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FROM OIL TO GAS: AN ANALYSIS OF MALTA'S POWER SECTOR TRANSITION WITH REGARD TO CO2 EMISSIONS, THE INTEGRATION OF RENEWABLES, AND THE ROLE OF ENERGY STORAGE

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ABSTRACT: Malta's electricity generation is based on heavy fuel oil and gas oil. However, profound changes are underway as the power sector is being shifted to natural gas and an HVAC interconnector to Sicily will connect the hitherto isolated Maltese electricity grid to Europe. Within this study projections for supply and demand have been compared, and the power sector transition has been reviewed with respect to carbon dioxide emissions and economic impact. The latter included a review of Sicilian electricity prices to investigate opportunities of electricity trade through the interconnector. A model has been built to compare various scenarios of electricity generation and import/export levels for different years. While the Maltese power sector transition will reduce overall national carbon dioxide emissions below 1990 levels, achieving high renewable energy shares will be challenging. Though Malta has managed to reach the two percent intermediate renewables share target for 2012, the national renewable energy action plan needs to be revised, in part due to the impact of the new fossil fuel setup. In turn, energy storage options might facility the way towards the further rise and integration of renewable energy integration. The modelling results indicated that investment into storage rather than generation capacity might be the better option once the older generation capacity at Delimara power station will retire. Seawater pumped hydro storage and ocean compressed air energy storage have been identified as two of the options that would fit Maltese settings.

Keywords: Malta, natural gas, carbon dioxide, energy storage, renewable energy

1 INTRODUCTION

In 2005 the island state of Malta was the only European Union member country with a renewable energy consumption share of zero percent, and it was not before 2011 that a one percent share had been achieved. Meanwhile electricity production from non-renewables is mainly based on imported heavy fuel oil that is associated with high levels of both local air pollution and CO2 emissions per kWh generated. However, substantial changes during the next few years will alter the Maltese energy landscape in terms of fossil fuels, renewables, as well as electricity grid infrastructure.

2 THE CURRENT POWER SECTOR SITUATION

2.1 Status of Fossil Electricity Generation

Malta produces some 2.3 TWh of electricity per year for a population of about 410 thousand. More precisely, electricity production was 2.28 TWh in 2012, up from 2.17 TWh in 2011 and 2.11 TWh in 2010. Until recently practically all electricity was produced at two power stations burning heavy fuel oil (ca. 86 percent) and gas oil (ca. 14 percent) and releasing some 1.9 million tonnes of CO2 per year (2011). However, only 130 MW of nominal capacity at Marsa, the older one of these two stations, remained in operation after Enemalta in December 2012 took a new extension at the Delimara station into operation. This new extension, a Diesel engine/combined cycle that currently runs on heavy fuel oil, significantly increased Maltese power generation efficiency through its individual efficiency of 46% at a nominal capacity of 149 MW. The other units at Delimara are steam turbines (2x60 MW, 32% efficiency), a combined cycle gas turbine plant (2x 37 MW gas turbines, 1x 36 MW steam turbine, overall 39% efficiency), and two open cycle gas turbines of 37 MW each (20% efficiency). At Marsa, there is an additional 37 MW open cycle gas turbine of the same efficiency, while 130 MW worth of steam turbines exhibit an average efficiency of 25%. In total, the current nominal capacity amounts to 620 MW, de-rated to 570 MW during the summer due to high ambient temperatures. This compares to a peak load of above 410 MW on hot summer days, while the base load is ca. 160 MW.

2.2 The Electricity Grid

The Maltese electricity grid is currently isolated. With Delimara power station at the southern coast, and Marsa power station in a south-central position, electricity is fed quite peripherally into the grid to be distributed across the country via two double 132kV cables and various 33kV (and smaller) power lines. Losses are high, given that the area covered is small. Eurostat data shows "distribution losses" as 11.7% of total net electricity production for 2011. However, much of this is attributed to non-technical "losses" (including theft), while technical transmission and distribution losses may be around 4.6% [1]. Meanwhile, self-consumption in the two power stations was 5.7 percent of the total electricity produced.

2.3 Renewables

Malta started out with the lowest renewables share of all EU member countries and was committed to reach a 10 percent renewable energy share of gross final energy consumption by 2020 with a trajectory as shown in Table 1.

Table 1: Malta's 2020 renewable energy share target with trajectory [2].

Year	2011-2012	2013-2014	2015-2016	2017-2018	2020
Target	2%	3%	4.5%	6.5%	10%

Malta faces various challenges with regard to renewables for several reasons. Most importantly, Malta has a population density of about 1,300 people per km2, making it one of the world's most densely populated nations, while renewable energy sources tend to have low energy intensities per unit of area. Wind turbines close to urban settings are opposed, and Malta largely relies on imports for its food security. To set land aside for the production of biofuels (which need to be imported) or ground-based solar PV parks would thus be questionable, even if marginal land is concerned (opportunity cost). Furthermore, the waters around Malta quickly deepen beyond depths suitable for conventional offshore wind technology, though a reef has been identified that could potentially carry a 95 MW wind park. The previous government in turn made offshore wind the cornerstone of its renewable energy plan (Table 2).

Table 2: The contribution of different renewable energy options to 2020 gross final energy consumption according to Malta's National Renewable Energy Action Plan submitted in June 2010 and resubmitted in May 2011 [1, 3].

Renewable Energy Option	%	GWh/year
Offshore wind	3.48	216
Biofuels	2.40	149
Energy from waste – Electricity	2.18	135
Solar PV	0.69	43
Onshore wind	0.61	38
Solar water heating	0.52	32
Energy from waste – Heat	0.32	20
TOTAL:	**10.20**	**634**

As will be described below, the offshore wind park, which remained in the planning stage, is problematic for various reasons. Photovoltaic (PV) systems, on the other hand, although represented only conservatively in Malta's National Renewable Energy Action Plan (NREAP), began to spread rapidly, with 17 MWp of total PV capacity having been installed by the end of 2012, and ca. 30 MWp by the end of 2013. Notably, Malta enjoys a mean global horizontal solar radiation of ca. 5 kWh/m²/day, and new PV systems yield around 1650 kWh/kWp/year. Thirty MWp would thus initially deliver 49.5 GWh/year and already overshoot the PV target of the NREAP. The drivers behind the increase in installed PV systems in Malta in recent years include falling PV system prices; grant schemes providing 50 percent of the eligible expenditure up to a maximum of €3,000; additional grant schemes for commercial establishments; and modest feed-in tariffs.

Based to a good part on the accelerated spread of PV systems, but also due to the substitution obligation with regard to biodiesel (now pre-mixed into fossil diesel); a substantial increase in solar thermal systems, increased use of wood pellets ("imported biomass"); a contribution from a mechanical-biological waste treatment plant, and an additional anaerobic digestion setup that produces electricity at the main sewage treatment plant, Malta managed to achieve a two percent renewable energy share in 2012 as required by the trajectory (Table 3).

Table 3: Maltese renewable energy consumption data for 2011 and 2012 [5]

Renewable Energy Category	2011 GWh	2012 GWh
RES-electricity		
PV	8.43	13.17
Micro-Wind	0.00	0.1
Waste-to-Energy (CHP)	1.55	8.85
RES-heat		
SWH	31.44	45.14
Waste-to-Energy (biogas to RTO)	3.08	2.50
Biomass imports	6.61	9.60
Bio-diesel in industry	0.88	2.53
Waste-to-Energy (CHP)	1.39	7.30
RES-transport		
bio-diesel	15.30	34.28
TOTAL:	**68.68**	**123.47**

2.4 Electricity Prices, Consumption Trends, GDP

Electricity tariffs vary according to consumption levels, with residential rates ranging from 16.1 cents/kWh to 70.0 cents/kWh (inclusive 5 percent VAT), and nonresidential daytime rates ranging from 14.6 cents/kWh (very high consumption) to 21.7 cents/kWh (exclusive VAT). An increase in tariffs in 2009-10 seemed to be a driver behind the reduced electricity consumption in 2010 that disrupted the long-term trend, however, the decrease in consumption turned out a short-term effect and coincided with an economic downturn (Figure 1). Final electricity consumption in 2011 was spilt into 33% residential and 67% non-residential, with the latter including 29% industry and the remaining 38% including the commercial sector.

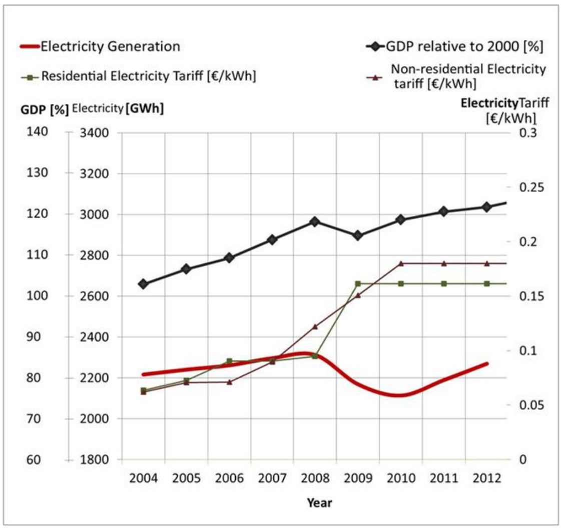

Figure 1: Historic trends in electricity tariffs, electricity generation/consumption, and GDP.

3 THE UPCOMING SETUP

3.1 Interconnector to Sicily

A 200 MW (at 220 kV) HVAC submarine cable to Sicily, the longest HVAC (rather than HVDC) interconnection in the world, is currently being implemented, with completion now expected by late 2014 or early 2015. At a stated cost of €182 million, part-financed through the European Energy Programme for Recovery, the project includes the construction of a distribution hub that was to connect the planned offshore wind park to the Maltese grid. Grid stability in the context of the offshore wind park integration was cited as a principal reason why the interconnector was required, and it was proposed that the interconnector capacity may be doubled with a second 200 MW cable later on [5]. However, with the expected changes in Malta’s NREAP, the most significant immediate effect might be that the completion of the interconnector will allow for the total decommissioning of the old Marsa power station to take the remaining 130 MW worth of steam turbines out of service. (The interconnector’s impact on Malta’s carbon footprint from electricity production will be discussed further below.)

3.2 New Gas-fueled Power Station

According to the programme of the party in government since March 2013, Malta is currently shifting its electricity generation infrastructure from oil to gas. (The electorate has been promised a 25% reduction in utility bills.) At the core of the restructuring plan is an LNG Floating Storage Unit with a land-based regasification installation supplying a new 215 MW gas-fired power station (combined cycle gas turbines) that should be operational by the end of 2015. In addition, Delimara power station’s 144 MW extension that started to operate in December 2012 will be converted to run on natural gas as well (while it was originally designed to use diesel). To be sure, there is still considerable dispute about the precise setup of the LNG Floating Storage Unit, principally because the current proposal maintains that a gas storage ship should be permanently berthed in Marsaxlokk Port next to the Delimara power station, while opponents claim this to be unsafe and lobby for a vessel out at sea that should store LNG and have an onboard re-gasificator. However, the latter setup is more expensive, and would take longer to establish. Notably, the investment for the new gas power plant will be placed by an Independent Power Producer to ensure heavily indebted Enemalta Corporation is not being burdened. As soon as the new gas plant is coming online, the 120 MW steam plant at Delimara will be decommissioned.

3.3 Future Generation Capacity Compared to Future Demand

The implementation of the interconnector and the new gas power station will combined allow for most of the older generation capacity to be switched off within just two years. Figure 2 shows projected electricity prices according to the announced price cut together with projections for electricity demand. The official projection of Malta's 2020 electricity demand of 3.14 TWh that was, for instance, used for the NREAP is considered too high [6]. However, it has been employed within this study, as the upcoming tariff reduction may lead to increased electricity consumption.

Figure 3 in turn illustrates how electricity generation and import capacity will change during the next few years, with an indication of peak load that needs to be met. Notably, in the depicted scenario peak loads increase proportionally with overall demand, while increased overall wealth and lower electricity tariffs may lead to higher cooling loads and more pronounced summer peak demand. Also note that renewables are excluded in this scenario. As discussed further below, contributions from photovoltaic installations right at the time when summer peak loads are experienced, may well allow for the Delimara gasoil part to remain offline. Increased grid efficiency would also reduce the generation requirement.

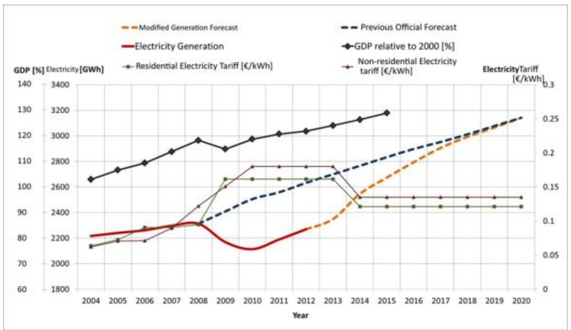

Figure 2: Projections for future electricity demand and electricity tariffs. See main text for comments.

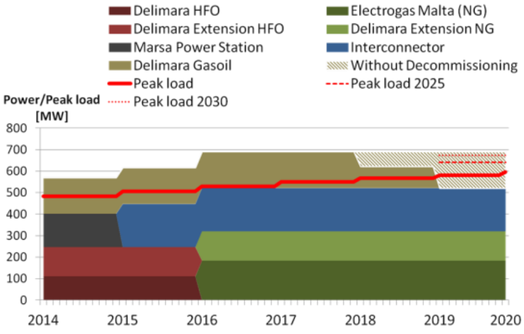

Figure 3: Scenario showing peak demand projections with changes in electricity generation and import capacity in future years (excluding renewables).

3.4 Cost Reductions and Interconnector Trade

The new power infrastructure will allow for electricity to be available at much lower cost due to fuel cost differences, higher efficiencies of the new generation capacity, and lower cost of imported electricity. Figure 4 shows a cost comparison scenario for projected 2016 demand for four supply setups. All four include contributions from 90MWp of PV installations, plus energy from waste and micro-wind according to the NREAP. However, this contribution has been subtracted from the depicted supply and demand, and the cost of renewable energy was not included in the shown unit cost, as the contribution is the same in all setups. The cost scenario for heavy fuel and gas oil ("oil") is based on Enemalta's full-cost recovery rate for electricity production of 2009 [7], adjusted for higher oil prices, while imported electricity cost (interconnector) is based on TERNA's projected Sicilian market prices (IPEX) for 2015. The cost of electricity produced from gas is taken as €95.99 per MWh, as reported by Enemalta and various media referring to the power purchase agreement that Enemalta signed with the Independent Power Producer, i.e. ElectroGas Malta, a consortium comprising Siemens GMBH, Socar, Gasol Plc and GEM Holdings [8]. The unit price charged to Enemalta has been reported to be locked in for five years, and the same figure has been assumed as cost for electricity produced at the Delimara extension that will be converted to gas.

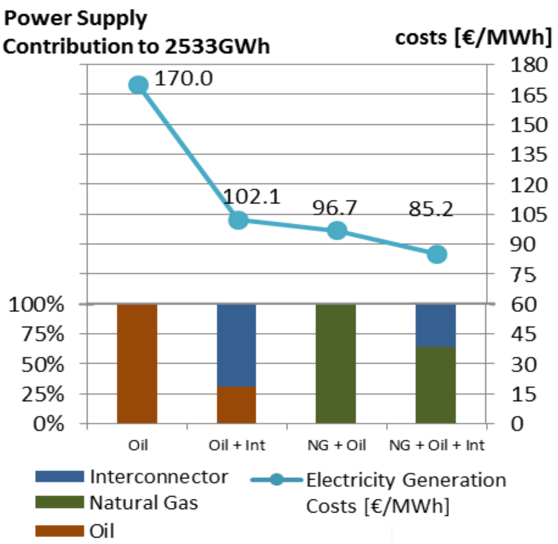

Figure 4: Cost scenarios for projected 2016 demand. See main text for assumptions.

The strong reduction in Maltese electricity generation costs, combined with the strong fluctuation of Sicilian electricity spot prices in the course of single days, invites the idea to gainfully trade electricity through the interconnector. Since the new 215 MW gas power station will be financed by a private-sector investor, it has to be assumed that the power purchasing agreement will stipulate a certain capacity factor for this plant. In the scenarios shown below it was assumed that a minimum of 150 MW (roughly the base load) has to be purchased at all times from the ElectroGas plant, otherwise Maltese power plants will deliver in relation to Sicilian spot market prices. The resulting trading patterns would strongly depend on the exact price difference in future years, which is difficult to project. Figures 5 and 6, for instance, show scenarios for a day in July 2016, including 90MWp worth of PV installations. Generally no cost has been included for the use of, and trade through, the interconnector. The scenario in Figure 5 uses a modelled IPEX Sicily curve based on the actual pattern experienced in 2013, but adjusted according to peak and off-peak prices projected for 2015 in a document commissioned by TERNA in 2009 [9]. The scenario in Figure 6, on the other hand, models the Sicilian price curve based on an annual three percent increase from 2012. Consequently, the trade pattern would be significantly different. Figures 7 and 8 show a similar comparison for a 2016 November day.

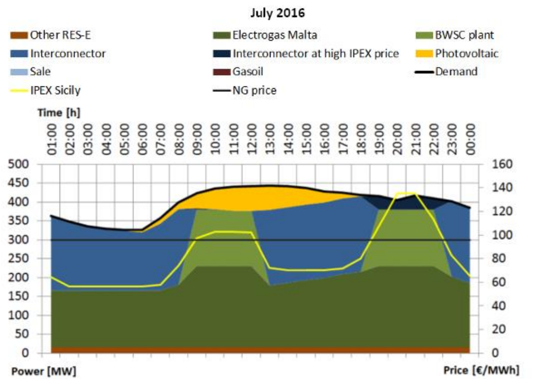

Figure 5: 2016 scenario for a day in July, with modelled IPEX curve based on a TERNA-based projection. See main text for assumptions.

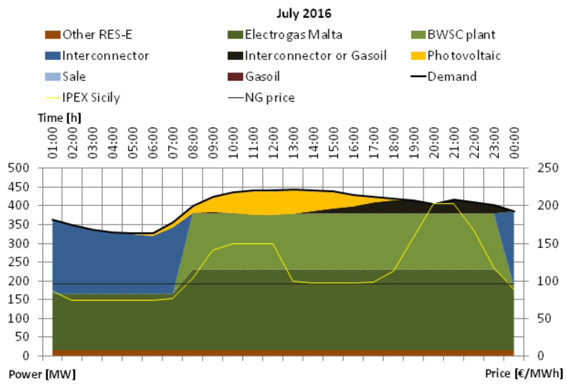

Figure 6: 2016 scenario for a day in July, with modelled IPEX curve based on a three percent annual growth projection. See main text for assumptions.

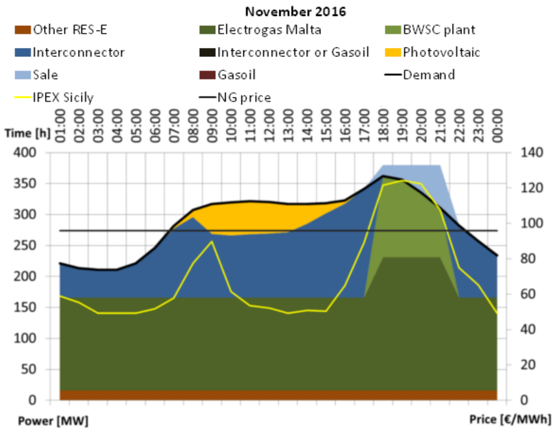

Figure 7: 2016 scenario for a day in November, with modelled IPEX curve based on a TERNA-based projection. See main text for assumptions.

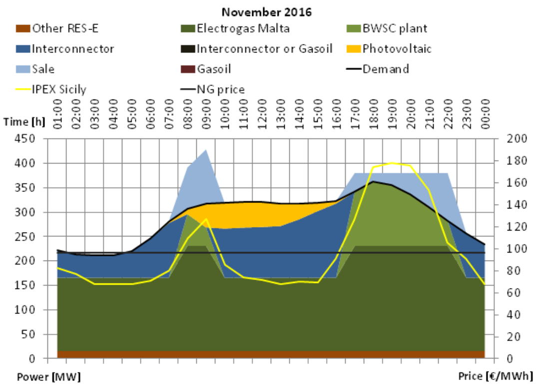

Figure 8: 2016 scenario for a day in November, with modelled IPEX curve based on a three percent annual growth projection. See main text for assumptions.

3.5 Carbon Dioxide Emissions Reduction

Carbon dioxide emissions will be substantially reduced due to the upcoming power sector transition. Figure 9 shows the dominant contribution of Maltese power generation to overall greenhouse gas emissions.

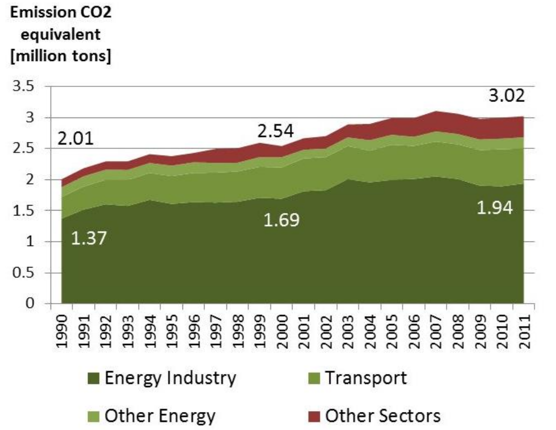

Figure 9: Contribution of different sectors to Maltese greenhouse gas emissions. The "Other Energy" category includes energy used in manufacturing industries, construction, etc., while "Other Sectors" includes emissions from agriculture, waste, solvents and other relevant processing and production [10].

Referring to the same scenarios as depicted in Figure 4, Figure 10 shows that the "NG+Oil+Int" scenario (that practically has no oil contribution) would reduce power sector emissions from two million tonnes of carbon dioxide to 843 thousand tonnes when compared to the old setup. (A similar scenario for 2020 would achieve a reduction from 2.05 million tonnes to 917 thousand tonnes.) Again, these scenarios assumed a minimum purchase of 150 MW of electricity from ElectroGas, while the required remainder will either be provided by the Maltese gas installations or purchased through the interconnector at the respective lower price. The carbon footprint associated with imported electricity is based on the current Sicilian power generation mix.

To be sure, the carbon footprint of imported electricity would not appear in the official emissions inventory of the importer. In 1990, total Maltese GHG emissions were 2.01 million tonnes of CO_2 equivalent. If 2020 electricity supply requirements are taken to be as high as 3.14 TWh (according to the official projection), and an average of 180 MW worth of electricity (1.577 TWh) each are purchased from the new ElectroGas plant and through the interconnector (while ignoring the Delimara extension and photovoltaic contributions), power sector emissions within Malta would be reduced to 542 thousand tonnes of CO_2 equivalent. (Emissions factor of 0.344kg/kWh assumed for the modern ElectroGas plant as well as the Delimara extension.) If the ElectroGas plant and the 144MW Delimara extension would combined deliver 300MW on average, and the remainder be purchased through the interconnector, 2020 power sector emissions within Malta would account to 904 thousand tonnes of CO_2. If all non-electricity emissions would combined remain at the 2011 level of 1.08 million tonnes of CO_2 equivalent, Malta's emissions in 2020 would thus be 1.62 million tonnes in the scenario without the Delimara extension, reducing nationwide 2020 emissions to 80.6% of total 1990 emissions despite more than doubling the electricity consumption and in the absence of any other emissions reduction measures.

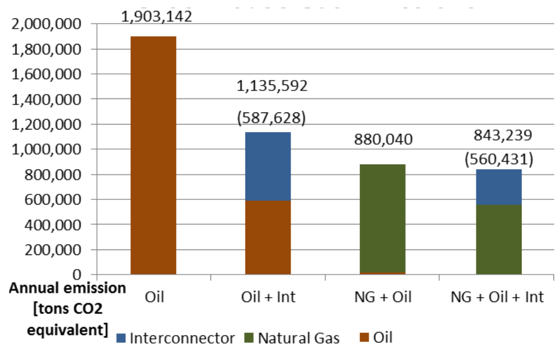

Figure 10: Carbon dioxide emissions scenarios for 2016 demand with colour codes according to electricity generation contributions as in Figure 4. Emissions associated with electricity imports are based on the current Sicilian power mix. Emissions within Malta are indicated in parentheses.

3.6 Gas Pipeline to Sicily

An additional energy infrastructure project that might come into existence in the somewhat more distant future is a natural gas pipeline between Malta and Sicily. An according plan has been selected by the European Commission as "project of common interest" (PCI) under the guidelines for the trans-European energy infrastructure (TEN-E) and will thus be eligible for European funding. Generally, such project benefits at least two Member States; contributes to market integration and further competition; enhances security of supply; and reduces CO_2 emissions. This particular PCI has been defined as a 150km pipeline with a capacity of 4.4 MCM/day from Sicily to an offshore storage unit in Malta, and a 12 km pipeline from this unit to Delimara [11]. Additional gas supply would allow for the remaining oil-based electricity generation capacity at Delimara to be converted to gas, while additional electricity generation capacity at the Delimara site would require substantial upgrades of the electricity distribution networks.

3.7 Future of Renewables

Malta's NREAP (2020 renewables targets) needs to be revised for various reasons. On the upside, photovoltaic capacity has increased beyond the plan. While less than 20 MWp worth of PV capacity had been operational in Malta by the end of 2012, over 55 MWp had been authorized (including operating ones) by the end of 2013, suggesting that well over 60 MWp will be up and running by the end of 2014.

Wind power, on the other hand, will lose the prominent role it was assigned in the NREAP. If imported biofuels are excluded, offshore wind is supposed to cover nearly half the planned generated renewable energy, even though the proposed project involves several problems. Notably, it has been demonstrated that the offshore wind plant as proposed generates electricity at a cost that is substantially higher when compared to electricity generated from onshore wind and PV installations in Maltese settings [6].

The profound changes in the Maltese fossil power sector have put wind at even greater disadvantage. Since the new 215 MW gas power station will be financed by a private-sector investor, minimum power purchases close to Malta's base load of ca. 160 MW may be required. While PV installations deliver all their output during daytime, wind power generated during night time would be difficult to integrate, unless the excess energy is either exported through the interconnector, or stored.

3.8 Energy Storage

Large shares of PV electricity and the integration of wind power would be possible through energy storage investments. Energy storage considerations within this study have focused on large-scale options that may store energy for several hours. As pumped hydro storage (PHS) is usually the preferred choice where geography allows it, it was investigated if seawater pumped hydro storage is well established, and if any corrosion problems due to the use of sea rather than fresh water have been reported. However, the plant at Okinawa, Japan, is still the only one of this kind operating anywhere in the world [12]. In Malta, a quarry location at the steep western coast could serve for a pumped hydro storage facility (Figure 11). Using the sea as lower reservoir, the depicted quarries area with an average reservoir depth of 30m could store water worth about 2.7GWh of electricity.

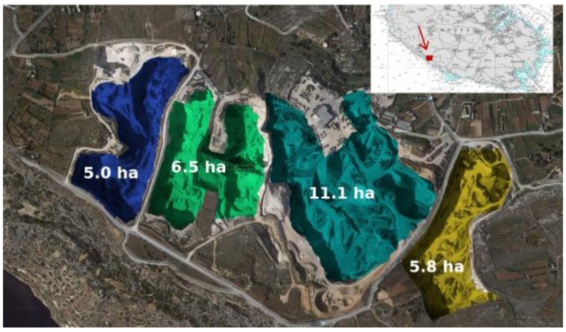

Figure 11: Potential pumped hydro storage facility location.

Subsea Pumped Hydro Storage (SPHS) has been found to be a concept that relates to the deep waters around Malta and could be combined with pumped hydro storage to utilize the pressure head between sea surface and sea floor [13]. Another, comparatively more mature technology that was identified to fit Malta's geographical settings, is Ocean/Offshore Compressed Air Energy Storage (OCAES). OCAES works similar to traditional CAES, but utilizes the pressure prevalent at great depths in oceans [14,15]. Two distinct regions in the waters around Malta have been identified where OCAES might be feasible. Both are relatively close to the coast (less than 20km) and show water depths beyond 600m. This is relevant, because underwater air bags working under constant pressure optimally would need a pressure of 60 bar (600m depth) to facilitate plant round-trip efficiencies of ca. 70%. Distances of less than 20km mean that no floating station is required. The generator, pump, etc. can be located onshore, and air pipes are connected to the underwater air bags, while no subsea electricity cable is required. To be sure, only small prototypes exist, but the cost of such installations should be relatively low.

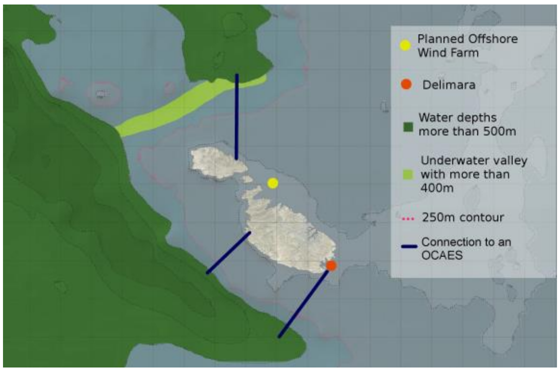

Figure 12: Ocean Compressed Air Energy Storage: suitable areas in relation to the Maltese islands.

To recover investments into any storage capacity, the facility can be used to support electricity trade with Sicily in the context described in section 3.4. As a matter of fact, it was found that investment into storage capacity could replace investment into generation capacity that will become necessary under investigated demand scenarios once the older parts of Delimara power station will retire. (This is in absence of additional interconnector capacity.) And notably, storage infrastructure would allow for intermittent renewable electricity capacity to be integrated on a large scale.

Figure 13 shows a 2030 scenario that involves a PHS facility with a capacity worth 320MWh of electricity (relating to the total wind capacity in the current NREAP) and a round-trip efficiency of 85% (Power in/out: 80MW). The ElectroGas plant capacity was taken as 200MW (not 215MW) in this scenario, and the parts of Delimara capacity that would be older than 25 years were taken as decommissioned. Annual 2030 demand was taken as 3.557 TWh, based on a growth scenario starting from the official 2020 demand projection, while the daily demand curve was based on the 2012 pattern. The result for the shown day was a 127% PHS utilization (100% equals one full charge and discharge), with charging (reservoir filling using electricity from the interconnector or from Maltese gas plants) in early morning, discharge later in the morning, charge in the afternoon, and discharge in the evening.

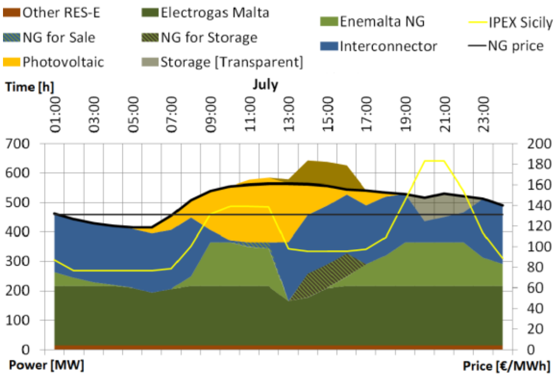

Figure 13: July day 2030 scenario for a setup that includes a pumped hydro storage facility. See main text for assumptions.

4 CONCLUSION

This study has clearly shown and quantified that the upcoming power sector setup, characterized by a shift from oil to gas and an interconnection to Sicily, will substantially reduce carbon emissions associated with Malta's electricity consumption, and thus also significantly lower the total national carbon footprint. Electricity generation cost will decrease radically. Modelling results to establish the extent of electricity trade through the interconnector involve high uncertainties and various assumptions. Integration of large shares of intermittent renewable energy, especially of wind power, would require storage infrastructure. The model results indicated that investments into storage capacity can support trade through the interconnector and replace investments into further electricity generation capacity.

The views expressed in this publication are those of the authors and are not necessarily shared by any organization the authors are affiliated with.

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