated and discussed but are not going to be radically changed ,since it is clear that it is not realistic to modify these system factors.

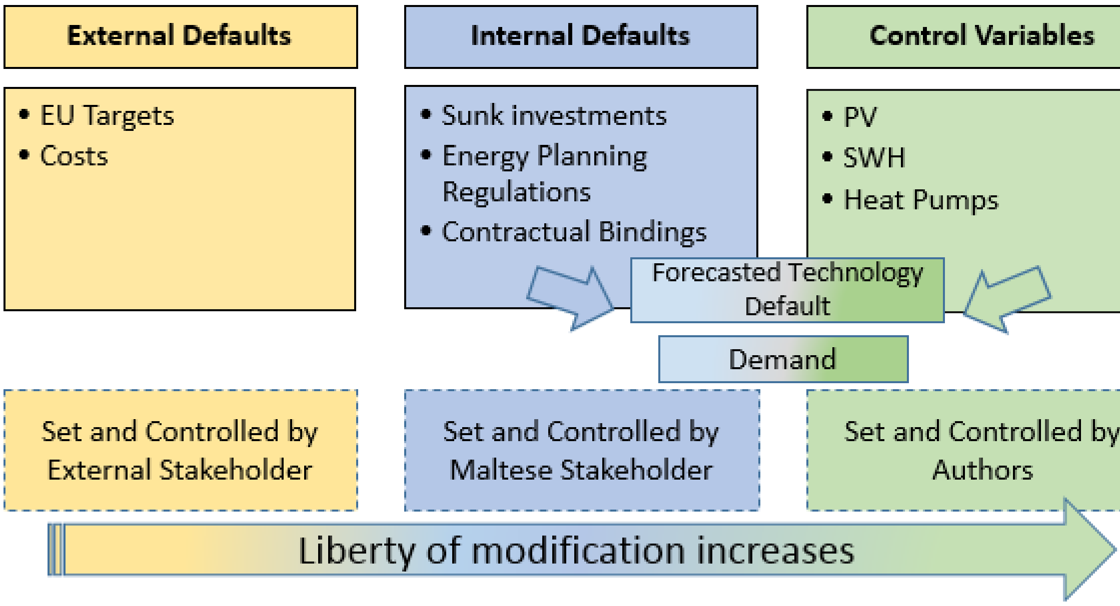



*Figure 71: Model Category Parameters*

The third category is constituted by those parameters, which are controllable by the authors, when modelling Malta's Energy system. These are variable elements of the future energy system of Malta, i.e. the extent and composition of power and thermal generation from RES. These will be the major control variables within the energy system modelling. Investments in those technologies were not made yet (sunk investments), which means there is still potential to control the technology path. Furthermore, the implementation can realistically be incentivised and has a potential to transform Malta's energy system towards decarbonisation.

Through the variation of these freely controllable inputs and according to the given internal and external defaults, the most cost effective system, which also meets the requirements of target compliance and system stability, can be found. The range in which these parameters can vary is restrained by the analysis concerning the available potential on Malta. Furthermore, the realistic viability of the suggested scenarios must be discussed. On the basis of a set of data which is partly fixed (internal and external parameters) and partly subject to evaluation and sensitivities, the authors will simulate several scenarios, in order to define the future optimal combination of existing, already defined and new power plants that will satisfy the requirements of system security, target compliance and cost effectiveness.

FIGURE 72 gives an idea of the EnergyPLAN modelling approach. The graphic is structured according to the internal and external defaults in the red boxes, which influence the control variables and the heating sector and demand structure. All parameters in the red boxes are model input parameters. The power sector is on the left side, the heating sector on the right side. The two sectors are interconnected since the heating sector consumes or displaces power.

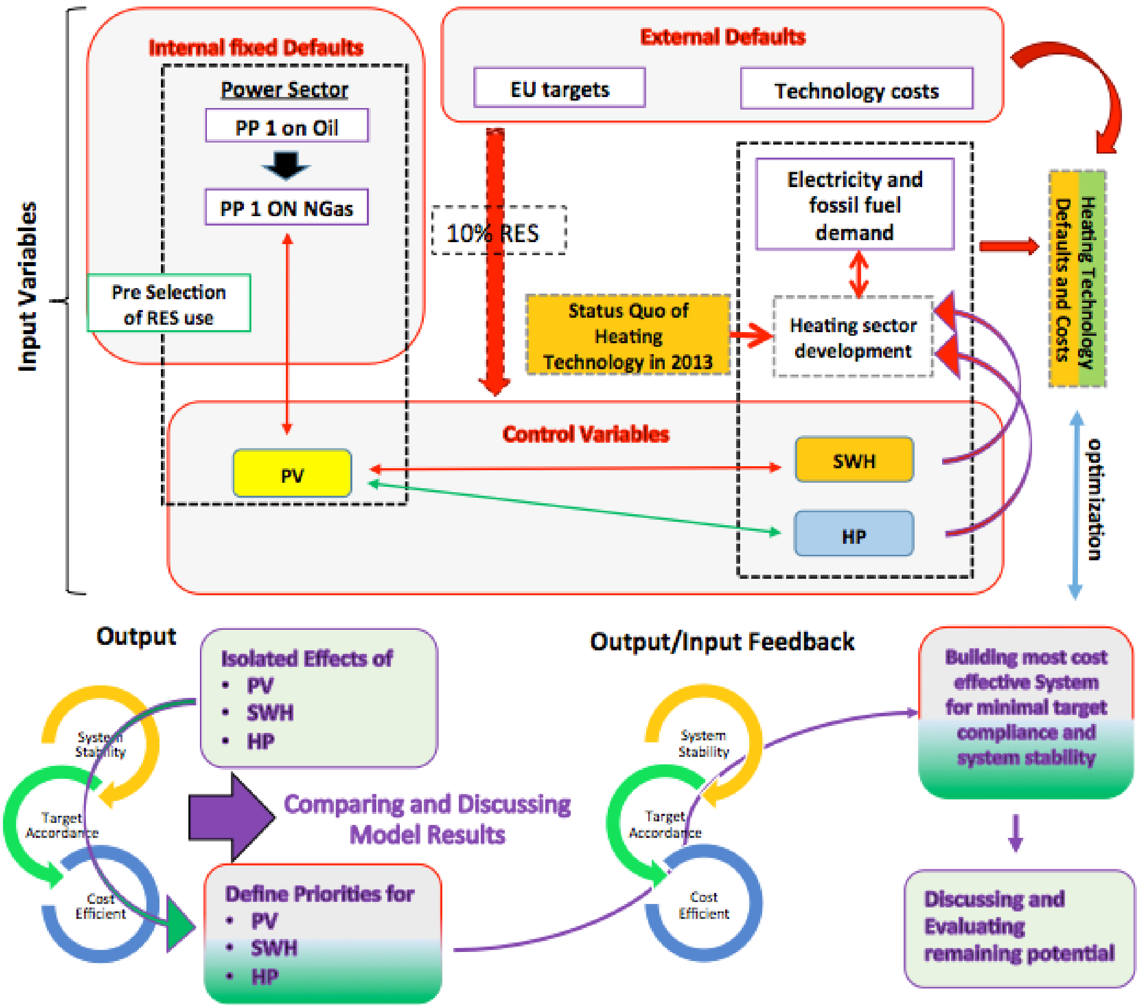



*Figure 72: EnergyPLAN Scenario Approach*

The external defaults do refer to factors such as the EU targets and the technology costs, which cannot be changed at national level. The element mainly influenced by and influencing both the exogenous defaults and the control variables is the heating sector. The final energy demand of the heating sector in 2013 will be forecasted to 2020, using the same recent trends in the heating sector. The way in which final energy demand is covered influences the consumption of fossil fuels and the consumption of electricity in the system, as well as determines the compliance with the EU targets.

The starting point for the modelling is an oil based system (PP1 on oil), which switches to gas in the power sector (PP1 on natural gas). Since a shift towards natural gas is initiated and bound in contracts, this step is already given as a strict internal default. However, in the first modelling it will be evaluated what the benefits gained through the shift are, which is then set as the new default for PP1 and used for all following simulations. The effects on the system of PVs, SWHs and HPs are evaluated in order to prioritize their deployment.

On the bottom, the results are analysed and discussed. The findings are used as feedback to alter some of the inputs in order to build the most cost effective system, which just complies with EU targets and maintains system stability. The red arrows mean that there is rather a competition between technologies, while green arrows indicate synergy effects.

Based on this scheme, different scenarios will be built and the best scenario, given the present system as starting point, will be individuated.

# 9. Modelling Malta's Energy system towards 2020

The only significant source for power generation comes from two large power plants (referred to as PP1), which have the same installed capacity in all scenarios. In the first scenario, they are run on oil, as it was the case in the past and present on Malta. Then the same scenario is modelled with PP1 running on natural gas, which is the planned status quo for 2020. PP1 running on natural gas is established as the new PP1 default for all following scenarios.

In all scenarios back up capacity, namely PP2, will be maintained. This consists of outdated power plants running on oil, which will be triggered only in emergencies. The conventional heating technology mainly consists of fossil fuel based space heating (LPG heaters) and electric water heating. In addition, cooling is conducted through air-to-air reverse heat pumps and is a major power consumer. Despite their technical functionality also as heating devices, HPs are not commonly used for heating until now.

For all scenarios a fixed final heating and cooling demand is estimated for 2020. The energy demand of the transport sector is also not a variable. Power consumption for purposes different from heating is estimated and fix, while the overall system's power demand for heating will slightly vary according to the technologies employed in the heating sector. The final energy demand (efficiency measures or sensitivity are not applied) will be the same in all scenarios, but the necessary primary energy will vary according to the use of technology, in particular when SWH, HPs and PV are used. HPs are used only for space heating and cooling, while SWH serve only the scope of water heating. SWHs, PV and HP are referred to as advanced or innovative technologies.

- SWHs always substitute electric water heaters with first priority. However, it has to be reminded that each SWH requires a backup conventional heater, which provides up to 30% of the hot water. For this reason a complete replacement of electric water heating is not possible and a minor share of both electric and fossil fuel based heaters are maintained in the system.
- HPs always substitute electric space heating with first priority.
- PV substitutes Gas power production.

The substitution priorities are legitimate since the conventional electricity-consuming individual heating technologies consume power at an assumed efficiency of ~100%, which is primarily generated with an efficiency of about 50 % in PP1. Hence, the total process efficiency of electric heating amounts to 50 %, while the individual LPG consuming technologies work at efficiencies of 85 %. This leads to a higher consumption of fossil fuels and higher pollution when employing electric heating. It has also to be considered that electric resistance technologies have the lowest investment costs. Therefore, it can also be expected that people abandon the technology also before its lifetime ending, if they are made aware of its little convenience in comparison to other technologies.

Power used in HPs profits from a high coefficient of performance of 3 (COP 3), since it uses ambient air as heating or cooling reservoir. It is therefore considered as a technology, which partially consumes renewable energy. Assuming that the whole electricity employed is produced by PP1, the overall process efficiency of the heat produced through HPs amounts to 150% (300%*50%).

The authors will model **three different model groups**, to which different starting restraints in regards of the use of advanced technologies are applied. Based on the different starting points and the applied restraints, the scenarios are divided into the three groups.

- **FORECAST-BASED MODELLING:** two models are built based on the historical trends and the foreseeable evolution of the advanced technologies, given the status quo and the existing regulations.
- **ISOLATED-MODELLING:** the isolated impact of the single advanced technologies on the system is evaluated in order to prioritize their deployment.
- **OPTIMAL SYSTEM DEVELOPMENT:** Starting from the existing system (reference year 2013) and given the results of the isolated modelling, optimal scenarios are designed.

## 9.1. Forecast-based Modelling

Before applying an analytical approach, in which the different options are compared and the best solution is evaluated, it is observed how the system could evolve, given the status quo, the historical trends and no relevant changes in the policy guidelines.

Two scenarios are built using a business as usual approach and an innovative approach. The former maintains the historical trends, while the latter involves greater choice awareness for heat pumps and SWHs. The evolution of the heating sector in the two scenarios has been presented and discussed in the chapter DEMAND. As for PV installations, the business-as-usual scenario maintains the average growth registered between 2010 and 2014, i.e. 13 MW/year, until 2020, while in the innovative scenario the higher average yearly growth registered between 2011 and 2014, i.e. 15,9 MW per year, is projected until 2020. These are the authors assumptions based on the registered development between 2010 and 2014.

Despite the intrinsic insecurity in forecasts, it is supposed that these two scenarios could represent the future of the Maltese system, if no specific new guideline (change or cancellation of incentives) is given that system represents the reality on Malta best. These models can be a term of comparison to the optimum outcome of the modelling, but are not directly connected with the design of the two other groups of models.

- **BUSINESS AS USUAL 2013 TO 2020 TREND**
  - The recent technology development will be extrapolated in a continuous growth trend until 2020.
    →The resulting energy system in 2020 is evaluated and checked on EU target status
- **INNOVATIVE 2013 TO 2020 TREND**
  - An innovative Technology development is assumed until 2020. The resulting energy system in 2020 is modelled
    →The resulting energy system in 2020 is evaluated and checked on EU target status

## 9.2. Isolated-modelling

In order to build the best possible scenario for Malta, which complies with the given targets and parameters, the effects of single controllable variables (SWH, HP and PV) within the energy system are isolated. In order to design a system more radically from scratch, a system, in which any use of advanced technologies is excluded, is set as a base reference.

The equivalent capacity of advanced technologies (control variables) producing 0,1 TWh of energy (either power or heating) is added isolated to check on the specific effect on the system. This capacity automatically substitutes the equivalent of 0,1 TWh electricity or heat produced by fossil fuels in the defaulted power and heating sector. With regards to the heating sector, also the relative conventional technology infrastructure is replaced and not accounted as a cost in contrast to the power sector, where defaults on conventional technology infrastructure cannot be altered anymore.

This results in three models, in which there is an isolated contribution of:

- SWH
- HPs
- PV

The isolated effects of the control variables on the system (primary energy consumption, related costs and investment costs) can be compared. As a result, a priority of deploying PV, SWH and HPs based on the costs, on the area consumption and on statistical accountability as RES in the system is defined. Since the production of 0,1 TWh energy is rather small, it does not radically affect target compliance and system stability yet.

## 9.3. Optimal system development

Technology use of 2013 is the starting point, as in the first group of models. According to the resulting priority in the isolated modelling, the authors will deploy the maximum capacity of the first prioritized technology until either the maximum demand for the generated energy (heat or power) is covered or the maximum potential evaluated for the technology is reached.

In the first step, the aim is to reach the target compliance of a 10% share on RES in final energy consumption. Hence, the most cost effective system, which complies with the European RES share target, is simulated. If that system also maintains energy system stability, it will represent the authors' recommendation, as Malta's ideal energy system in the short term. That system will also be compared to the innovative and conservative forecasts, which were designed based on the status quo in 2013.

Since the RES potential is limited on Malta, mainly due to geographical restraints and system stability, the authors evaluate how much RES resources are remaining after the optimal scenario to achieve the target is built, still considering the same principal restraints. Therefore, the path towards Malta's energy system in 2030 can be modelled.

Hence, this modelling section is run in more steps, from just the achievement of the target till the deployment of the maximum available potential with and without the interconnector in place:

- More installation capacity of the most cost efficient RES technologies is added until the 2020 target is just reached. → Optimal System for Minimal Target Compliance
- Optimal System with maximal RES share of the two first to be utilised advanced technologies
- Optimal System with maximal RES share of all advanced technologies
- System without Interconnector

The final goal is to find the most cost effective system, which uses the maximal restrained RES potential without endangering system stability.

## 9.4. Results

### 9.4.1. Forecast-based modelling

**Target**

Modelling a business as usual and an innovation-based evolution of the energy system, starting from the status quo in 2013 and taking the recent development of advanced technologies into account.

*Business as Usual 2013 to 2020 trend*

**Input**

- PP1 uses natural gas as fuel.
- A capacity of 131 MW PV is expected to be installed.
- The heating sector looks as detailed in HEAT DEMAND UPSCALING BUSINESS AS USUAL chapter and summarized in FIGURE 73.

| Business as Usual heating 2020 | | | | |
|---|---|---|---|---|
| | | demand share | input energy consumption (TWh) | final heat generation (TWh) |
| water heating | SWH | 15,8% | | 0,062 |
| | fossil fuel | 9,1% | 0,042 | 0,036 |
| | electric | 75,0% | 0,295 | 0,295 |
| | | | | **0,394** |
| space heating | fossil fuel | 68,1% | 0,265 | 0,225 |
| | electric | 0,0% | 0,000 | 0,000 |
| | HPs | 31,9% | 0,035 | 0,106 |
| | | | | **0,331** |
| | el input | | **0,331** | |
| | ff input | | **0,308** | |

*Figure 73: Heating in Business as Usual Scenario for 2020*

**Output**

The energy system would cost 390 Mio € and emit 1,325 Mio tons of $CO_2$ annually. RES share on power production would be 11,5 %.

| Business as Usual 2013 to 2020 trend | | |
|---|---|---|
| power demand | 2,191 | TWh |
| RES share on power production | 11,5 | % |
| annual fuel consumption | 6,19 | TWh |
| CO2 emissions net | 1,325 | Mt |

| Costs | M EUR | Including CO2 |
|---|---|---|
| Variable costs | 314 | 17 |
| Fixed operation costs | 24 | |
| Annual Investment costs | 52 | |
| **TOTAL ANNUAL COSTS** | **390** | |

*Figure 74: Quick Fact Results Business As Usual*

No problems in regards of the energy system stability can be identified. PP1 produces around 1,99 TWh annually, which means a capacity factor of 62,4 %. PV production peaks at 97 MW and produces 22 MW on average. The interconnector is not used at all.

PP2 is used with a peak of only 14 MW and that occurs so rarely that no significant annual amount of power production from PP2 was registered. No cross border trading volume is used.

| Business as Usual 2013 to 2020 | Characteristics of System Stability | Binding Grid Stabilisation Share | | 30% | | |
|---|---|---|---|---|---|---|
| | | TWh | capacity factor | Annual Min (MW) | Annual Avg (MW) | Annual Max (MW) |
| | PP1 (364 MW) | 1,99 | 62,4% | 85 | 226 | 364 |
| | PP2 (184 MW) | 0 | 0 | 0 | 0 | 14 |
| | PV (131 MW) | 0,2 | 0 | 0 | 22 | 97 |
| | | | | | | |
| | EEEP | 0 | 0 | 0 | 0 | 0 |
| | CEEP | 0 | 0 | 0 | 0 | 0 |
| | Export | 0 | 0 | 0 | 0 | 0 |
| | Import | 0 | 0 | 0 | 0 | 0 |

*Figure 75: System Stability Facts in business as usual scenario*

Given the premises of this scenario, the target would be fulfilled only to 89% as summarized in the following table. The major single contribution of 35 % would come from 0,2 TWh PV power production.

| Business as Usual 2013 to 2020 | RES SHARES ON FINAL ENERGY DEMAND | | | | Target | |
|---|---|---|---|---|---|---|
| | | Final Energy Demand | 5,737 | TWh/year | | |
| | RES | 10 % RES Target of Final Energy | 0,574 | TWh/year | % on RES Target | |
| | CO2 Emissions | | x | m tons | x | m tons |
| | | | | | | |
| | E-RES | e-RES TOTAL | 0,2 | TWh/year | 35% | of Target |
| | e-RES | PV | 0,2 | TWh/year | 35% | |
| | e-RES | | | TWh/year | | |
| | | | | | | |
| | H-RES | Total RES Heat | 0,132 | TWh/year | 23% | of Target |
| | h-RES | SWH | 0,062 | TWh/year | 11% | |
| | h-RES | HP | 0,070 | TWh/year | 12% | |
| | | | | | | |
| | TOTAL | Transport | 1,799 | TWh/year | | |
| | t-RES | Biofuel Imports for Road Transport | 0,179 | TWh/year | 31% | of Target |
| | | | | | | |
| | TOTAL | Target Achivement Level | 0,511 | TWh/year | 89% | of Target |
| | RES Missing | | 0,063 | TWh/year | 11% | |

*Figure 76: Target Compliance in Business as Usual scenario*

### *Innovative 2013 to 2020 trend*

**Input**

- PP1 uses natural gas as fuel.
- PV installations would grow to 148 MW.
- The heating sector evolves, as summarized in FIGURE 77 and explained in the HEAT DEMAND UPSCALING INNOVATIVE chapter.

| Innovative heating 2020 | | | | |
|---|---|---|---|---|
| | | demand share | input energy consumption (TWh) | final heat generation (TWh) |
| water heating | SWH | 25% | | 0,097 |
| | fossil fuel | 9% | 0,042 | 0,036 |
| | electric | 66% | 0,260 | 0,260 |
| | | | | **0,394** |
| space heating | fossil fuel | 48,6% | 0,189 | 0,161 |
| | electric | 0,0% | 0,000 | 0,000 |
| | HPs | 51,4% | 0,057 | 0,170 |
| | | | | **0,331** |
| | el input | | 0,317 | |
| | ff input | | 0,232 | |

*Figure 77: Heating for Innovative Scenario in 2020*

**Output**

The system would have total annual costs of 384 Mio € and 1,300 Mio tons $CO_2$ emissions. The variable costs have a share of 80 % on total costs.

| Innovative 2013 to 2020 trend - adjusted | | |
|---|---|---|
| power demand | 2,182 | TWh |
| RES share on power production | 11,9 | % |
| annual fuel consumption | 6,11 | TWh |
| CO2 emissions net | 1,299 | Mio tons |

| Costs | Mio EUR | Including CO2 |
|---|---|---|
| Variable costs | 308 | 17 |
| Fixed operation costs | 24 | |
| Annual Investment costs | 52 | |
| **TOTAL ANNUAL COSTS** | **384** | |

*Figure 78: Quick Facts Innovative Scenario*

The EU target would slightly be overachieved by 6 %. Since, the author want to compare the innovative trend with an optimally modelled scenario, which just reaches the EU target by 100 %, the input parameters were scaled back by 6% in this model. The following table shows the target achievement through an innovative trend.

**Adjusted Innovative 2013 to 2020**

| RES SHARES ON FINAL ENERGY DEMAND | | | | Target | |
|---|---|---|---|---|---|
| | Final Energy Demand | 5,737 | TWh/year | | |
| **RES** | **10 % RES Target of Final Energy** | **0,574** | **TWh/year** | **% on RES Target** | |
| **CO2 Emissions** | | **1,299** | **m tons** | **x** | **mio tons** |
| | | | | | |
| **E-RES** | **Electricty RES TOTAL** | **0,200** | **TWh/year** | **35%** | **of Target** |
| e-RES | PV | 0,2 | TWh/year | 35% | |
| e-RES | | | TWh/year | | |
| | | | | | |
| **H-RES** | **Heat RES TOTAL** | **0,195** | **TWh/year** | **34%** | **of Target** |
| h-RES | SWH | 0,090 | TWh/year | 16% | |
| h-RES | HP | 0,105 | TWh/year | 18% | |
| | | | | | |
| TOTAL | Transport | 1,799 | TWh/year | | |
| **t-RES** | **Biofuel Imports RES Transport** | **0,179** | **TWh/year** | **31%** | **of Target** |
| | | | | | |
| **TOTAL** | **Target Achievement Level** | **0,574** | **TWh/year** | **100%** | **of Target** |
| **RES Missing** | | **0,000** | **TWh/year** | **0%** | |

*Figure 79: Target Compliance Innovative Scenario*

### *Conclusion*

The business as usual scenario would fail to reach the 2020 target by 11 % RES Share missing. The innovative scenario would even overachieve the target, but was normalised in order to reach the target exactly. The contribution of SWHs, HPs and PVs to the system was slightly decreased in order to let the system set up just achieve (and not overachieve) the target. Therefore, it is made comparable to the optimal system for minimal target compliance in the upcoming third model group, for example.

## 9.5. Isolated Modelling

The same heating technology default, i.e. 91% water heating covered by electric devices and 87,5% of space heating covered by fossil fuel based heater, while the remainder is covered by fossil fuel based and electric heaters respectively, is used in all free modelling scenarios.

### *PP1 on oil*

**Target**

Analysing the status quo of the system when PP1 is fuelled by oil.

**Input**

- 363 MW capacity distributed in two power plants is used as PP1, which runs on oil.
- In the heating sector the same ratio between fossil and electric heating as in 2013 is used but all advanced technologies have been excluded and replaced by conventional technology.

**Output**

When simulating the use of oil as a fuel in PP1, and considering PP1 as the only source of power generation combined with a heating sector exclusively based on individual gas/oil boilers, as well as electric resistance heating, the total annual costs of the energy system amount to 420 Mio EUR. $CO_2$ emissions are at 1,785 Mio tons.

| PP1Oil + no advanced technology | | |
|---|---|---|
| power demand | 2,257 | TWh |
| RES share on power production | 0 | % |
| annual fuel consumption | 6,55 | TWh |
| CO2 emissions net | 1,738 | Mio tons |

| Costs | Mio EUR | Including CO2 |
|---|---|---|
| Variable costs | 355 | 23 |
| Fixed operation costs | 23 | |
| Annual Investment costs | 42 | |
| **TOTAL ANNUAL COSTS** | **420** | |

*Figure 80: Quick Facts PP1 on Oil*

Variable costs have a share of almost 84,5 % on total costs. Power demand is at around 2,26 TWh. The only RES contribution to the system (0.4%) is due to the use of biofuels in the transport sector.

### *PP1 on natural gas*

**Target**

Shift all primarily used production capacity of PP1 from fuel oil to natural gas. This scenario will analyse the cost and emission effects on the system from the fuel change of oil to natural gas, which has been already announced.

**Input**

The only change in the input parameters, compared to the base model, will be that the large power plants PP1 run on natural gas. Since Malta is isolated from pipeline systems, natural gas can only be used in form of LNG. One must add an extra of around 2 EUR/GJ to the natural gas costs of 9,3 EUR/GJ, considering that a European price reference is taken. That adds up to costs of 11,3 EUR/GJ.

**Output**

The substitution of oil in PP1 with natural gas simulates the upcoming shift to natural gas as the main fossil fuel, while PP1 is still considered as the only source of power generation. Combined with a heating sector exclusively based on individual gas/oil boilers, as well as electric resistance heating, the total annual costs are decreased by 2,6 % (11 Mio EUR) amounting to a total of 409 Mio EUR. $CO_2$ emissions decreased by 16 % from 1,738 Mio. tons to 1,457 Mio tons.

| | | | | |
|---|---|---|---|---|
| **START MODEL STATUS QUO OIL** | Total Annual Costs | 420 | Mio € | Reference |
| | CO2 Emissions (net) | 1,738 | Mio tons | Reference |
| | Accountable as a RES | 0 | % | Reference |
| **NEW REFERENCE Model GAS** | Total Annual Costs | 409 | Mio € | **-2,6%** |
| | CO2 Emissions (net) | 1,457 | Mio tons | **-16,2%** |
| | Accountable as a RES | 0 | % | **0** |

*Figure 81: Quick Facts Comparison PP1 on Oil vs. PP1 on Gas*

The cost decrease drivers are variable costs, which decreased through the lower costs $CO_2$ emissions (and related costs) and cheaper fuel. It must be reminded that the assumed price for $CO_2$ emissions is an important factor (13 € /ton in the modelling). Cost savings increase with the amount of necessary $CO_2$ allowances to cover the production, as well as with the cost difference between gas and oil fuel. Furthermore, savings could be much higher, if natural gas (LNG) could be obtained cheaper. In this modelling, the relative fuel price advantage of natural gas on Oil is only marginal. In general, there is a large potential for higher cost savings through the use of natural gas power plants.

Both economic and environmental advantages occur with PP1 using natural gas instead of oil. Therefore, all other scenarios will modelled with PP1 running on natural gas, which also reflects the reality of Malta's upcoming energy system, since the fuel switching decision has been already made by Maltese stakeholders and defined in a PPA and GSA.

*The following three scenarios refer to the previous scenario based on natural gas, but in addition advanced technologies producing 0,1 TWh energy output substituting the equivalent of 0,1 TWh from traditional technologies are introduced to analyse the isolated effect of each technology to the energy system.*

### *PV Effect*

When substituting 0,1 TWh power production from fossil fuels with PV power production in the system, the total annual costs are decreased by 3 Mio € (-0,7 %), amounting to 406 Mio EUR, despite the increased investment costs due to the installation of PVs.

| | | | | |
|---|---|---|---|---|
| PV EFFECT on NEW REF | Total Annual Costs | 406 | Mio € | -0,7% |
| | CO2 Emissions (net) | 1,416 | Mio tons | -2,8% |
| | Accountable as a RES | 100 | % | |
| NEW REFERENCE Model GAS | Total Annual Costs | 409 | Mio € | Reference |
| | CO2 Emissions (net) | 1,457 | Mio tons | Reference |
| | Accountable as a RES | 0 | % | Reference |

Figure 82: Quick Facts Comparison PP1 on Gas vs. PV

The share of variable costs decreased to 82,5 %. A production of 0,1 TWh from PV would consume about 390.000 m$^2$, calculated with a PV panel efficiency of 16%, optimal tilt angle and GCR 60%. If both the residential and non-residential sector are included in the analysis (though excluding brownfields), this area amounts to 17% of the total available area (or 40% of the available rooftop are in the residential sector).

The introduction of PV leads to a 5,6% share on power production from RES and lowers $CO_2$ emissions by 2,8 %, since some gas power production is replaced by PV production.

| PV Effect | | |
|---|---|---|
| power demand | 2,257 | TWh |
| RES share on power production | 5,6 | % |
| annual fuel consumption | 6,45 | TWh |
| CO2 emissions net | 1,416 | Mio tons |

| Costs | Mio EUR | Including CO2 |
|---|---|---|
| Variable costs | 335 | 18 |
| Fixed operation costs | 24 | |
| Annual Investment costs | 47 | |
| TOTAL ANNUAL COSTS | 406 | |

Figure 83: Quick Facts PV Effect

The overall cost and $CO_2$ emission reductions are much smaller than in the PP1 fuel switch to natural gas. However, the addition of PV contributes to the RES Share target achievement for Malta.

*SWH Effect*

When producing the equivalent of 0,1 TWh of thermal energy with SWHs, substituting mainly electric resistance water heating (and a minor share of fossil fuel based generation), the total annual costs are decreased by 7 Mio € (-1,7 %) amounting to 402 Mio EUR. The big cost difference occurs mainly through the displacement of 0,095 TWh power, which reduces primary fuel consumption. Not 100 % of 0,1 TWh used SWH production can be attributed as power replacement since SWH consume about 5 % power as well. $CO_2$ emissions decrease by 3,3 %. The cost and $CO_2$ emission reductions are more relevant than with the PV effect.

| | | | | |
|---|---|---|---|---|
| **SWH EFFECT on NEW REF** | **Total Annual Costs** | **402** | **Mio €** | **-1,7%** |
| | **CO2 Emissions (net)** | **1,409** | **Mio tons** | **-3,3%** |
| | **Accountable as a RES** | **100** | **%** | |
| **NEW REFERENCE Model GAS** | Total Annual Costs | 409 | Mio € | **Reference** |
| | CO2 Emissions (net) | 1,457 | Mio tons | **Reference** |
| | Accountable as a RES | 0 | % | **Reference** |
| PV EFFECT on NEW REF | Total Annual Costs | 406 | Mio € | **-0,7%** |
| | CO2 Emissions (net) | 1,416 | Mio tons | **-2,8%** |
| | Accountable as a RES | 100 | % | |

*Figure 84: Quick Fact Comparison Gas, PV and SWH*

SWH production of 0,1 TWh thermal energy would consume around 94.000 $m^2$, which is about 9% of the identified roof top area potential for PV on residential buildings and 4% of the residential and non-residential available rooftop area. $CO_2$ emission reach a low of 1,409 Mio tons annually.

| **SWH Effect** | | |
|---|---|---|
| power demand | 2,162 | TWh |
| RES share on power production | 0 | % |
| annual fuel consumption | 6,42 | TWh |
| CO2 emissions net | 1,409 | Mio tons |

| **Costs** | **Mio EUR** | **Including CO2** |
|---|---|---|
| Variable costs | 333 | 18 |
| Fixed operation costs | 24 | |
| Annual Investment costs | 45 | |
| **TOTAL ANNUAL COSTS** | **402** | |

*Figure 85: Quick Facts SWH Effect*

*HP Effect*

When generating 0,1 TWh of thermal energy through electric HPs instead of through fossil fuel based technologies (and a minor share of electric heating), the total annual costs are also decreased by 7 Mio € amounting to 402 Mio EUR, as in the previous case of SWHs. However, $CO_2$ emission are decreased only less than half as much as using SWHs.

| | | | | |
|---|---|---|---|---|
| **HP EFFECT on NEW REF** | **Total Annual Costs** | **402** | **Mio €** | **-1,7%** |
| | **CO2 Emissions (net)** | **1,435** | **Mio tons** | **-1,5%** |
| | **Accountable as a RES** | **66** | **%** | |
| **NEW REFERENCE Model GAS** | Total Annual Costs | 409 | Mio € | **Reference** |
| | CO2 Emissions (net) | 1,457 | Mio tons | **Reference** |
| | Accountable as a RES | 0 | % | **Reference** |
| SWH EFFECT on NEW REF | Total Annual Costs | 402 | Mio € | -1,7% |
| | CO2 Emissions (net) | 1,409 | Mio tons | -3,3% |
| | Accountable as a RES | 100 | % | |
| PV EFFECT on NEW REF | Total Annual Costs | 406 | Mio € | **-0,7%** |
| | CO2 Emissions (net) | 1,416 | Mio tons | **-2,8%** |
| | Accountable as a RES | 100 | % | |

*Figure 86: Quick Fact Comparison Gas, PV, SWH and HPs*

The energy produced by HPs does not completely count as renewable energy, but two thirds of it contribute to the RES share in final energy demand. Since HPs replace electric resistance heaters with first priority, a small electricity displacement of 0,008 TWh takes place and the system cost reduction is due to this factor and to the reduction of investment costs in the heating sector (since HPs are already installed for cooling purposes).

| **HP Effect** | | |
|---|---|---|
| power demand | 2,249 | TWh |
| RES share on power production | 0 | % |
| annual fuel consumption | 6,46 | TWh |
| CO2 emissions net | 1,435 | Mio tons |

| **Costs** | **Mio EUR** | **Including CO2** |
|---|---|---|
| Variable costs | 339 | 19 |
| Fixed operation costs | 23 | |
| Annual Investment costs | 41 | |
| **TOTAL ANNUAL COSTS** | **402** | |

*Figure 87: Quick Facts HP Effect*

### 9.5.1. Conclusion of isolated modelling

FIGURE 88 sums up the characteristics of the use of SWH, HP and PV for the production of 0,1 TWh of energy and their impact on the system concerning costs, $CO_2$ emissions, RES contribution and land use. The technologies are ordered in the priority how they should be deployed. The deployment priority is measured mainly on the annual economic savings and the accountability as a RES technology. Secondary importance is given to $CO_2$ savings and to the area consumption of a technology (set in relation to the total available area in the residential sector). The parameter "max development" shows the maximum amount of conventional power or fossil fuel, which could be substituted by each technology. The parameter is determined by the total demand for water heating, space heating or electricity respectively and by technical restrictions specific of the technology.

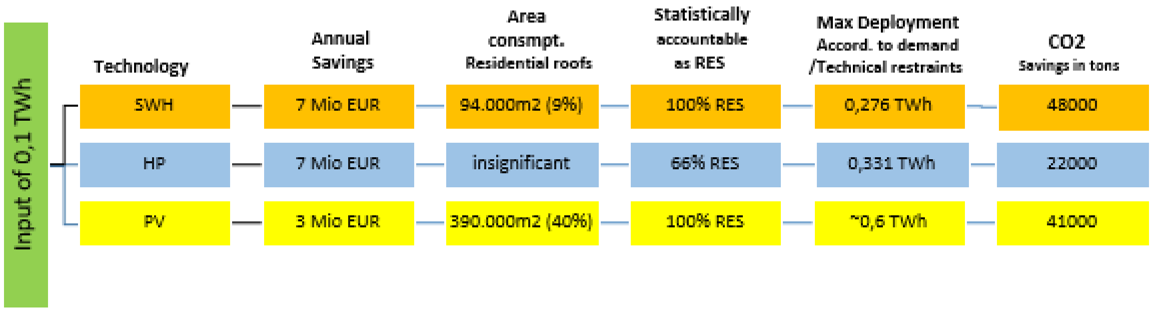



*Figure 88: Summary of SWH, HP and PV Comparison*

SWHs and HPs, both providing 0,1 TWh of thermal energy, lead to the same cost savings of 7 Mio EUR. However, SWHs provide a higher contribution to the RES share and displaces more fossil fuel than HPs per unit. As a result, more than double the $CO_2$ emissions are decreased by the use of SWHs. The parameter of area consumption is in favour of HPs, but since the total area consumption for SWH is acceptable when compared to the overall roof top area on Malta, that argument can be neglected. It must be noted that SWHs cannot be the exclusive way to reach RES share target, since hot water demand is too low, if compared to the total final energy demand. Furthermore, it has been explained that SWHs cannot provide for more than 70% of the total energy demand for water heating in the RES-H POTENTIAL chapter.

PVs, in comparison, present higher total costs and require a larger area consumption, which is a discriminant since Malta has strong land constraints. Therefore, it is ranked with last deployment priority. However, PV presents the overall highest potential, since power demand (over 2 TWh) is higher than heat demand. As presented in chapter RES-E POTENTIAL, the land constrains lead to a maximum potential of around 0,6 TWh. This theoretical maximum potential of PV is further reduced by the limited interconnector capacity and by the external market circumstances (prices).

The maximum deployable HP potential corresponds to the total space heating demand. Heat pumps are ranked with second deployment priority even though only 2/3 of their heat and cooling production (given a COP 3) can be accounted for as RES. However, even when 1/3 more heat pump capacity than PV capacity must be installed to reach the same RES creditability, HPs are still cheaper than PV and consuming less area. Since $CO_2$, emissions are not the overweighed parameter HPs are a better solution than PV. An additional benefit of the deployment of renewable energies in the thermal sector rather than in the electric sector is that they do not relevantly affect the stability of the system.

Nevertheless, heat pumps become more beneficial, when more power is produced through PV instead of gas power plants. In fact, savings through HPs are even increased because power produced through PV can be consumed cheaper by HPs than when produced in PP1.

All scenarios in the next model group are orientated on the RES deployment priority. However, the maximum shares in advanced technology usage are limited through the maximum shares of conventional technology, which can be displaced and the technology specific deployment constraints. The system stability parameter is another crucial factor, which must be maintained imperatively. That is relevant in particular in regards of PV installations.

## 9.6. Optimal system development

All scenarios will use the already existing technology status quo from 2013, which will be complemented by the most beneficial (cost effective and efficient) advanced technologies until either the 2020 target is just fulfilled (first step) or the deployment potential of the RES is utilised by 100% or system stability is disturbed.

### *Cost efficient minimal target compliance scenario*

**Target**

Modelling the most cost effective energy system, which also complies to the EU target. That also means that the target is reached minimally.

**Input**

The already existing technology status quo from 2013 is taken as a starting reference point and as much SWH capacity as needed to just fulfilling the EU 2020 target is added. SWHs have been identified as the most beneficial technology in the free modelling section. As a result, the full potential of SWHs, generating 0,276 TWh of thermal energy, will be utilised in combination with the PV and HPs capacities, which are already installed in 2013.

- 0,276 TWh from SWH
- 0,044 TWh from HPs (0,110 TWh electricity in input)
- 0,075 TWh from PV (50 MW installed capacity)
  0,179 TWh biofuels in the transport sector

**Output**

The system would cost 377 Mio € annually. SWHs displace electric heaters and a minor share of fossil fuel based water heaters. $CO_2$ emissions amount to 1,262 Mio tons.

| **Optimal Modelling: Cost Efficient Minimal Target Compliance 2020** | | |
|---|---|---|
| **Technology Status Quo 2013 + max SWH + system** | | |
| power demand | 2,012 | TWh |
| RES share on power production | 4,4 | % |
| annual fuel consumption | 5,97 | TWh |
| CO2 emissions net | 1,262 | Mio tons |

| Costs | Mio EUR | Including CO2 |
|---|---|---|
| Variable costs | 300 | 16 |
| Fixed operation costs | 25 | |
| Annual Investment costs | 53 | |
| **TOTAL ANNUAL COSTS** | **377** | |

*Figure 89: Quick Facts Cost efficient Minimal Target Compliance*

As it can be seen in the following table, the target of 0,574 TWh RES share is just reached, without any need to further deploy the technologies with second and third deployment priority, which just remain at their 2013 capacities. The major contribution of 0,276 TWh (48%) is coming from SWHs.

**Cost Efficient Minimal Target Copliance — Status Quo 2013 + max SWH in 2020**

| **RES SHARES ON FINAL ENERGY DEMAND** | | | | **Target** | |
|---|---|---|---|---|---|
| | Final Energy Demand | 5,737 | TWh/year | | |
| **RES** | **10 % RES Target of Final Energy** | **0,574** | **TWh/year** | **% on RES Target** | |
| **CO2 Emissions** | | **1,262** | **mio tons** | **x** | **mio tons** |
| | | | | | |
| **E-RES** | **Electricty RES TOTAL** | **0,075** | **TWh/year** | **13%** | **of Target** |
| e-RES | PV | 0,075 | TWh/year | 13% | |
| e-RES | | | TWh/year | | |
| | | | | | |
| **H-RES** | **Heat RES TOTAL** | **0,320** | **TWh/year** | **56%** | **of Target** |
| h-RES | SWH | 0,276 | TWh/year | 48% | |
| h-RES | HP | 0,044 | TWh/year | 8% | |
| | | | | | |
| TOTAL | Transport | 1,799 | TWh/year | | |
| **t-RES** | **Biofuel Imports RES Transport** | **0,179** | **TWh/year** | **31%** | **of Target** |
| | | | | | |
| **TOTAL** | **Target Achievement Level** | **0,574** | **TWh/year** | **100%** | **of Target** |
| **RES Missing** | | **0,000** | **TWh/year** | **0%** | |

*Figure 90: Target Compliance in Cost efficient Minimal target Compliance Scenario*

### 9.6.1. Conclusion of cost optimal minimal target scenario

The system reflects the most cost efficient way to reach 2020 targets based on the technologies that were already installed in 2013 and not adjusted any further, apart from the addition of SWHs. The system is about 13 Mio € cheaper than the system turning out in the business as usual scenario, which was not achieving the target. The optimal model is also 7 Mio € cheaper than the target achievement registered in the innovative scenario and also saves more $CO_2$ emissions. Therefore, it is advisable to utilise Malta's SWH potential first, rather than installing PV technology. Furthermore, SWH has no crucial effect on the power system stability in contrast to PV, if installed in large volumes. This would require an adjustment in the actual policy, which tends to privilege PV installations rather than SWHs, although both technologies receive a financial support.

In general, the system profits in all the three scenarios compared to the fossil fuel based default model without advanced technologies, no matter which of the considered technologies is installed (refer to FIGURE 91). However, the installation of SWHs should definitely be prioritized and deployed maximally as done in the last scenario, where 100 % (0,276 TWh) of SWH potential is utilised. 10 % of the transport sector energy demand (0,18 TWh) is due to biofuels, 50 MW of PVs are already installed, while the remainder 0,044 TWh of renewable energy to achieve the target are contributed by HPs, which have second priority in the installation.

| | | | | |
|---|---|---|---|---|
| **No Advanced Technologies** | Total Annual Costs | 409 | Mio € | **Reference** |
| | CO2 Emissions (net) | 1,457 | Mio tons | **Reference** |
| | Accountable as a RES | 0 | % | **Reference** |
| **Business As Usual** | Total Annual Costs | 390 | Mio € | -4,6% |
| | CO2 Emissions (net) | 1,325 | Mio tons | -9,1% |
| | Target 2020 Level | 89 | % | |
| **Innovative Trend to Minimal Target Compliance** | Total Annual Costs | 384 | Mio € | -6,1% |
| | CO2 Emissions (net) | 1,299 | Mio tons | -10,8% |
| | Target 2020 Level | 100 | % | |
| **Optimal Model to Minimal Target Compliance** | **Total Annual Costs** | **377** | **Mio €** | -7,8% |
| | **CO2 Emissions (net)** | **1,262** | **Mio tons** | -13,4% |
| | **Target 2020 Level** | **100** | **%** | |

*Figure 91: Comparison Business as Usual, Innovative and Optimal Model to minimal Target Compliance*

In FIGURE 92, it is highlighted that the completely deployable potential of SWHs has been used, while only a minor share of the PV potential has been deployed. It is also reminded that the two potentials are in conflict with one another due to limited area availability. For that reason, the available potential for PV installations is reduced to 400 MW (instead of the original 434 MW).

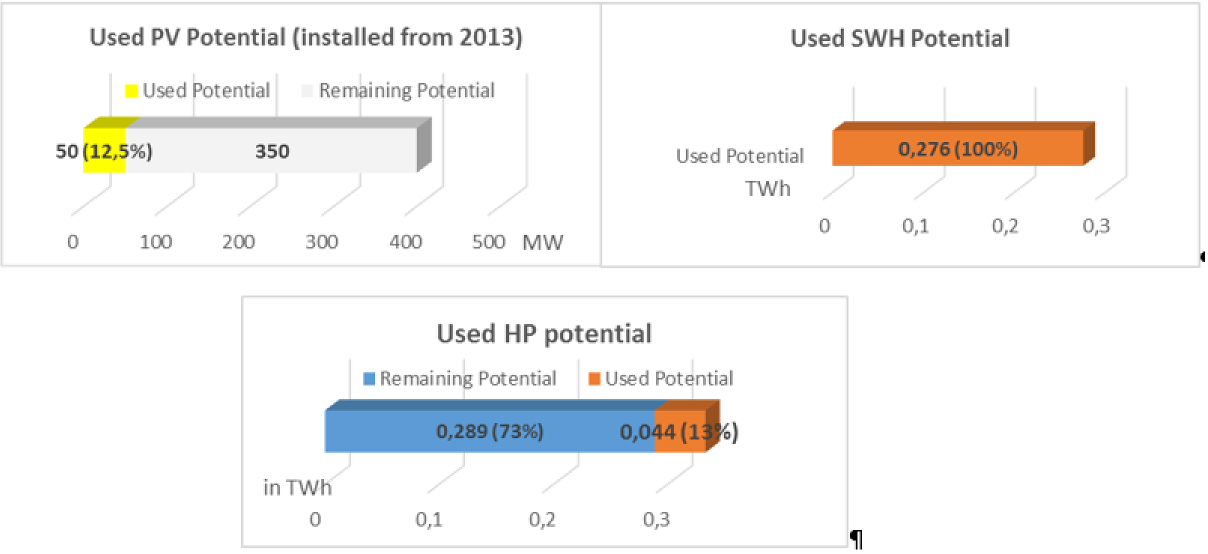



*Figure 92: Deployment of advanced technology potential*

In this optimal scenario for minimal target achievement, the potential of HPs and PVs is still deployed only to a minimum extent, leaving room for higher RES shares in scenarios where more effort is put into targeting an energy system with high RES shares.

### *Max SWH + max HP*

**Target**

Adding the maximum amount of SWHs and HPs to the existing system and evaluate the target overachievement.

**Input**

- 0,276 TWh from SWH
- 0,331 TWh from HPs (0,110 TWh electricity in input)
- 0,070 TWh from PV (50 MW installed capacity)
- 0,179 TWh biofuels in the transport sector

**Output**

The target is overachieved by 30%. HPs provide 0,221 TWh of renewable final energy. The total RES contribution is at 0,746 TWh or 13% of the final energy demand. SWHs still add the largest single contribution to this result. The target could easily be reached when just tapping RES potential within the heating and transportation sector. That had also the advantage that no large-scale system balancing of fluctuation power generators had to be operated.

**Optimal Modelling Status Quo 2013 + max SWH + max HP in 2020**

| RES SHARES ON FINAL ENERGY DEMAND | | | | Target | |
|---|---|---|---|---|---|
| | Final Energy Demand | 5,737 | TWh/year | | |
| **RES** | **10 % RES Target of Final Energy** | **0,574** | **TWh/year** | **% on RES Target** | |
| **CO2 Emissions** | | **x** | **m tons** | **x** | **m tons** |
| | | | | | |
| **E-RES** | **Electricty RES TOTAL** | **0,07** | **TWh/year** | **12%** | **of Target** |
| e-RES | PV | 0,07 | TWh/year | 12% | |
| e-RES | | | TWh/year | | |
| | | | | | |
| **H-RES** | **Heat RES TOTAL** | **0,497** | **TWh/year** | **87%** | **of Target** |
| h-RES | SWH | 0,276 | TWh/year | 48% | |
| h-RES | HP | 0,221 | TWh/year | 39% | |
| | | | | | |
| TOTAL | Transport | 1,799 | TWh/year | | |
| **t-RES** | **Biofuel Imports RES Transport** | **0,179** | **TWh/year** | **31%** | **of Target** |
| | | | | | |
| **TOTAL** | **Target Achievement Level** | **0,746** | **TWh/year** | **130%** | **of Target** |
| **RES Missing** | | **-0,172** | **TWh/year** | **-30%** | |

*Figure 93: Target Compliance in Max SWH and Max HP scenario*

In the resulting system, the total costs are decreased further by 16 Mio € to 361 Mio € (FIGURE 94).

**Optimal Modelling:** **Technology Status Quo 2013 + max SWH + max HP in 2020**

| | | | Costs | Mio EUR | Including CO2 |
|---|---|---|---|---|---|
| power demand | 2,03 | TWh | Variable costs | 286 | 16 |
| RES share on power production | 4,4 | % | Fixed operation costs | 24 | |
| annual fuel consumption | 5,77 | TWh | Annual Investment costs | 51 | Change to Minimal Target Compliance |
| CO2 emissions net | 1,205 | Mio tons | **TOTAL ANNUAL COSTS** | **361** | -4,2% |

*Figure 94: Quick Facts Max SWH and Max HP*

### 9.6.2. Max advanced technologies with system stability

**Target**

Since there is still RES potential untapped, which would increase the environmental sustainability of the system, the authors look for the maximum use of advanced technologies which does not endanger the system stability and further decreases the system costs. Costs are primarily considered as monetary costs for Malta's energy system. However also indirect costs for land consumption must be considered in the case of Malta.

**Input**

Using EnergyPLAN's serial calculator it is found that the input of 240 MW PV leads to a system optimum where system costs are minimized and system security requirements are fulfilled. The maximum 150 MW of export capacity is used, while maintaining 30% of the demand covered by firm capacity. The installation of 240 MW PV is uncritical in regards of the existing area resource, from which the PV potential was derived in the RES chapter.

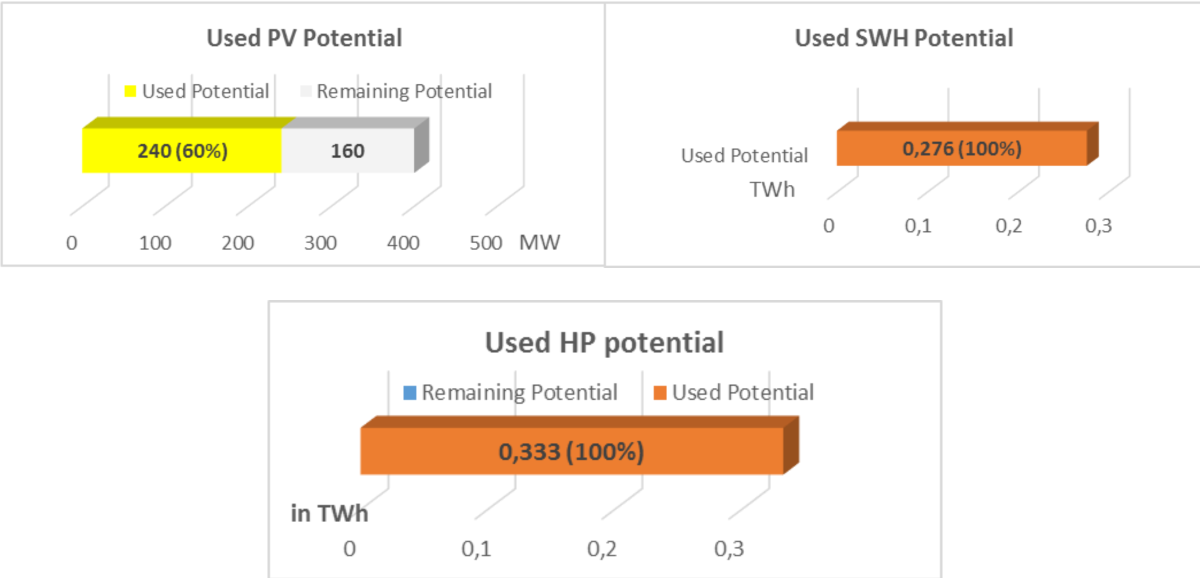



*Figure 95: Deployed advanced technologies in Max SWH, Max HP and Max PV scenario*

**Output**

The total costs of the system reach an optimum of 353 Mio € with a share for variable costs of 77,9 % on total costs. $CO_2$ net emissions are decreased to 1,09 Mio tons, holding a share of only 4 % (14 Mio EUR) on variable costs.

| Optimal Modelling: Technology Status Quo 2013 + max SWH + max HP + max PV in 2020 | | | | | | |
|---|---|---|---|---|---|---|
| | | | | **Costs** | **Mio EUR** | **Including CO2** |
| power demand | 2,03 | TWh | | Variable costs | 260 | 14 |
| RES share on power production | 21,9 | % | | Fixed operation costs | 26 | |
| annual fuel consumption | 5,55 | TWh | | Annual Investment costs | 67 | Change to Minimal Target Compliance |
| CO2 emissions net | 1,089 | Mio tons | | **TOTAL ANNUAL COSTS** | **353** | -6,4% |

*Figure 96: Quick Facts Max SWH, Max HP and Max PV scenario*

The 10 % RES share target is fulfilled to 180 % in this scenario, reaching an 18 % RES share on final energy consumption. The major contribution of 65 % would come from PV followed by SWH (48%) and HP (38 %). Only 66% (0,22 TWh) of the total thermal production from HPs (0,33 TWh) is accounted as a RES contribution to the target. It must be noted that the RES target within the transport sector was covered through the import of biofuels exclusively and therefore cannot be considered optimal. However, the alternative of using e-mobility is assumed to be a significant and realistically to be implemented solution only in a timeframe beyond 2020.

| Optimal Modelling Status Quo 2013 + max advanced technologies in 2020 | RES SHARES ON FINAL ENERGY DEMAND | | | | Target | |
|---|---|---|---|---|---|---|
| | TOTAL | Final Energy Demand | 5,737 | TWh/year | | |
| | **RES** | **10 % RES Target of Final Energy** | **0,574** | **TWh/year** | **% on RES Target** | |
| | **CO2 Emissions** | | **x** | **m tons** | **x** | **m tons** |
| | | | | | | |
| | **E-RES** | **Electricty RES TOTAL** | **0,36** | **TWh/year** | **63%** | **of Target** |
| | e-RES | PV | 0,36 | TWh/year | 63% | |
| | e-RES | | | TWh/year | | |
| | | | | | | |
| | **H-RES** | **Heat RES TOTAL** | **0,494** | **TWh/year** | **86%** | **of Target** |
| | h-RES | SWH | 0,276 | TWh/year | 48% | |
| | h-RES | HP | 0,218 | TWh/year | 38% | |
| | | | | | | |
| | TOTAL | Transport | 1,799 | TWh/year | | |
| | **t-RES** | **Biofuel Imports RES Transport** | **0,179** | **TWh/year** | **31%** | **of Target** |
| | | | | | | |
| | **TOTAL** | **Target Achievement Level** | **1,033** | **TWh/year** | **180%** | **of Target** |
| | **RES Missing** | | **-0,460** | **TWh/year** | **-80%** | |

*Figure 97: Target Compliance in Max SWH, Max HP and Max PV scenario*

PP1 is operated with a capacity factor of 50 %, producing 1,6 TWh power annually. The maximum conventional peak generation of 364 MW is reached at no time, since it is shaved by PV generation. Theoretically, the back-up use of PP2 is not needed. PV produces 0,36 TWh with an average production of 42 MW and a max peak of 186 MW.

| Technology Status Quo 2013 +max advanced Technologies in 2020 | Characteristics of System Stability | Binding Grid Stabilisation Share | | 30% | | |
|---|---|---|---|---|---|---|
| | | TWh | capacity factor | Annual Min (MW) | Annual Avg (MW) | Annual Max (MW) |
| | **PP1 (364 MW)** | 1,6 | 50% | 39 | 183 | 355 |
| | **PP2 (184 MW)** | | | 0 | 0 | 0 |
| | **PV (250 MW)** | 0,36 | | 0 | 42 | 186 |
| | | | | | | |
| | **EEEP** | 0,03 | 0 | 3 | 0 | 141 |
| | **CEEP** | 0 | 0 | 0 | 0 | 0 |
| | **Export** | 0,03 | 0 | 3 | 0 | 141 |
| | **Import** | 0 | 0 | 0 | 0 | 0 |

*Figure 98: System Facts in Max SWH, Max HP and Max PV scenario*

Under this scenario it is also found that 240 MW are the maximum deployable PV capacity according to the defined system stability requirements of 150 MW peak export. Hence, the truly realistic production from PV is 0,360 TWh and not of 0,6 TWh, as indicated in the ideal theoretical maximum of FIGURE 88.

### *Exclusion of Interconnector*

**Target**

Energy System without interconnection capacity. It is researched what is the maximum amount of PV installable in the system, while avoiding the need for export and for PV installations shut downs to assure system stability (no CEEP).

**Input**

The interconnector between Malta and Sicily is already in place with the main aim of supporting the Maltese power demand, i.e. importing electricity from Italy in case of need. However, none of the models built in EnergyPLAN for 2020 foresees any import needs, since the new gas power plant will be up and running by 2020. In 2020 export is required instead, if the installed capacity of PV increases by amounts > 89 MW.

Since export from Malta to Italy is presently allowed only in emergency situations, it is investigated how the system looks like, if no more than 89 MW PV are installed.

**Output**

89 MW PV capacity producing 0,13 TWh in combination with the full SWH and HP potential can be installed in Malta's energy system without using an interconnector and under the premise of a 30 % minimum grid stabilisation share at any time. The costs of the system would amount to 353 Mio € (also excluding the investment cost for the subsea cable), which make this solution cost equal to the previuos maximal RES deployment model. This solution also minimises the area consumption through PV. An overachievement of the 10 % target is observed also in this model.

| **Optmal Modelling:** Technology Status Quo 2013 No Interconnector + max advanced Technologies in 2020 | | | | | | |
|---|---|---|---|---|---|---|
| | | | | **Costs** | **Mio EUR** | **Including CO2** |
| power demand | 2,03 | TWh | | Variable costs | 280 | 15 |
| RES share on power production | 7,8 | % | | Fixed operation costs | 23 | |
| annual fuel consumption | 5,71 | TWh | | Annual Investment costs | 49 | |
| CO2 emissions net | 1,181 | Mio tons | | **TOTAL ANNUAL COSTS** | **353** | |

*Figure 99: Quick Facts No Interconnector*

In the most cost efficient scenario for minimal target compliance, there were also no import or export volumes required. Hence, the interconnector is dispensable in that scenario. One could argue the need in case power supply emergencies occur. However, there is still enough PP2 back up capacity in the system. When modelling Malta's energy system without the interconnector in that scenario the overall system costs decrease by 6 Mio € annually summing up to 371 Mio € in comparison to the system costs of 377 Mio € if the interconnector is included.

## 9.7. Overall conclusions from modelling Malta's energy system in 2020

*RES technology recommendation for Malta*

The first block of modelling enabled the authors to individuate the technologies to be prioritized. It is found that the installation of solar water heaters is the cheapest way to add up renewable energy to Malta's energy system, though they have a limited maximum potential. The second most convenient and effective technology to achieve higher RES shares is represented by heat pumps. Both SWHs and HPs have also the advantage of not affecting the system stability relevantly and consume the least area while PV shall be deployed with third priority.

*Most cost efficient scenario for minimal target compliance*

Given the recommended RES technology premises, the current energy system status quo is taken and its optimal development was assessed until 2020. It was found that just by deploying the whole SWHs potential the target of a 10 % RES share on final energy demand would be achieved with minimal and most cost efficient RES deployment in 2020. The system, which was found to comply with the EU targets at the lowest efforts must contain:

- 10% of the transport demand provided by bio fuels;
- SWH deployment at its maximum potential providing 0,276 TWh thermal energy
- Same deployment of PVs (0,070 TWh) and HPs as in 2013

*Maximum RES penetration in 2020*

The model, which leads to the smallest energy system costs, while maintaining system stability in 2020 was found under the technically maximal deployment of

- SWH (0,276 TWh)
- HPs (0,333 TWh)

in combination with the installation of

- 340 MW PV (0,360 TWh), representing 60 % of Malta's PV roof top potential

A greater deployment of PV did not lead to higher cost savings.

*Role of the interconnector*

It was found that an interconnector is not needed for Malta's energy system, as it has been designed in the most cost efficient & minimal target compliance scenario for 2020. In fact, the interconnector causes extra costs without creating a benefit until the installation of 89 MW PV. If only as much RES technologies (PV) are installed so that all power production can be absorbed by the domestic energy system, overall system costs are equally expensive summing up to 353 Mio EUR.

*Summary of Results*

FIGURE 100 shows the effect of a fuel change in PP1, from oil to natural gas, which becomes the new standard default for all 2020 models (top green frame). In the second green frame all major scenarios, which were investigated in the chapter MODELLING MALTA'S ENERGY SYSTEM TOWARDS 2020, are compared in an overview. The reference is represented by the business as usual trend until 2020. The optimal model of Malta's 2020 energy system containing the maximum RES share (considering the restraints on RES deployment for Malta) would save 9,5 % on total annual costs for Malta's energy system compared to the business as usual scenario. Furthermore, it saves 17,8 % of $CO_2$ emissions.

| | | | | |
|---|---|---|---|---|
| **No Advanced Technologies PP1 on Oil** | Total Annual Costs | 420 | Mio € | Old Status |
| | CO2 Emissions (net) | 1,738 | Mio tons | Old Status |
| | Accountable as a RES | 0 | % | Old Status |
| **No Advanced Technologies PP1 on Gas** | Total Annual Costs | 409 | Mio € | New Default |
| | CO2 Emissions (net) | 1,457 | Mio tons | New Default |
| | Accountable as a RES | 0 | % | New Default |

**DIRECTLY Comparable since same general system set up (green frames)**

| | | | | |
|---|---|---|---|---|
| **Business As Usual Trend until 2020** | Total Annual Costs | 390 | Mio € | **Reference** |
| | CO2 Emissions (net) | 1,325 | Mio tons | **Reference** |
| | Target 2020 Level | 89 | % | **Reference** |
| **Innovative Trend to Minimal Target Compliance in 2020** | Total Annual Costs | 384 | Mio € | **-1,5%** |
| | CO2 Emissions (net) | 1,299 | Mio tons | **-2,0%** |
| | Target 2020 Level | 100 | % | |
| **Optimal Model to Minimal Target Compliance in 2020** | **Total Annual Costs** | **377** | **Mio €** | **-3,3%** |
| | **CO2 Emissions (net)** | **1,262** | **Mio tons** | **-4,8%** |
| | **Target 2020 Level** | **100** | **%** | |
| **Optimal Model to Maximal RES Penetration in 2020** | **Total Annual Costs** | **353** | **Mio €** | **-9,5%** |
| | **CO2 Emissions (net)** | **1,089** | **Mio tons** | **-17,8%** |
| | **Target 2020 Level** | **180** | **%** | |

| **Optimal Model Maximal RES Penetration without Interconnector in 2020** | | | |
|---|---|---|---|
| Total Annual Costs | **353** | **Mio €** | **-9,5%** |
| CO2 Emissions (net) | **1,18** | **Mio tons** | **-10,9%** |
| Target 2020 Level | **100** | **%** | |

*Figure 100: Basic Facts Comparison of the major 2020 models*

### 9.7.1. Discussion of cost optimum and CEEP

The system's cost optimum occurs for a quite broad range of PV installed capacities from 240 MW to 370 MW (i.e. a generation difference of 0,160 TWh from PV), in which the same total costs of 353 Mio € occur. Therefore, the low end of 240 MW is taken as the optimum, since roof top area consumption, as well as balancing issues, would be lower. 240 MW PV represent also the maximum PV penetration, without need for capacity shut downs, when setting the allowed peak export capacity to 150 MW. When allowing the full 200 MW interconnector capacity for exports the physical limit occurs at 310 MW, whereas the system costs do not change their trend until 370 MW.

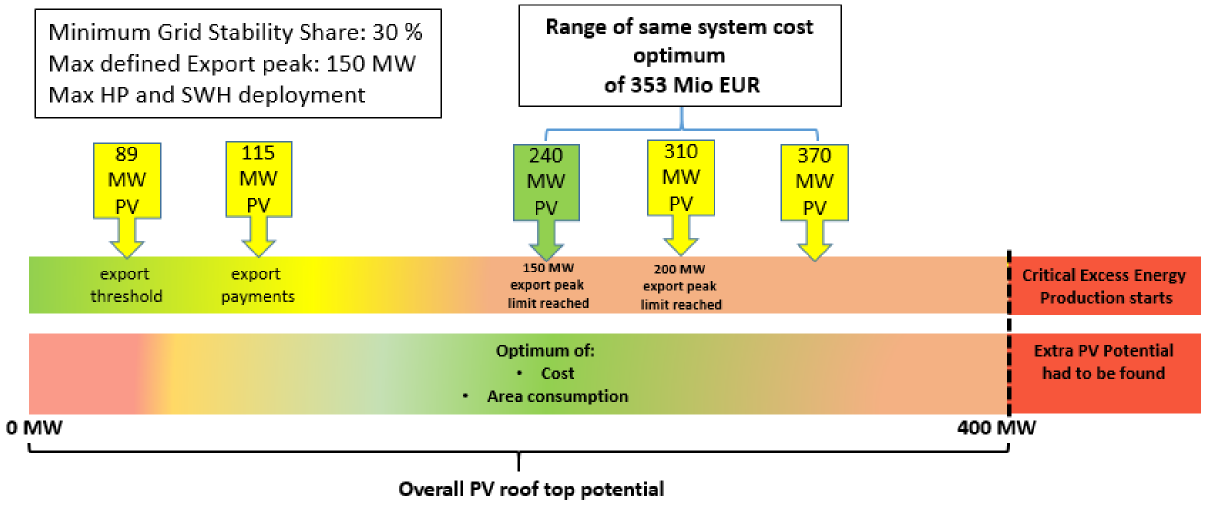



*Figure 101: Overview of Malta's system optimum*

Critical excess production must not have a negative meaning per se as long as system costs do not increase because of it. In fact, critical excess production can be overcome by shutting down PVs in certain hours, when system stability is at risk. Such option is being accepted in all systems with a high penetration of RES in the power sector, i.e. Denmark, Germany and Italy, and leads to the loss of just few percentage points of RES power generation.

As soon as a certain penetration of RES (240MW) is reached in Malta's energy system, a further increase of PV capacity does not lead to further benefits. The fact that this occurs already before CEEP appears must be related to the prices for power exports. That situation appears in a context of a price spread between Malta and Sicily, which makes the export trade off to Sicily not ideal. This is not surprising considering that Sicily has the same peak power production characteristics (PV midday peak) as Malta, as well as limited export possibilities itself. Therefore, prices seem not to be high enough to cover the (LCOE) levelised costs of electricity production from PV and, most of all, from PP1, which is necessary for grid stabilization reasons. However, as long as exports can still be sold at positive prices, which is the case, it is better to export PV power instead of shutting it down.

### 9.7.2. Sensitivity on minimal grid stabilisation share and export capacity

The two major delimitations for a maximum RES deployment of fluctuating RES like PV are the minimum grid stabilisation share (power generated from firm capacity in the system at any time) and the capacity for exports through the interconnector from Malta to Italy. For all the modelling of 2020 scenarios, it was defined that only 150 MW of the installed 200 MW interconnector capacity could be deployed for exports and that a minimum grid stabilisation share of 30 % must be maintained.

*Minimum grid stabilisation share*

Decreasing the grid stability share from 30 to 20 % is an option, if it is proven that the system is able to provide higher shares of variable supply. It does allow deploying 45 MW more PV capacity (285 MW total) until the peak export limit is reached. The increased PV production leads to savings of 1 Mio € annually.

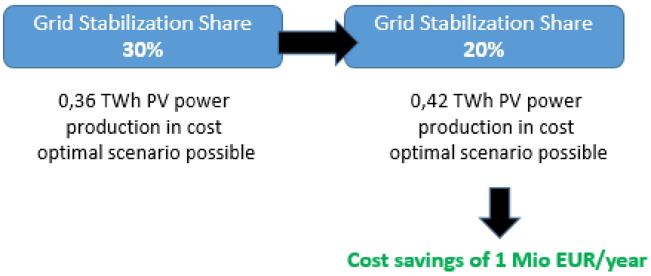



*Figure 102: Effect of reduced grid stabilisation share*

*Export Peak*

An increase of allowed export capacity above 150 MW (to 200 MW) enables to install more PV capacity without CEEP incurring, however no system costs savings are registered, if the minimum grid stabilization share is maintained at 30%. This is because the extra power, which can be exported, is mainly produced by the PP1. This leads to higher consumption of fossil fuels and increased $CO_2$ emissions, whose costs cannot be covered by the export sales. In fact, prices in Sicily are relatively low at midday, when the peak generation from PV and the maximum export occur. However, the combination of a reduced grid stabilisation share (20%) and an export peak of 200 MW allows installing 310 MW PV and leads to combined system savings of 2 Mio € annually.

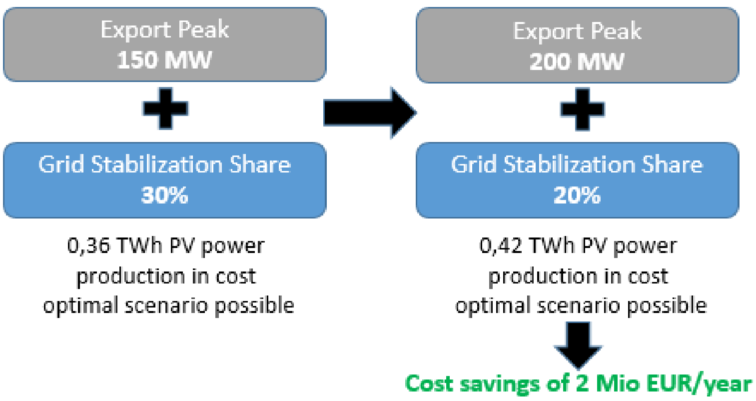



*Figure 103: Effect of reduced grid stabilisation share in combination with increased interconnector peak*

### 9.7.3. Discussion of 2020 energy system's constraints

The major remaining or yet untapped potential for the Maltese energy system is a further deployment of power generation from fluctuating RES like PV and the introduction of demand side management. Major reasons for the limits of the PV capacity in Malta's energy system can be found in the restraints of the grid stabilisation share in combination with the interconnector operation and lack of flexible demand, which quickly lead to excess power in the system. The grid stabilisation share often leads to excess power generation, because power generation from PP1 is orientated on maintaining grid stability share rather than matching with the demand profile.

That excess power can be categorized either as exportable excess power production (EEEP) or as critical excess power production (CEEP), when its amount exceeds the exportable amount, set by the usable interconnector capacity, hence shut downs have to be operated or extra demand has to be introduced. It must be noted that the exported power does not follow market rules, but system stability needs. Hence, no economical convenience is gained from the export itself. For this reason, the system's cost optimum is reached already before CEEP occurs, respectively before any shut down has to be operated. Therefore, it must also be noted that the first produced units of PV power have a higher cost saving, than later PV power production units indirectly causing EEEP in the systems, since PP1 produces as backup.

Hence, a way to reduce EEEP without disclaiming further power production from PV must be found in order to increase the system's profitability. That can be done by triggering flexible demand for example by introducing E-mobility to the system. The authors will evaluate the option of E-mobility in Malta's energy system for 2030.

# 10. Modelling Malta's Energy System towards 2030

*The modelling of the Maltese energy system in 2020 has a clear starting point, orientated on the defined RES share targets for Malta, which have to be achieved in 2020. The path for the energy system is directly affected by decisions being already in place (i.e. the construction of the gas-fired power plant). Variables for Malta's energy system in 2030, as well as guidelines for energy systems from the EU are rather undefined and uncertain yet. However, the aim of this chapter won´t be to evaluate the evolution of the energy system in detail, but to investigate how the introduction of specific elements, mainly e-mobility, varying the minimal grid stabilisation share and a different operation of the interconnector, would affect the energy system in 2030. The results are compared to the optimal energy system with max RES penetration that was defined for 2020.*

*Final energy consumption in all sectors, i.e. transport, heating and others is assumed not to increase further. The authors decided to maintain the energy demand at the same level as in 2020, since Malta is an Island with very limited and already intensely used land area and a quickly aging population, because a high share of retired residents live on Malta. Hence, any kind of growth is expected to be decoupled from additional energy consumption. In the heating sector, the ratio between electricity and fossil fuel employed is not altered either. In this way, the specific effects of the new elements in 2030 will be easier to assess also.*

*In the transport sector, electricity will replace a certain share of fossil fuels, therefore the overall system's power demand will be affected. E- mobility seems quite a viable solution on an Island with heavy car usage for low range stop and go driving and relatively little driving distances. The major disadvantage of low ranges from e-vehicles is not an issue on Malta, since the distances to be driven are always limited, and some of the major advantages (little emissions and efficient acceleration) from e-vehicles are most important in urban areas as they are characteristic for Malta.*

The general targets for Malta's energy system modelling in 2030 are set as following.

- Introducing a 20 % share of electric vehicles replacing the same share of conventional cars.
- Decreasing the grid stabilisation share from 30 to 20 %
- Increasing the peak export capacity for the interconnector

Consequently, some side effects allow deploying the remaining fluctuating RES potential to a maximum without disturbing system stability or increasing system costs. *Starting point in regards of RES deployment is the cost optimal system from 2020 (third model in model group three).*

The starting status quo for the model in 2030, is *the optimal maximal RES scenario from 2020 (third model in model group three).*The general targets for modelling Malta's energy system of 2030 are set as following.

- Introducing a 20 % share of electric vehicles replacing the same share of conventional cars.
- Decreasing the minimal grid stabilisation share from 30 to 20 %
- Increasing the peak export capacity for the interconnector from 150 MW to 200 MW

It is anticipated that synergies between the three main interventions and the RES deployment occur, since electric demand from e-mobility is flexible to some extent. Furthermore overall power demand rises through the demand of EVs. Consequently, more fluctuating PV capacity can be deployed in Malta's energy system without disturbing system stability or increasing system costs.

In fact, the batteries of the electric vehicles can act both as power storage and electricity supply when they are connected to the grid and charging or transferring the charge back to the grid (vehicle to grid mode). According to preliminary analyses run by Energinet.dk[140], the power demand of electric vehicles can be removed or shifted by several hours in certain periods. This means that vehicles can absorb excess power generation in certain hours (i.e. midday peak of PV generation) and provide power to the system when no sufficient other supply is available. The cause and effect relationships between the above-mentioned measures in the energy system will be evaluated and presented in the end of this chapter.

## 10.1. E-mobility in 2030

**Input for Transportation**

63.000 E-vehicles (20% of the total) with technical specifications of the 2014/2015 type Tesla Model S are introduced. Tesla's model S can be seen as the best EV today, but with a still limited market diffusion. It is assumed that the technical specs of Tesla's model S will represent the state of art for an average e-vehicle in 2030. The small Tesla S battery version, with a capacity of 70 kW, is assumed to be installed in each vehicle. When considering the whole EV fleet, the total battery capacity adds up to 4410 MW.

Normal loading time with a standard cable and standard residential power connection (11 kW grid to vehicle and vehicle to grid connection capacity) takes about 20 hours.[141] The EV has a power demand of 237,5 Wh/km equivalent to 2,64 l/100km, if the vehicle was running of gasoil.

- Range in km: 400km[v]
- Assumed average driving: 30 km/day

Since power supply peaks at midday due to power production from PV, the authors set the charging window for e-vehicles in a 4-hour timeslot from $11^{am}$ to $3^{pm}$, rather than having long charging windows during night, when only conventional power is available. That also means that batteries can never be fully charged during that time, which is not an issue since it usually also takes 14 days until a battery is completely empty. $\frac{400\ km\ range}{30\ km\ per\ day}$=14 days.

Hence, the charging time of 20 hours in 14 days is distributed over five days of 4 hours charging. That means that every car is charging every 5 in 14 days (36% of middays) during midday. Or evenly distributed, 36% of all cars are always connected to the grid for charging during the midday window.

[v] 400 is taken as an approximation and for easier calculations. Original ranges can go up to 440 and vary according to motorization and way of driving. Tesla Homepage

There are two options of using e-mobility in EnergyPLAN. A "dump charge" option, where EVs can be used as a tool for demand side management (grid to vehicle) and a "smart charge" option using EVs for demand- and supply side management (grid to vehicle and vehicle to grid mode) combined. The authors only use the grid to vehicle option, since priority is given to shaving the peak of PV power generation around midday, representing the major need for Malta's energy system.

## 10.2. Modelling 2030

**RES in 2030**

It is assumed that the maximum potential of advanced technologies, as in the optimal max RES model of 2020, is deployed. Furthermore, additional PV capacity can be installed to cover the increased power demand through EVs, without endangering energy system stability and decreasing the energy system's profitability. In fact the presence of flexible demand, which can be triggered when excess production from variable RES (PV) occurs, makes a higher penetration of RES possible.

RES input:

- 0,276 TWh SWH (like in 2020)
- 0,331 TWh HPs (like in 2020)
- 0,460 TWh PVs (increase of 0,1 TWh) – 310 MW installed
- Minimum grid stability share of 30 %

**E-mobility in the transport sector**

The total energy demand for fossil fuels in transportation is 1,8 TWh. For simplicity and due to lack of data it is assumed that this demand is from individual vehicles only. That assumption seems also legitimate since public transportation and heavy transportation on Malta are quite limited. 315.000 vehicles were registered on Malta in 2013. Referring to a population of only 420.000 and the small land area, the authors assume that individual transport is a rather saturated sector and calculate with the same number for 2030. It is also assumed that the contribution of biofuels to the transport sector remains stable at 0,179 TWh/year, as estimated for 2020. Each car consumes 5,714 MWh of fossil fuel or biofuel on average (1,8TWh/315.000). A replacement of 20 % through e-vehicles would decrease the number of combustion cars from 315.00 to 242.000 cars and decrease the fuel demand by 0,360 TWh to 1,44 TWh (1,26 TWh fossil fuel and 0,18 TWh biofuels). Hence, the average car fleet from 2013 consumed three times more petrol or diesel than the e-vehicle's equivalent of 2,64 l/100km of gasoil[142]. This means that the average e-vehicle consumes only 1,905 MWh annually (5,714MWh/3). Multiplied by the total number of 63.000 cars the total demand for power through e-vehicles totals 0,120 TWh.

Since 310 MW PV are installed, 25% of the power generation comes from RES, therefore the power input in e-vehicles requires only 0,180 TWh of fossil fuel consumption (75% of the power required produced by gas fired power plant with an efficiency of 50%). This leads to an overall fossil fuel saving of 0,180 TWh. Hence, higher shares of PV power generation increase the RES share in the final energy consumption and also makes the choice of electrical based technologies more convenient and sustainable.

- ➔ Primary oil consumption: - 0,360 TWh
- ➔ Power consumption: + 0,120 TWh
  - Fossil fuel consumption for power production = 0,180 TWh

Therefore, net primary energy savings would equal 0,180 TWh (0,360 - 0,180 TWh).

**Output**

The RES share on power production increased to 27,2 % while the RES share on final energy demand amounts to 19,8%, with a PV contribution which increased from 0,36 TWh in 2020 to 0,46 TWh in 2030. The costs are further decreased by 4,8 % (17 Mio € ) from 353 Mio € (cost optimum in 2020) to 336 Mio EUR. The major savings (15 Mo € ) occur through the peak shaving of e-mobility, while only 2 Mio € are caused by the higher PV penetration which can be offset by e-mobility.

**Optimal Modelling: e-mobility peak shaving in 2030**

| | | | | Costs | Mio EUR | Including CO2 |
|---|---|---|---|---|---|---|
| power demand | 2,15 | TWh | | Variable costs | 238 | 13 |
| RES share on power production | 25,4 | % | | Fixed operation costs | 26 | |
| annual fuel consumption | 5,34 | TWh | | Annual Investment costs | 72 | Change to Optimal 2020 |
| CO2 emissions net | 1,000 | Mio tons | | TOTAL ANNUAL COSTS | 336 | -4,8% |

For comparison, also the optimal model for 2020 is recalled:

**Optimal Modelling: Technology Status Quo 2013 + max SWH + max HP + max PV in 2020**

| | | | | Costs | Mio EUR | Including CO2 |
|---|---|---|---|---|---|---|
| power demand | 2,03 | TWh | | Variable costs | 260 | 14 |
| RES share on power production | 21,9 | % | | Fixed operation costs | 26 | |
| annual fuel consumption | 5,55 | TWh | | Annual Investment costs | 67 | |
| CO2 emissions net | 1,089 | Mio tons | | TOTAL ANNUAL COSTS | 353 | |

The relevant fuel consumption reduction (-0,21 TWh compared to the cost optimal model for 2020) is mainly caused by the reduction of fossil fuel consumption in the transport sector due to the introduction of E-mobility, which also allows a higher self-consumption during midday. That decreases power exports, which are getting exponentially expensive if export volume increases. In fact, exports from Malta to Sicily do not follow commercial reasons, but are only driven by technical needs and for this reason are mostly non convenient for Malta.

Optimal Modelling + E mobility peak shave 2030

| RES SHARES ON FINAL ENERGY DEMAND | | | | Target | |
|---|---|---|---|---|---|
| TOTAL | Final Energy Demand | 5,737 | TWh/year | | |
| **RES** | **10 % RES Target of Final Energy** | **0,574** | **TWh/year** | **% on RES Target** | |
| **CO2 Emissions** | | **x** | **m tons** | **x** | **m tons** |
| | | | | | |
| **E-RES** | **Electricty RES TOTAL** | **0,46** | **TWh/year** | **80%** | **of Target** |
| e-RES | PV | 0,46 | TWh/year | 80% | |
| e-RES | | | TWh/year | | |
| | | | | | |
| **H-RES** | **Heat RES TOTAL** | **0,494** | **TWh/year** | **86%** | **of Target** |
| h-RES | SWH | 0,276 | TWh/year | 48% | |
| h-RES | HP | 0,218 | TWh/year | 38% | |
| | | | | | |
| TOTAL | Transport | 1,679 | TWh/year | | |
| **t-RES** | **Biofuel Imports RES Transport** | **0,179** | **TWh/year** | **31%** | **of Target** |
| | | | | | |
| **TOTAL** | **Target Achievement Level** | **1,133** | **TWh/year** | **198%** | **of Target** |
| **RES Missing** | | **-0,560** | **TWh/year** | **-98%** | |

*Figure 104: Target Compliance in 2030 e-mobility scenario*

### 10.2.1. Conclusion

The effects of changes in the operation of the interconnector (from max 150 MW used to 200 MW) and of the given reduced grid stabilization share (from 30% to 20%) were already analysed in the end of the 2020 modelling. The benefits resulting from such adjustments have been added to the benefits of e-mobility in the modelling of 2030.

The following FIGURE 105 shows the single cause and effects according to the introduction of measures further transforming Malta's energy system in 2030. All effects are referenced to the cost optimum model in 2020, in which power production from HPs, SWH and PV production is maximised according to the 2020 energy system design (maximum technical potential and cost optimum). PV production accounts for 0,36 TWh in that system and system costs are at 353 Mio EUR.

Three measures have been introduced in the modelling of 2030:

- E-mobility;
- Reduction of grid stabilisation share to 20 %;
- Increase of the allowed export peak.

The three measures lead to a cost effect themselves. E-mobility for example leads to a reduction in overall fuel demand. A lower grid stabilisation share requires less PP1 production, which results in a lower fuel demand as well. As an indirect effect, each of the measures allows slightly higher PV production in the system (PV offsetting). Therefore, further system cost savings occur.

| Cause and Effect Table for 2030 Energy System Modelling | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Measure | cost savings | PV Offsetting | System costs | | Overall PV power | | Cost decrease to Optimal 2020 model | |
| E-mobility | 17 | Mio | 338 | Mio | 0,36 | TWh | -4,2% | |
| | | | | | | | | |
| PV offsetting | | 0,1 | TWh | | | | | |
| PV savings | 2 | Mio | 336 | Mio | 0,46 | TWh | -4,8% | |
| | | | | | | | | |
| Grid Stability Share 20 % | 1 | Mio | 335 | Mio | | | -5,1% | |
| PV offsetting | | 0,08 | TWh | | | | | |
| PV savings | 1 | Mio | 334 | Mio | 0,54 | TWh | -5,4% | |
| | | | | | | | | |
| Export peak >150 MW | | | | | | | | |
| | | | | | | | | |
| PV offsetting | | 0,06 | TWh | | | | | |
| PV savings | 1 | Mio | **333** | **Mio** | **0,6** | **TWh** | -5,7% | **Cost Optimum 2030** |

*Figure 105: Cause and effects in 2030 e-mobility scenario*

By far the biggest improvement of 4,2 % of cost savings is reached by the mere introduction of e-mobility since it saves oil fuel consumption in rather inefficient car combustion machines and $CO_2$ emissions. It also reduces the need for exports, since e-mobility functions as a midday peak shaver. Some additional savings through a PV offsetting of 0,1 TWh due to e-mobility as a PV peak shaver and power consuming element increases the overall saving to 4,8 % in comparison to 2020. The further measures only have a minor effect. The accumulated overall system costs can be decreased by 5,7 % to 333 Mio € in reference to the cost optimum of 353 Mio € in 2020. If the max RES penetration model in 2020 is compared to the max RES penetration in 2030 under the same grid stabilisation share and same interconnector capacity, the cost savings result slightly lower, as presented in FIGURE 106.

| | | | | |
|---|---|---|---|---|
| Optimal Model to Maximal RES Penetration in 2020 | Total Annual Costs | 353 | Mio € | Reference |
| | CO2 Emissions (net) | 1,089 | Mio tons | Reference |
| | Target 2020 Level | 180 | % | |
| | | | | |
| Optimal Model to Maximal RES Penetration including 20 % e-mobility in 2030 | Total Annual Costs | 336 | Mio € | -4,8% |
| | CO2 Emissions (net) | 1 | Mio tons | -8,2% |
| | Target 2020 Level | 204 | % | |

*Figure 106: Max RES 2020 in comparison to Max RES in 2030 under same minimal grid stabilisation share*

### 10.2.2. Discussion and sensitivity on the results

*E-mobility*

Some optimisation potential within e-mobility was left untapped, because e-mobility was defined as flexible only in regards of demand side management (grid to vehicle) and only during midday hours, when PV peak production occurs. In fact, that application only represents a dump charge ability in which e-mobility functions as a peak shaver in grid to vehicle mode (G2V), whereas the deployment of e-mobility in vehicle to grid mode (V2G) is also a possibility. According to a paper from Fattori et al.[143] the (V2G)-benefits are not just marginal when PV is the major RES technology in a system, in contrast to Richardson' s[144] findings for systems with wind power being the major RES technology.

The combination of both modes (smart charge) could optimize the system even further. However, since Malta's flexibilization need is mainly the element of midday peak shaving only the G2V option was applied in this project. Another reason for not using smart charge is based on the assumption that smart charging cannot be implemented yet, since an active cooperation of the end-consumers is necessary. This requires sustainable awareness, which has not prospered on Malta yet. Furthermore, the economic incentives for users participating in smart charge and discharging must be given and since they were not analysed in this project that option was not included. Whereas, chances that e-mobility users on Malta would be motivated to charge their EV during midday are rather high, since power prices would theoretically be low during middays since PV production leads to excess power production. However, that would also require a power market design, in which power end customers can profit from different power tariffs. An incentive to allow participating EV users on lower midday tariffs would shave some excess power production improving the power system. Therefore, the government should have an interest in such policies.

Experience on e-mobility penetration in Norway, which will be presented in the E-MOBILITY policy chapter, shows that even higher E-mobility rates in 2030 seem possible and that the 20 % e-mobility scenario is not so far-fetched. However, it must be noted that investment costs for EVs are currently still substantially higher than for conventional cars. Nevertheless, when anticipating a continuous drop of prices for batteries and increasing fuel costs, that price difference can become marginal in 2030. Consequently, EVs would be competitive not only in their running costs, but also in their investment costs.

*Interconnector and minimum grid stabilisation share*

In 2030, an increase of peak export capacity to 200 MW seems likely assuming that the Sicilian system is able to absorb more power in imports, since its interconnection to the Italian mainland is also being enforced. That would stabilize a general export flow of PV power during middays from Malta through Sicily and Italy towards central Europe and would allow higher PV penetration in Malta`s energy system.

The height of the necessary grid stabilisation share is debatable and an increase in peak interconnector capacity could be an argument that also the minimal grid stabilisation share can be decreased, since the interconnector can be used more freely. Furthermore, Malta's system operators will have a 20-

years learning curve on the management of PV power within the energy system by 2030. Hence, it is assumed that a smaller grid stabilisation share would still allow system stability. Another important argument that lowering the minimal grid stabilisation share is reasonable results as a direct consequence from the introduction of e-mobility in 2030. As shown in a paper from the department of EnergyPLANning in Aalborg[145], the smart use of e-mobility as a storage medium for power is an excellent way of providing flexibility to the system. The reaction time for charging or discharging a battery is quite fast, which makes it a great instrument for balancing power.

### *Costs in 2030*

Costs for individual heating technology are not changed, since it is considered that the technology is rather well developed already. However, cost savings of 20% from 2020 to 2030 are assumed in regards of PV. That does reflect the same cost saving rate as was assumed from 2015 to 2020 but in double the timeframe. That slower cost reduction rate is due to saturation of learning effects and the catch up market development.

The forecast of the gas price level in 2030 is rather difficult and uncertain. Therefore, the authors only assume that if no major gas fracking boom occurs in Europe, prices will rather increase. Furthermore, all European member states are supposed to increase the RES share in their energy systems. That automatically displaces power production from conventional plants. If the displacement reaches a level in which the coal and nuclear plants become too inflexible to be operated anymore, the share of gas power production can be assumed to rise. Hence, demand for natural gas will increase. However, the natural gas price is not being changed in the EnergyPLAN modelling, compared to the 11,3 € /GJ applied for in the 2020 modelling. It must only be noticed that any future price increase for natural gas would make the use of RES comparatively cheaper.

# 11. Cooperation mechanisms as alternative instrument

Despite the evidence of sufficient RES potential, which could easily cover 10% of the final energy consumption on Malta and the fact that its deployment has a positive effect on the system costs, the political forces in Malta seem rather reluctant to undertake relevant investments towards sustainability, in the short term. This is due to several reasons. First of all, as already mentioned Enemalta undertook relevant direct investments or subscribed agreements with third parties, i.e. the interconnector to Sicily, Delimara 3 and the gas CCGT from the independent power producer ElectroGas in recent years.

The subscribed agreements with Electrogas concerning the gas CCGT contain an 18-year PPA, as well as an 18-year GSA. The specific terms of the agreements have not been made public, but it can be guessed that a minimum power and gas volume withdrawal is required as part of the deals. That leaves a limited space for the production of power through RES. A similar issue arises from the agreement stipulated between Enemalta and Enel Trading concerning the operation of the interconnector between Malta and Sicily. The clauses are not public, but it is known that the option of operating the cable in export from Malta is very restricted, while the imported volumes from Italy are partially agreed in advance.

Therefore, Enemalta is already bound to important variables of the energy system and it is clear that any additional capacity entering the system would require a careful balancing and can quickly lead to costly overcapacities. The government is also worried that the setting of the system is not optimal for the introduction of a large use of fluctuating power generation. For these reasons, the Maltese government is looking at the option of accessing cooperation mechanisms as a solution to achieve the targets of RES penetration set by Europe for 2020, without intervening in the own energy system and taking the risk of harming the system from a technical and economical point of view. The functioning of cooperation mechanisms is discussed in the following.

## 11.1. Cooperation mechanisms

The European Directive, 2009/28/EC[146], also known as Renewables Directive, frames the possibility to develop renewable energy installations on international level by deploying three possible kinds of cooperation mechanisms between the Member States and one cooperation mechanism involving third countries. These are:

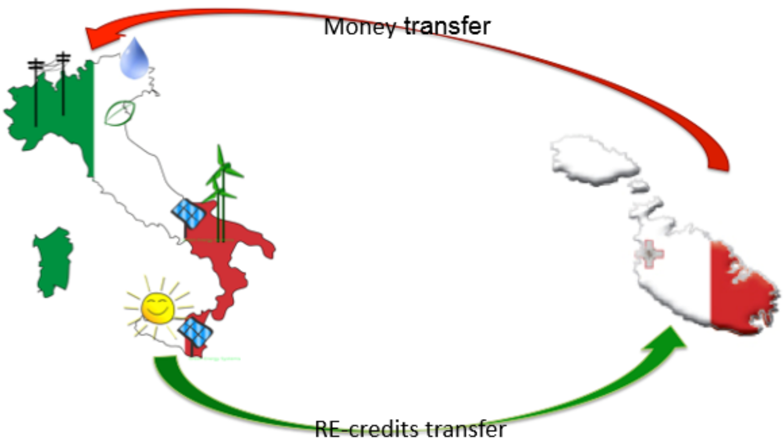
- statistical transfers,
- joint projects within the EU or with third countries and
- joint support schemes.

The cooperation mechanisms provide the possibility to support renewable energy production in other Member states (MSs) and to receive renewable energy credits from the other MS in return, which can be accounted as a contribution towards the “2020 energy targets” under specific conditions. The Member State, in which the renewable energy is produced, is called host country, while the Member

State withdrawing the RE credits is named off-taking country. Cooperation mechanisms concluded within the EU can refer to any kind of renewable energy, however it is preferred to focus on their potential in the electricity sector only.

Terms and conditions of the mechanisms (period, costs) are agreed between the Member States involved. The aim of the mechanisms is to optimize the use of resources across Europe, since the cheapest and most efficient renewable energy resources, as well as consumption and financial resources, are not equally distributed among Member States. The mechanisms provide a framework to deploy the best resources first, in order to achieve the 2020 energy targets at the lowest cost possible at European level.

In case of statistical transfer, a given share of energy produced by RES in one country is virtually transferred to an off-taking country. The cost of the transfer reflects the average costs borne by the host country to support the deployment of RES. This mechanism is technology neutral and can be seen as a short-term solution for countries, which are not able to comply with the given target shortly before 2020. The host country must exceed the own target, before transferring RE-credits to another Member State. This mechanism can be potentially cheap, since the transfer can refer also to only one year and it does not require specific administrative work.




FEATURES

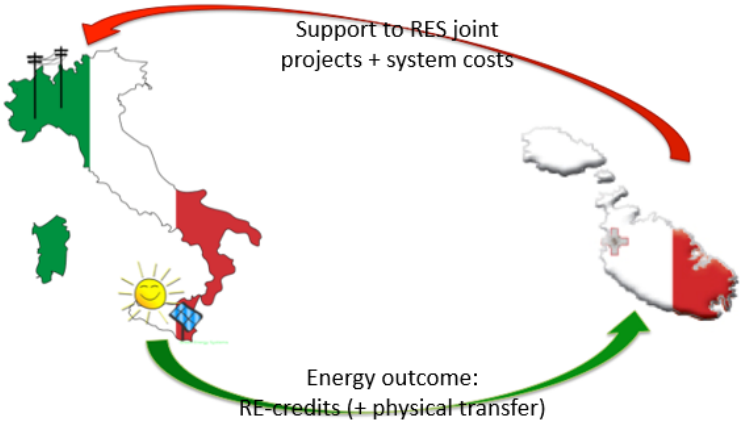
- Technology neutral mechanism;
- Price set on the basis of support, administrative and system costs in the host country. **Potentially cheap solution**;
- The host country can transfer only RE-credits exceeding the own target;
- **Temporary, short term solution.**

CHECKLIST

- **Match countries with surplus and deficit of RE credits by 2020**;
- Determine the energy volumes to be statistically transferred;
- Choose time frame of the contract;
- Choose the type of contract;
- Fix the cost of the transfer;
- Determine non-compliance clauses.

*Figure 107: Statistical cooperation mechanisms*

In case of joint projects, the energy outcome of specific RES installations in the host country results in the statistical accounting towards the energy statistics of the off-taking country, which co-financed the project or projects. This mechanism refers to specific installations, which have been built in the host country after June 2009 or which are being built as a result of the cooperation agreement and financed by the off-taking country. The financing and the RE-credits accounting can be agreed upon between the Member States according to the direct and direct costs and benefits for the involved countries. The period of the agreement generally covers the whole installation lifetime or support period.




FEATURES

- **Specific project(s) involved**;
- Existing or new projects;
- Possibility of physical transfer;
- RE-credits assigned according to costs and benefits sharing;
- **Possibility to cooperate with third countries**.

CHECKLIST

- Define the objectives to be achieved in the host and off-taking country;
- Define project parameters:
    - **Technology or geographical limitations;**
    - Sharing of costs and benefits;
    - **Physical transfer**;
- Conduct feasibility studies (joint projects and related infrastructure);
- Fix the sharing of risks and the cost of the transfer;
- **Define a support scheme**.

*Figure 108: Joint project mechanism*

In case of joint support schemes, Member States may decide to join or partly coordinate their national support schemes, sharing renewable energy output, related support costs and resulting RE-credits. Such mechanism can be convenient in case Member States present similar RES potentials and well-integrated markets. Since Malta cannot be match with any other European country, this option is discarded and not further examined.

All kinds of cooperation mechanism require individuating a suitable partner, which also agrees to enter such agreement, and to set a price for the transfer of the RE-credits. Furthermore, they can combine the transfer of RE-credits with the physical transfer of the energy produced between the States entering the agreement, but this is not a necessary condition, unless the host country does not belong to the European Union.

On one side, physical transfer legitimates the statistical transfer of RE-credits in return of economical support in the eyes of the off-taking country public opinion since the benefits of increased security of supply and reduced GHG emissions would be gained. On the other side, there are studies[147] arguing that physical transfer in the form of an obligation to trade a certain share of energy between the involved Member States is against the functioning of the free competitive market, i.e. against the market dynamics and the demand and supply rules, which regulate cross border trading.

As already introduced, Malta evaluates the option to set cooperation mechanisms with European Member States to achieve the 2020 targets. Possible partnerships for cooperation mechanisms are evaluated based on geographical proximity, national policies, RES deployment and support costs. The costs related to this solution depend on the kind of cooperation mechanism considered and on the partner country, i.e. its resources, specific LCOE and existing RES support schemes.

*Physical Transfer in Malta's context*

The Maltese authorities do not see physical transfer as a necessary element of the mechanism[148]. On one side, physical transfer would bring benefits in terms of security of supply and GHG emissions, since a share of green power would contribute to the national electric balance and decarbonisation, on the other side Malta expects to have sufficient domestic capacity to provide security of supply on its own. Furthermore, the choice of a physical transfer mechanism would limit the options of partnerships to Italy exclusively since that is the only country that is directly interconnected with Malta. However, Italy is not among the countries presenting the lowest support costs to RES in Europe. Therefore, cooperation mechanisms are not likely to include power delivery to Malta, although, that would be the only possibility for cooperation mechanisms to reduce fossil fuel consumption and the related GHG emissions on Malta.

*Statistical Transfer in Malta's context*

A first choice for Malta is to agree on the statistical transfer of the necessary RE credits to comply with the target in 2020 with a country, which already achieved the target, e.g. Bulgaria or Estonia. This mechanism could result to be cheap, since the two Member States could agree on a transfer price, which only partially covers the RES support costs in the host country. In fact, the transfer would occur only for the accounting of 2020. The resolution of undertaking such kind of agreement can also occur short before 2020, because no specific administrative framework is required.

*Joint projects in Malta's context*

A second option would be to undertake joint projects in another Member State, where the costs related to the deployment of renewable energy (LCOE) are low and/or the national support to RES is limited in time and amount. In this case Malta would take on the expenses related to the support for the whole lifetime of the specific installation, receiving in return part or the totality of the RE-credits related to the RES energy generation. In addition to the direct costs and benefits, a project has also indirect costs and benefits, i.e. balancing costs, grid enforcement costs, GHG emissions avoided and employment generation. They are also accounted for, when negotiating the sharing of direct costs and benefits (mechanism price and RE-credits assignment).

### 11.1.1. Consequences of cooperation mechanisms for Malta

At this point, it is recalled that the main outcome of the modelling in the previous chapter is that up to a certain point, more renewables in the system result in lower total system costs since investments in PV panels or in other technologies producing renewable energy are offset by savings in fossil fuels and $CO_2$ emissions. In case it is chosen to rely on cooperation mechanisms, particularly when excluding the option of physical transfer, no fossil fuel of $CO_2$ emissions saving occurs in contrast to the option of deploying more RES domestically. On the contrary, the RE-credits have to be paid for, constituting an additional cost without direct benefits in the system. Therefore, no convenience for the system is registered in regards to the deployment of cooperation mechanisms.

### *Socio economics*

The authors believe that the commissioned study will prove to the Maltese government that, despite its geographical restraints, the country presents sufficient RES potential to achieve the target with own forces. Besides, the choice to undertake cooperation mechanisms on the mere basis of the financial balance of the government does not take the socio-economic impact of such choice into any account. Socio-economic evaluations include the direct costs for the system, which have been calculated and discussed in the modelling phase, and the implications to economic development and employment.

It is notorious that successful evolvements of new industries lead to the proliferation of related activities, which produce a profit, contributing to the national GDP. Even when the development of a new industry implies the close down of another one, it can be assumed that the new industry creates higher values for the economy since that is usually the reason the industry displaces another industry in the first place. In the case of Malta, a complete substitution of conventional energy sources is not anticipated. Hence, it can be concluded that the creation of green jobs would not eliminate a consistent number of jobs in the LPG, power plants and oil industry. Furthermore, quoting an official of the General Workers Union on Malta, the benefits of green jobs would "outweigh any traditional job losses as better paid jobs will be created"[149]. A further growth of the green energy sector in Malta could decrease the already low unemployment rate of Malta (6,4% in 2013[150]).

Many studies have been conducted on the development of green economies, on the growth of green jobs and on the correlation of their different aspects. However, it must be reminded that Malta is a small and isolated Island system, which has limited financial and natural resources to transform its energy system. The opportunities in Malta's green economy have been examined extensively by the Green European Foundation[151]. On one side, the paper mentions the major constraint in regards of the diseconomies of scale and on the other side it highlights the fact that the development of the green economy would be the only option to reduce its dependence on the importation of fuels for Malta. While it cannot be foreseen that Malta, a technology buyer, will build a complete local supply chain for PVs or SWHs, it can be imagined that highly specialized industries producing small components for the installations can be developed also in Malta since some industries already have a good experience in the hi-tech manufacturing[152].

Furthermore, a quick diffusion of solar related technologies made retail and installation enterprises proliferate on Malta. Given the geographically limited market of Malta, which would quickly be saturated with PV and other renewable technologies, it is nevertheless worth developing the know-how on technologies, since those can be an exportable good. The development of PV joint projects with extra European countries, in particular with the North African States, could be a business opportunity for Malta in the near future. Such projects can either be developed in the framework of cooperation mechanisms in order to receive RE-credits, or in the perspective of international cooperation, development and partnerships.

The positive impacts in terms of green jobs and gaining know how would be lost for the economy, in case it is chosen to invest in cooperation mechanisms instead of continuing to domestically finance the support of RES on Malta. Although the direct support of RES turns out to be more expensive than in other countries, the socioeconomic effects justify a domestic deployment of RES. In addition to that, it has been proven that the energy system becomes cheaper with increasing contributions of RES. Therefore, it is highly recommended to the Maltese government to reconsider the position concerning the destination of the financial resources, which should address domestic growth rather than outsourcing the RES deployment in other countries.

## 11.2. Convenience of cooperation mechanisms

Cooperation mechanisms can be a convenient option if evaluated only from a point of view of the national financial balance, hence only as an alternative disbursement of the national budget to the support of domestic RES deployment, which is why the Maltese government is considering them. At present PV and SWH installations are being subsidized by FiTs and grants respectively, whose funding mainly comes from the national budget. Since the national budget is limited, the Maltese government investigates the cheapest way to achieve the target in 2020 and the targets, which will be set beyond that.

It is calculated that, at present, the net support cost to residential PV, borne by the government, amounts to 45 EUR/MWh, given the difference between the marginal price of electricity, fixed by Enemalta, amounting to 110 EUR/MWh, and the FiT granted to PV power generation, amounting to 155 EUR/MWh and delivered for 20 years (residential sector, rooftop installations, 2014).[153]

Comparatively, the total support to RES in some other Member States is lower because cheaper technologies are employed (i.e. hydropower and wind) and the market is more mature and large-scale installations are possible. FiTs lower than 150 EUR/MWh can easily be tracked around Europe. In fact, Malta has a very good solar resource, however the technology in itself is rather expensive, the domestic market is still at an early stage and no economy of scale can be applied due to the geographical restraints.

On the other side, most of the European countries present average low market prices. The lower the market price is, the higher the net support borne by the national finances has to be, which is granted as a fixed feed in tariff. Therefore an advantage for the Maltese government is that the marginal price granted by Enemalta is as high as 110 € /MWh currently. Nevertheless, Enemalta is partially owned by the government, which therefore shares the costs of the high marginal price as well.

However, it has been found that paying the total or a part of the net support cost to renewable energy generated in some other countries could be cheaper. For example, hydropower and power produced from biomass plants in Sweden are supported only through green certificates, which have a value around 20 EUR/MWh and are issued for 15 years.[154]

It can be imagined that Malta undertakes hydro or biomass joint projects in Sweden and has to bear their support costs for 15 years, in order to receive the RE-credits in return for the same period. In addition, when some additional costs are required to cover balancing or other related costs arising in Sweden, it is rather evident that the disbursement will be lower than in case the same RE-credits are derived from PV installations accessing the Maltese support scheme. Furthermore, in this way Malta avoids any indirect cost related to RES, in particular balancing costs related to PV installations.

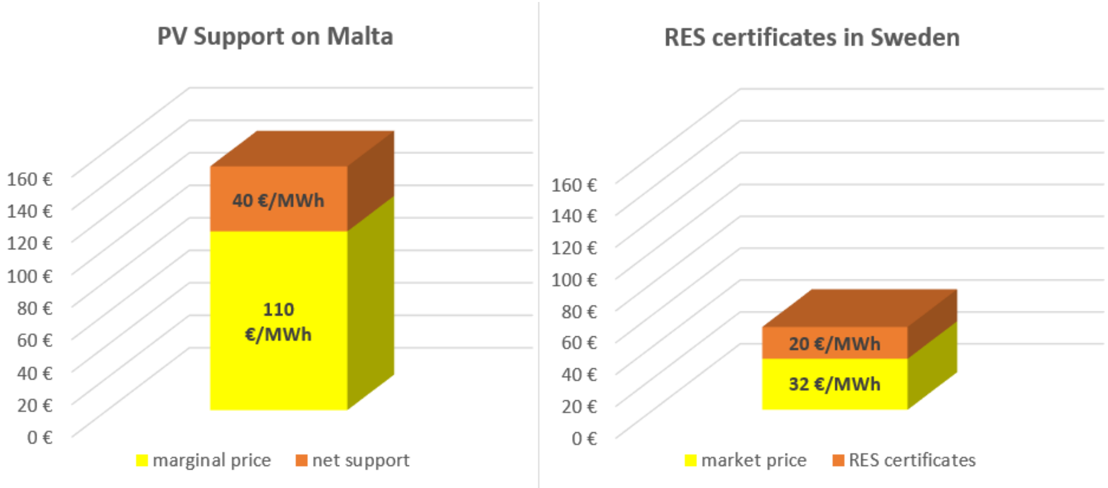



*Figure 109: Comparison Support Schemes (Malta & Sweden)*

It is highlighted that the total support costs borne in Malta and Sweden are comparable only because they lead to the same RE-credit outcome, but they refer to different technologies in different market and incentive contexts. Hence, on one side cooperation mechanisms can lead to a direct saving for the national budget, since cheaper technologies can be deployed in other countries, but on the other side cooperation mechanisms hinder direct energy system, socio-economic and environmental benefits, which also translate in economic benefits for Malta's economy as a whole.

# 12. Policy Recommendations

## 12.1. Substitution of individual heating

### 12.1.1. Power retail prices

According to the residential tariffs for electricity published by Enemalta, permanently inhabited households pay 10,47 € cents /kWh for the first 2.000 kWh consumed, 12,98 € cents / kWh for the second 4.000 up to 6.000 kWh and 16,07 € cents / kWh for the extra consumption up to 10.000 kWh.[155]

Since households consume between 4.000 and 8.000 kWh a year, depending on the utilisation of electricity consuming devices (cooling, electric heating and water heating), residential customers pay an average price ranging between 11,72 and 13,13 € cents/kWh. For simplicity, calculations are operated on the basis on the second band price, i.e. 12,98 € cents / kWh.

Residential Rates (inclusive of 5% VAT)

| Band | Cumulative Consumption | From 31.03.2014 |
|---|---|---|
| 1 | 0 - 2,000 | 0.1047 |
| 2 | 2,001 - 6,000 | 0.1298 |
| 3 | 6,001 - 10,000 | 0.1607 |
| 4 | 10,001 - 20,000 | 0.3420 |
| 5 | 20,001 & over | 0.6076 |

*Figure 110: Power retail prices on Malta*

### 12.1.2. SWH Technology

Since solar water heaters were identified as the best-advanced technology for Malta, the authors recommend incentive systems promoting SWH technology. The average residential water heater costs 1.440 € and has an average output of 2155 kWh (2 $m^2$). Hence, the same amount minus 5 % of power, which is consumed by SWH, could be saved on the electricity bill since SWHs replace electric heaters, which have an efficiency of around 100%. As a result, 2047 kWh at a rate of 12,98 € cents/kWh are saved. That results in a yearly saving of 266 EUR. The investment would amortize in around 5,4 years, when applying a statistical amortisation calculation, as proposed by , where:

$$\frac{Investment}{average\ yearly\ earning} = Amortisation\ time$$

It must be noted that this calculation does not consider the interest on investment and does not actualize the value of the future earnings.

The authors suppose different steps, how the investment in SWH can be made attractive to investors.

- **Rising awareness regarding the advantages of SWHs**

According to the aforementioned results, it is clear that solar water heaters provide a relevant economic advantage on electric heaters, since they are paid back in less than 6 years, given a lifespan of around 20 years. While large end consumers are generally aware of saving potential of their infrastructure, domestic end consumers have to be guided towards convenient solutions with more care. Therefore, a campaign on the benefits raising from the installation of SWHs should be operated by the government. This has partially been done already, since Enemalta started to offer energy audits to end-consumers in 2008.[156]

- **Increasing the retail prices for power**

In case power retail prices increase, the power replacement through SWH becomes also more valuable, since the traditionally most used technology (electric water heaters) becomes more expensive in its operation cost. Given the power displacement of 2047 kWh and an increase of power prices from 12,98 € cents to 16 € cents (+19%) the annual savings through the installation of SWH would increase to 328 EUR. Therefore, amortisation time could be decreased by one year to 4,4 years. Another positive effect would be that PV installations become also more attractive for self-consumption. Nowadays it seems more convenient to feed the produced electricity into the grid, receiving a FiT of around 15 c/kWh, rather than utilizing the same electricity, i.e. saving the retail cost of 12,98 € cent/kWh. On the other side, increasing retail prices do not encourage a higher use of HPs, unless at the same time also the price of LPG, direct concurrent to HPs for space heating purposes, is increased. Furthermore, in Malta's case power price increase is not a realistic option in the short time, at least until 2018, since stable power prices were a major pledge to the voters.

- **Grant scheme on solar water heaters.**

Since 2011, the government provides investment grants of 40 % on the total investment for solar water heaters capped at 400 EUR. The grants were extended every year and are still running in 2015. Given an investment for the average residential solar water heater of 1440 EUR, the grant would cover 28% of it, decreasing the net cost to 1040 EUR. Hence, amortisation time for the average SWH on Malta is 3,9 years without an increase in the power price.

The authors recommend maintaining the grant scheme. The amortisation time of 3,9 years seems rather attractive already. Instead, the government should run information campaigns on that opportunity. That goes along with choice awareness and discourse theories, stating that the opportunity of using a new technology must properly be communicated to society. FIGURE 111 shows an overview of SWH amortisation times as a function of power prices and incentives on Malta.

Another way of increasing investments in SWH could be a differentiation of grant schemes according to the household's income. Consequently, low-income households should get higher grants and cheap leasing opportunities for SWHs. That would make sense, since low-income households usually cannot make larger investments upfront.

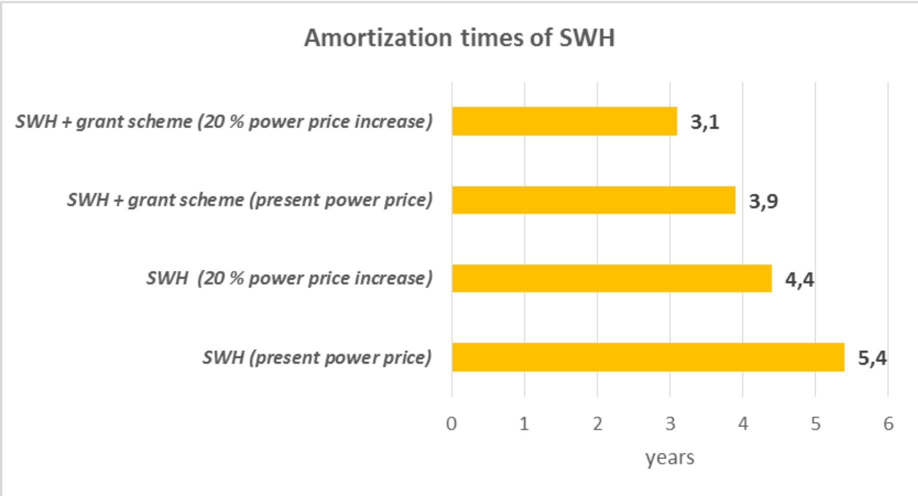



*Figure 111: Comparison of SWH amortisation*

### 12.1.3. HPs

As presented in the previous chapters, a great number of heat pumps is already in place on Malta. However, they are mostly used for cooling purposes. The use of the same devices for heating purposes should be advertised, since they would contribute both to energy efficiency and to the RES target achievement, without causing additional investment costs. However, it must be checked whether the installed devices present a sufficiently high COP to consider part of their output as renewable energy (according to the Directive 2009/28/EC). It is calculated that heat pumps must present a COP of at least 2,94 in order to comply with the requirements of the Directive[157]. Hence, Maltese authorities should survey and inventory the installed devices and their specifications. If it is found that a relevant number of households own outdated technology, a campaign for HPs replacement shall be started. A wide spreading for the use of heat pumps, which present sufficient efficiency, could greatly help the achievement of the 10% RES share target by 2020.

Arguing in favour for the use of HPs for heating purposes, their operational costs are compared to the ones of conventional LPG heaters. Liquigas delivers LPG bottles of 10 kg for 13,75 EUR[158] on Malta. This equals 490 MJ or 136 kWh, hence the cost of LPG amounts to around 10 € cent/kWh LPG. It is assumed that each household requires around 1600 kWh of heating per year (total space heating demand divided by the number of residential-equivalent heating devices, as calculated in the chapters demand and EnergyPLAN modelling). For the generation of 1,6 MWh space heating, given an efficiency of 85%, 1,88 MWh of LPG are required, while it is sufficient to consume around 0,53 MWh of electricity, if a HP with COP 3 is employed for the same purpose. Considering 100% of the electricity generated by PP1 with an efficiency of 50%, the latter solution consumes around 1,07 TWh of primary energy.

From an economic point of view, the conventional solution leads to a cost of 188 EUR, while the HPs requires an operational cost of only 69 € (second band residential price), which is almost 3 times lower. An increase of the power retail prices to 16 € cent/kWh would lead to an expense of 85 € (16 € more) for the same heating generation (refer FIGURE 112) Yearly savings would amount to 119 € at the present electricity price level, to 103 € in case of +20% in the retail prices.

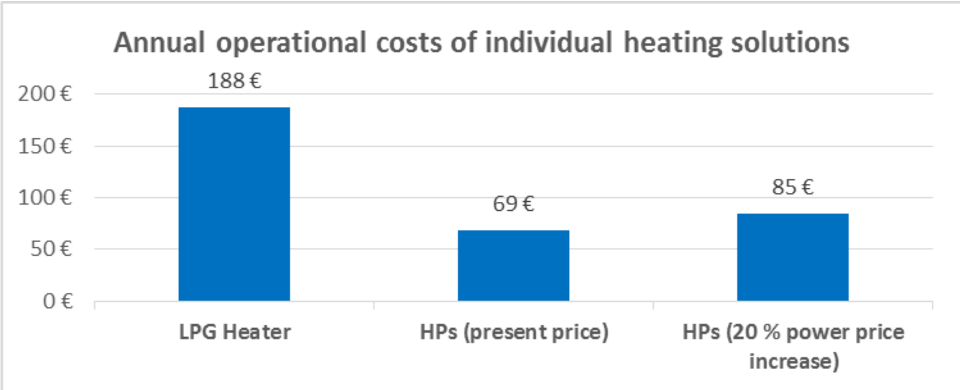



*Figure 112: Comparison of annual operation costs between LPG heaters and HPs on Malta*

In case the investment for the HP (660 EUR) has to be accounted for, the amortisation time would amount to 5,5 years (6,4 years in case of increased retail prices), which is similar to the result achieved with SWHs. The fact that the initial cost is lower than in the case of SWHs makes the authors believe that a grant support is not necessary in this case. Furthermore, the installation of a reversible heat pump leads both to the saving of LPG consumption in winter and to the additional comfort of space cooling in the summer. The following FIGURE 113 shows the amortisation times of SWHs and HPs in an overview.

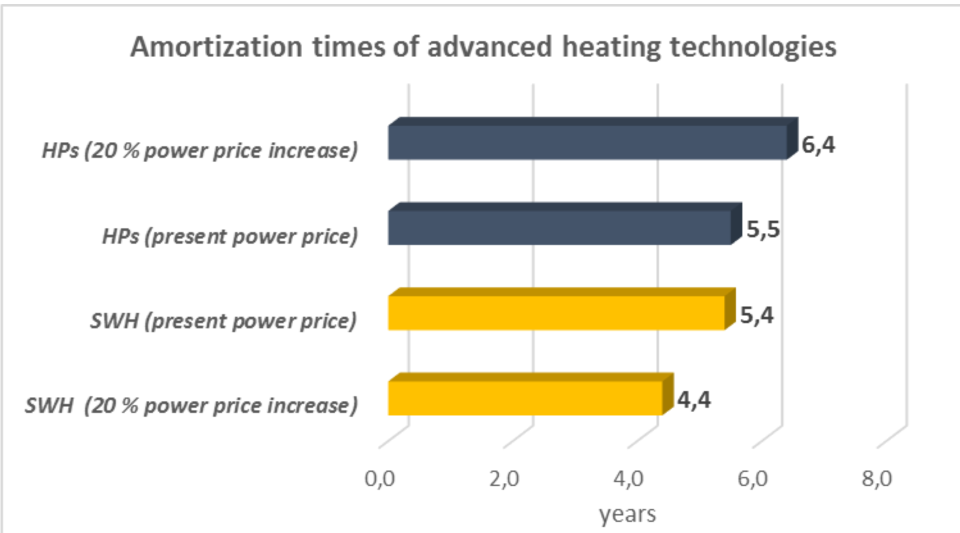



*Figure 113: Comparison amortization between SWHs and HPs*

## 12.2. PV

This project does not see PV as the first technology to be deployed in order to achieve the target concerning renewable energy in the system in the most cost effective and least land consuming way. However, this is the technology, which has been mostly subsidized und discussed in Malta so far.

PV is the most expensive advanced technology among the considered ones in this project. Hence, financial support is necessary, if further PV deployment is wanted. Since this project's results neither show that more PV installations are needed to achieve the RES target, nor that PVs are the optimal solution as long as there is enough untapped RES potential in the heating sector, the authors recommend to rather use the restrained financial means for SWHs and HP support schemes first. In any case PV support schemes should make PV installations never a more profitable investment than SWHs or HPs.

It can be noted that power production from PV becomes increasingly beneficial, if the overall power consumption in heating and e-mobility increases in long term (system in 2030). Hence, a larger penetration of PV could substitute power production from gas power plants, which leads to cheaper and cleaner energy production. To maintain the required grid stabilization share, PV power generation has always to be backed by power production in PP1, which leads to exports in certain hours. As already discussed, this often doesn't generate profits. However, this problem is decreased when flexible peak shaving demand (e-mobility) exists in the system and when the minimal grid stabilisation share is set lower than 30% as in the system of 2020.

It is suggested that support schemes for PV are set lower in the future, since the technology is not as technically mature as SWH technology for instance, which results in further reductions in LCOEs for PV. For that reason, a close monitoring of PV technology prices is recommended to prevent over subsidies. The authors also stress the fact that there is a synergy between HPs and PVs since HPs consume power, which could be self-produced via PV panels. Hence, it is recommended to couple the support of PV installations with an incentive to buy a heat pump or substitute the old heating/cooling devices with newer and more efficient ones. A scrappage scheme as used in the transportation sector for old cars could represent a way to do so. The goal should be to motivate people to use PVs in combination with heat pumps. Hence, little grant schemes on the installation of HPs in combination with PV systems should be given.

### 12.2.1. FiT or grant schemes

A switch from feed in tariffs (FiTs) to grant schemes could be beneficial, since low-income households cannot face a conspicuous upfront investment in the perspective of long-term earnings. Hence, this solution would increase the number of PV installations also on low-income households and would encourage self-consumption. Adequate campaigns or automatic control mechanisms could also push towards a smart consumption of electricity, i.e. the switch on of high consuming devices in hours of high solar production.

## 12.3. Cooling monitoring

Although reverse heat pumps with sufficiently high COPs produce not only heating, but also cooling with an efficiency higher than 1, there is no European Directive or guideline, which suggests a methodology for the calculation of the contribution of free cooling to the RES target. On the contrary, the Commission Decision 2013/114 only foresees that in warm climates, where reverse heat pumps are installed, only few load hours have to be imputed to heating generation, hence calculated as partially renewable energy generation, since the devices mainly serve the scope of cooling. This is not evaluated as coming from a partially renewable source at the moment.

It is highly recommended that the governments of the southern countries of the European Union should lobby for a specific methodology and regulations regarding cooling technologies and their accountability as a RES in European the statistics. In the Shares Manual, the most recent document published by Eurostat[159] concerning the statistical accounting of renewable energy at national and European level, not even one technology providing cooling is listed as contributing to the final energy RES share. This fact makes it evident, that a lack of regulation is present at European level. Also, the Eurostat statistics on final energy demand by source do not mention specifically the cooling demand, leaving space also for improvement concerning the monitoring of the energy consumption for cooling purposes. It is not unlikely that there is no choice awareness for RES cooling accounting at the EU, which should be targeted by all countries who have an interest in building a proper RES cooling framework.

## 12.4. E-Mobility

Taking Norway as a reference for extreme successful e-mobility promotions, the first incentives for e-mobility on Malta seem too little for a consequent market penetration of electric vehicles, since until the end of June 2013 only 87 electric vehicles had been registered[160]. Malta had a scheme granting 25 % support on e-vehicle investments for the period 2011-2012, but only up to 4000 EUR. In contrast, Norwegian e-vehicle owners[161]:

- get a good discount on the annual vehicle tax;
- do not have to pay VAT (25 %) on e-vehicle purchases;
- access free public parking;
- have free use of toll roads;
- can drive on bus lanes;
- free access to domestic ferries.

FIGURE 114[162] shows the rapid increase of electric vehicles in Norway. So despite the fact that geographic conditions (vast country, thinly populated) are much worse for the use of e-vehicles than in Malta, the number of e-vehicles increased from about 10.000 in 2012 to almost 60.000 in 2014 (+145% per year) in only two years. In order to achieve the registration of 63.000 EVs in Malta by 2030, an average annual growth of 58% would be necessary. It is evident that attractive incentives are sufficient to thrive innovation.

However, it must be noted that taxation on conventional cars and on oil are generally high, which makes the incentives for e-vehicles even more attractive. On the other side, the geography for e-mobility (short distances and high urban traffic) is far better on a densely populated Island system like Malta.

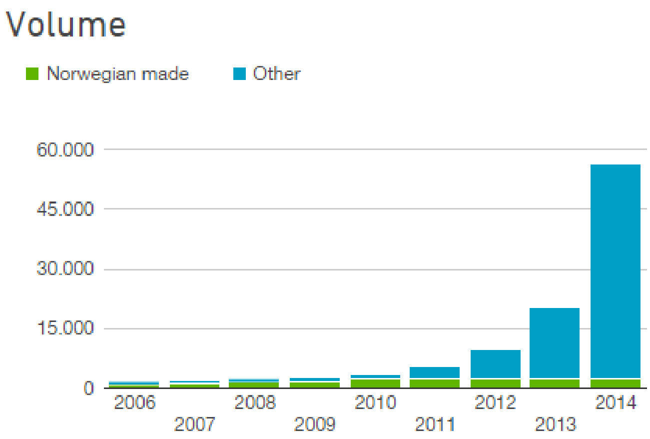



*Figure 114: Development of e-vehicles in Norway*

The authors recommend introducing similar incentives for Malta, which do not necessarily have to be as high as in Norway since e-mobility technology will also be more advanced considering the timeframe of 15 years from now to the target year of 2030. However, it must be assumed that campaigns to raise choice awareness for e-mobility on Malta are much more important than in Norway since the Scandinavian countries are usually more perceptive for advanced and alternative use of technologies.

# 13. Conclusions

*In the following, the main findings of this project, which answer the research question, are briefly summarized for the reader. The aim of the project was to develop the Maltese energy system towards the achievement of the European target of 10% RES in the final energy consumption by 2020, while maintaining system stability and minimizing the costs of the system. The potential of RES was analysed, the costs and benefits of the different technologies compared and a scenario meeting the aforementioned requirements presented. Additionally a suggestion to further progress until 2030 is given according to the energy system characteristics in 2020.*

### *RES potential and RES target*

It was found that the PV potential, although land consuming and therefore strictly limited, would be large enough to produce around 30 % of Malta's power demand. In fact, that would be sufficient to reach the 10 % RES share in 2020. It has to be considered, however, that a high penetration of PV requires countermeasures, such as the introduction of flexible demand, to be a convenient solution and avoid system stability issues. The only other significant renewable source for power production is represented by wind, which is however available only theoretically, since the environmental impact assessment operated on Malta prohibits the utilisation of wind power, at least for the moment.

Other major RES potential was identified in the heating sector. SWHs and HPs could almost completely cover Malta's demand for heating. In combination with some RES contribution (biofuels) from the transport sector, the RES potential of the heating sector would also be sufficient to reach a 10 % share in 2020.

### *Efficiency of RES deployment*

Modelling results showed that SWHs replacing conventional electric water heaters are the most cost efficient and most environmentally beneficial RES, which also cause no challenges for the system's stability. The second most beneficial RES technology was identified in HPs, which can be used for space heating and cooling substituting electric and LPG heaters. HPs are efficient technologies, which provide RES energy in heating mode, furthermore they can be considered as flexible electricity consumers to some extent, which encourages higher penetration of PVs.

PV technology was found to be the least beneficial source RES technology among the compared ones. The reason for that can mainly be found in the higher technology specific costs but also in the impact at system level since PV cause high supply peaks, which require the operation of firm capacity to ensure grid stabilisation. This factor leads to high volumes of exported power, which do not produce any profit since the interconnected market of Sicily presents lower prices during the peak hours. Consequently, the theoretically highest overall potential for PV (100% deployment of PV available rooftop) is realistically cut in half in order to limit additional costs for the maintenance of system stability.

### *Optimal system deployment*

In any case, the deployment of RES decreases the costs for Malta's energy system up to a point, where 100 % of heating as well as cooling and no more than 360 GWh PV power production  are deployed. A higher PV penetration requires higher flexibility within the energy system. Annual costs can be decreased from 390 Mio € (fossil-fuel only system) to 377 Mio EUR, in case a system, which just achieves the 10% RES target in final energy consumption, is considered. The technical maximum penetration of the considered RES, which also minimises the overall costs, would reduce costs for Malta's energy system further to 353 Mio EUR.

*The second part of the research question required to look, beyond 2020, at a further development of the system towards decarbonisation.*

### *System flexibilization for higher RES shares in 2030*

The most beneficial intervention to increase the flexibility of Malta's energy system would be the introduction of e-mobility as a significant shaver for midday peaking PV power production. Reducing the grid stabilisation share has only a minor effect, as well as increasing export capacity, since cross border prices are quite poor and do not allow any economic profit.

Energy system costs are further decreased to around 335 Mio € when introducing 20 % e-mobility and reducing the minimal grid stabilisation share to 20 %. In total, in 2030 a share of around 20 % RES in final energy consumption could be reached with the applied technologies and measures without causing system instability or extra costs.

# 14. Reflections on the Project

## 14.1. Delimitations

### 14.1.1. Forecasts and assumptions

In the authors opinion most “professional” forecasts and assumptions are usually perceived too well and taken for granted in models and policies as given facts, while forecasts and assumptions are uncertain by their nature. Major opinion and evidence can be tracked in literature from N.N. Taleb on that topic.[163] Whenever there is a lack of reliable data and things cannot forecasted or assumed easily, the authors often stick to basic logic of interpreting future demands or prices considering their general drivers and the effects of certain parameter constellations, rather than applying comprehensive literature studies.

### 14.1.2. Sensitivity on demand and technology use

The results presented in the energy system modelling chapters are sensitive to the specific assumptions, which have been set. First of all the thermal energy demand and the final energy consumption of Malta. It is reminded that due to lack of data, thermal energy demand had to be estimated by the authors, while the RES target is calculated on the same level of final energy demand as in 2013. Hence, an overestimation of the thermal energy demand would imply an overestimation of the SWH and HPs maximum potential, while an underestimation of the final energy demand would mean that more RES than calculated are necessary to meet the target in 2020. It is reminded that any system evolution different than the ones presented in this project would consistently distort the results and the conclusions of the authors.

As for the technology specifications, i.e. costs and efficiencies, general assumptions have been taken, which should be validated by more detailed analyses. In particular, it has been chosen that all installed heat pumps present a COP 3 and that one device suffices for both heating and cooling purposes. The former information is derived from the technology features of modern devices available on the islands, while the latter is a simplification, whose closeness to reality should be verified in further research.

### 14.1.3. Exclusion of RES technologies

The political decision to exclude wind power from the future midterm scenarios for Malta’s energy system due to environmental, visual impact and space constraints is understandable although it prevents higher shares of RES in the energy system. For that reason wind power was not included in the modelling despite sufficient theoretical wind resource in the country.

The utilisation of Malta’s wind power potential is likely to be a positive contribution to Malta’s energy system since gas power plants are a flexible component to regulate fluctuating wind power production. Additionally a wind power production profile presents a different profile than PV. Firstly, wind power presents more fluctuations than PV power, which makes the balancing more complex, but also enables a higher penetration due to less concentrated production. Furthermore, the presence of optimal wind and solar conditions is not simultaneous, hence wind can be considered as a complementary resource to PV. Therefore, in case land restrictions are softened or offshore projects are proven feasible, the authors believe that wind power production could be well integrated in the system.

Another source for power and heat production would be waste to energy through waste incineration or anaerobic digesters producing biogas. This solution would lead to both renewable energy generation and to less land consuming disposal of waste. However, the authors did not considered that technology as an option in the modelling, since a quick research made clear that the potential of waste is too low in order to justify that solution as a significant contribution to Malta's RES target achievement. Nevertheless, it must be mentioned that waste incineration would be a solution of waste disposal and would make the use of area consuming landfills redundant.

## 14.2. System design

### 14.2.1. Heating sector

It is reminded that strong assumptions based on little data were necessary to define the Maltese heating and cooling sector. Higher or lower demands would substantially alter the RES potential in the heating sector and consequently in the whole system. Furthermore, the potential of SWHs could eventually be increased by better and centralized thermal storage systems or by their employment also for space heating purposes (installation of individual radiators). In addition, HPs could be eventually used for water heating purposes, if they are air-to-water or water-to-water devices instead of air-to-air devices, as it is assumed to be. Hence, other scenarios would be possible, in addition to the proposed ones. Furthermore, not all the available technologies, i.e. solar cooling and district heating, have been investigated.

District heating and cooling could be a suitable option if PP1 was diverted to CHP. The transformation would slightly decrease the electricity input, while improving the overall process efficiency. Additionally, solar district heating system could also be set in place, if enough free area is individuated. However, issues could be that Malta's heating demand is too little to cover the high investment costs of a district heating infrastructure. Furthermore, it is hard to think to build such an infrastructure in a so densely inhabited country, which also has a number of historical buildings. On the other hand, Malta is so densely populated that a district heating and cooling system could easily be feasible, as highlighted in the EU heat roadmap.

An extensive assessment of the investment needed and of the resulting benefits would be required, in order to prove the feasibility of the introduction of district heating in Malta. However, this goes beyond the limits of this project.

### 14.2.2. Interconnector

The authors decided that only 150 MW of the total 200 MW interconnector capacity can be used in export in a first stage and that export flow should only be used in emergencies and not as the common usage. That is because Malta and Italy agreed for a power flow almost exclusively in the contrary direction (Malta importing).

In the meantime, the interconnector is used for power imports from Sicily, while the new large 215 MW gas power plant is still under construction. In the short-term, evidence from results of the

EnergyPLAN models that the interconnector is in fact not needed at all, if PV installation stay below 90 MW and the new 215 MW gas power plant is operating. On the other hand, the importance of the interconnector acquires a new meaning when thinking about mothballing the PP2 backup units completely. That thought is not so far-fetched since evidence of EnergyPLAN modelling shows they are hardly or not used at all. A complete mothballing would not only save the maintenance costs but would also offset valuable land resource on Malta.

A power flow from PV producers in the south (Malta, Sicily) to the Italian mainland and further to central Europe during midday seems likely in the future assuming a better integration of power markets in a pan-European power market, as wished at European level[164]. Some process in that direction can already be observed in the ongoing grid enforcements between Sicily and Italy, although delays are accumulating.[165] In the long term, the authors expect a general midday export flow from Malta transiting Sicily to the European main land.

*Cross-border prices*

As experienced in the modelling section for 2020, the interconnector is not necessarily needed. Its original function is dedicated to bypass the mothballing and refurbishment of power plants, while the new gas power plant is still under construction. However, in all models with a time horizon 2020 and beyond the interconnector is exclusively used in order to export excess energy production.

When it comes to market prices and cross border spreads, it must be reminded that Malta does not have a wholesale market. Hence, Enemalta fixes a marginal price on a yearly basis, which considers the average generation mix. However, EnergyPLAN considers a marginal price, which is set by the most expensive technology in use. In the case of Malta's 2020 energy system the marginal price will always be set by the gas power plant. When PV penetration is high, a situation in which most of the EEEP is produced, the marginal technology is still the gas power plant, which has to run nevertheless in order to meet the necessary requirements of the minimum grid stabilization share.

The power market of Sicily has its own marginal market price, which has been given in input. Given the high PV penetration leading to the generation of cheap and abundant power, Sicily presents a low electricity market price around midday. Therefore, most of the power, which is exported from Malta to Sicily around midday, moves from a higher to a lower price zone, leading to financial losses for Malta, which cannot cover its marginal costs. This leads to the consequence of low profit for the Maltese system, when increasing the PV installed capacity and consequently the power amount to be exported to Sicily. Given the similarities of the Maltese and Sicilian electricity generation mix and load profile, it is not likely that this situation will evolve and change, but further studies on the price development in Sicily and on the possible cross-border dynamics should be conducted.

### 14.2.3. Grid stabilization share

Reducing the minimum grid stabilization share can be an option in a context of infrastructure implementation towards a smart energy system, mainly including flexible demand and supply. If a fixed grid stabilisation share must be maintained at all time, it is especially hard to balance Malta's energy system, since it has a high midday PV peak, which must be backed by PP1 production to secure enough generation from firm capacity, although this leads to inconvenient export. That also leads to additional fossil fuel consumption and $CO_2$ emissions, which lower the sustainability and cost efficiency of the system. The solar conditions under which PV power is generated on Malta are extremely stable (62 % clear sky over the year). Hence, the need for a minimum grid stabilisation share of 30% can be doubted. Furthermore, firm capacity is represented by advanced natural gas power plants consisting of multiple units, which makes the operation of firm capacity very flexible.

Additionally, other sources of flexibility can be triggered. The introduction of e-mobility, the use of smart meters, as well as centralized electricity driven heating with storage possibilities could further improve the system. Another option for system flexibilization would be represented by a flexible operation of the desalination plants (if sufficiently large water storages would be available) or of other electricity consuming appliances, whose functioning can be shifted.

### 14.2.4. Technical set up for PV

It has been proven in the modelling section that technical restrictions would not enable to deploy the PV potential of 434 MW (400 MW if the full potential of SWHs is also deployed), calculated according to the geographical restrictions. However, it has also been proven that the installation of PV in horizontal setup would theoretically lead to a higher land availability, hence to a higher PV potential as when PV panels are set up at optimal tilt angle. If more demand that is flexible or higher interconnection capacities are introduced to Malta's energy system the overall PV penetration can be increased. Hence, the deployment of PV panels should be proceeded in horizontal setup considering the restricted area availability on Malta.

Besides, in the condition in which the whole potential (calculated based on area availability) cannot be deployed due to technical restraints, the horizontal setting can be an option, if it is considered that space on Malta has a high value. For example, most of the commercial installations have to bear also the cost of the rooftop rent, which is calculated based on occupied square meters and not of installed capacity. Hence, it could be considered to concentrate the same amount of installed capacity in a smaller area, although the energy output would be a little lowered by the sub-optimal setting. In any case, such setting could lead to much bigger and more cost effective (due to economy of scale) installations, where large areas are available, i.e. quarries and industrial rooftops.

### 14.2.5. System synergies

Along the project, the different energy sectors, i.e. electricity, heating and transportation, as well as their contribution to the RES target achievement, have been maintained quite separate. However, it is clear that the choices in the single sectors the whole system. In particular, it can be highlighted that the penetration of more electricity consuming technologies lead to higher installable PV capacity without incurring in inconvenient costs or system unbalances. This element has been discussed for e-mobility, which specifically aims at shaving the peak of power generation from PV. The installation of heat pumps slightly increases the potential of PV, which can be installed while decreasing system prices and maintaining system stability. Furthermore, higher shares of renewable electricity in the system increase the overall efficiency of heat pumps from 150% (when the whole electricity is produced by PP1) to 300% in case all the electricity employed is produced by RES.

## 14.3. Policy and organization

### 14.3.1. Stakeholders

As already mentioned, the Maltese stakeholders are divided between the need to comply with the EU decarbonisation pathway and the economical convenience of maintaining the status quo. The power sales agreed on in the PPA from the independent power producer to Enemalta are fixed not only on price but also on quantity. Therefore, the penetration of RES in the power and heating sector can quickly become a serious and expensive problem since the new technologies would have to replace the conventional ones, which were already paid for. According to the findings highlighted in the modelling section, an increase in the PV installed capacity and in its power production leads to a reduction of the PP1 capacity factor, i.e. its full load hours of operation, which are connected to a cost but also to an earning.

The confidential specifications of the PPA concerning the minimum power withdrawal from the gas-fired power plant should be compared with the model's outcome. In fact, the authors cannot say whether a capacity factor of 50% for PP1, as it results to be in the model deploying the maximum capacity of all advanced technologies, is sufficiently high to comply with the agreements. This parameter has to be added to the other technical limitations registered in the system to eventually further constrain the PV potential.

*Investor's responsiveness*

The ideal technology development in order to optimize the system has been suggested and the convenience of the advanced technologies has been proven. However, such system changes can only proceed if enough investors are convinced about the opportunity of advanced technologies. Hence, either technologies must be sufficiently incentivized in order to make investments attractive enough or information campaigns on the superior technology must be run. That can only be done through the technology selling industry or the government. In case the government itself is biased and not convinced to convert Malta's energy system towards sustainability, it is hard to imagine that enough action is undertaken from that side. Furthermore, it must be remembered that any kind of financial support has to comply with the national budget limitations.

### 14.3.2. Cooperation mechanisms

It has been discussed that cooperation mechanisms are not a good option for Malta as a system, since they would avoid cost savings in the energy system, which derive from renewable sources, as shown in the modelling chapter. Besides, socio-economic benefits, which were mentioned only qualitatively, are missed. In fact, cooperation mechanisms represent a cost without having an impact on the energy system or on the economy of the country, in particular if not combined with a physical transfer.

However, it has been shown that cooperation mechanisms can be a convenient option if only the national financial balance is considered, since the net support cost of specific technologies in other countries can be cheaper than the support to PV installations in Malta.

However, the comparison operated between the net support paid to PV in Malta and to RES in other countries does not consider the fact that the technology costs are likely to decrease in the coming years, in particular in a country like Malta, where renewable technologies are at the beginning of market penetration. Therefore, it can be imagined that in some years the gap between the support schemes needed in Malta or in another country, like Sweden, to obtain the same amount of RE-credits could be tightened.

Furthermore, the authors question that the government cannot only look at the short-term financial status, without considering the broader point of view of the domestic economic growth and of the benefits arising in the energy system through the introduction of renewable energy. Therefore, the authors suggest concentrating on the deployment of domestic resources with the aid of ad hoc policies, instead of investing in RES projects abroad.

### 14.3.3. European framework in 2030

For 2020, specific targets are set for each EU Member State's energy system. Therefore, it is clear which RES quantities are needed in order to comply with the 2020 target. For 2030, no country specific targets have been assigned yet, while it is already defined that the whole EU is supposed to move towards a 27% RES share in final energy consumption and -40% GHG emissions compared to 1990. As soon as a specific target will be set for Malta, long-term policies in the energy sector will have a clearer objective to point at and an optimal scenario can be built based on more elements.

Also in regards to cooperation mechanisms, at present it is not possible to say whether the European Commission will renovate the current framework, hence enabling Member States to invest in renewable energies in other countries, while registering RE-credits in the own statistics, or if changes will occur. This is particular relevant in the case of joint projects. In fact, it must be cleared whether an installation, which is built in 2015 and supported until 2030, can also provide RE-credits to the off-taking country for the whole period, contributing also to the target achievement set for 2030.

## 14.4. Discussion on Costs

### 14.4.1. Costs for PV technology

Costs for PV installations were indicated at a quite high level from official sources on Malta when compared to advance developed PV markets like Germany for example for the year 2013. The authors assumed a fast learning curve for the PV market development in general and a fast catch up development of the Maltese market until 2020. Hence, cost savings through PV could turn out to be much lower. However, even investment costs for PV on Malta, which result to be 40% higher than in Germany, lead to annual system cost savings. The other way around, when using the same PV cost reduction rate of 14,6 % annually, which took place in Germany between 2006 and 2013 for Malta until 2020, cost savings through PV would double to 6 Mio annually on Malta.

### 14.4.2. LNG Gas Fuel Costs

The PPA and GSA (gas supply agreement) between Enemalta and the IPP Electrogas are open to bilateral renegotiations every 5 years. That might leave room for bargaining power on LNG prices. In fact it is noted that the present low price of LNG supply from the U.S., amounting to almost half the European prices, and the fact the U.S. just became a net exporters of the resource could change the international balances and take negotiation power away from Socar, which provides natural gas to Malta (as partner of Electrogas).

However, it is hardly foreseeable how the natural gas price evolves in the long term towards 2030. For this reason, no price evolution is applied to the modelling, and the effects of possible evolutions are only discussed on the side. According to different assumptions, prices could stay stable, slightly increase or strongly increase. This could affect the government's will to support measures, which allow a stronger priority for RES technologies in order to support a displacement of power production from PP1.

## 14.5. Research Recommendations

As already mentioned, due to the focus of the project and to the time limit of its writing, certain topics are not examined in detail or not treated at all. The bottom-listed bullets should be analysed in more detail in order to optimize Malta's energy system further or to show some more alternatives.

- District Heating and Cooling
- Grid Stabilisation Share
- Transport Sector
- Smart E mobility
- Quantitative Analysis of the Socio economics
- Operation of Wind Power

The feasibility of district heating and cooling on Malta could still be analysed, as well as their potential impact on the energy system. An exact quantification of the minimal grid stabilization share requires examining the setting of the Maltese energy system in more detail. That would comprise an exact examination of Malta's network, and a detailed assessment of the potential of demand and supply side management.

The way towards the achievement of the 10 % target within the transport sector, as well as the exactly related costs, has still to be assessed. As for e-mobility, a further analysis of its full potential could be undertaken and the option of smart charge, which makes e-vehicles work both as flexible supply and demand, should be taken into consideration.

Some hints on socio economic factors related to the path towards sustainability of Malta have been given along the project, however a quantitative analysis has still to be run. Furthermore, no deployment of wind power and waste to energy had been evaluated in the project, despite the theoretically sufficient wind climate.

Although the Maltese energy system is rather small, it presents plenty of research opportunities, in particular because so little progress towards a sustainable energy system had been made so far on Malta.

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Energy PLAN
Advanced energy system analysis computer model

Training content comprising video tutorials, guidebooks and exercises is provided on EnergyPLAN's homepage. It must be emphasized that, the software is a free open source program, which empowers people to model sustainable energy systems.

Deeper knowledge about Renewable Energy Systems can be obtained from:

"Renewable Energy Systems - A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions"

By Professor Henrik Lund

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