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Energy scenarios for Malta☆

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ABSTRACT

Many island power systems are powered by diesel generators or long underwater cables, which result in greater operating costs or losses than stand-alone systems. It is therefore desirable to integrate renewable energy (RE) sources into these mini grids.

The main objective of the paper is to describe, analyse and present a more unified approach for assessing the technical feasibility/potential of different energy scenarios for the islands of Malta. In this study, three different scenarios are analysed. Integrating RE sources (RES) in energy systems reduces losses, cuts fossil fuel consumption whilst maintaining system stability and increasing job opportunities. Hydrogen conversion and storage methods are also analysed as a method for greenhouse gas (GHG) reduction in the transport sector and as a way to reduce excess electricity produced from RE.

1. Introduction

As discussed in the Kyoto Protocol, different nations agreed and ratified the protocol in order to reduce the GHG emissions. The European Community undertook to cut its GHG emissions by 8% of 1990 levels over the first Kyoto Protocol (KP) commitment period (2008–2012) [1]. Different ways exist to achieve this, amongst these are the efficiency improvement of fossil fuelled generating plants and the introduction of energy form renewable sources. Malta ratified the Kyoto Protocol and has to abide to the Directive on the Promotion of Renewable Energy (2001/77/EC). Malta's stated target under this directive is to generate 5% of its electricity from RE sources by 2010 [1].

Malta's situation is quite particular with a high population density, limited available land space and an ever increasing electricity demand. Aiming to provide 100% electrical energy from renewable sources is difficult to achieve and too costly. However, attention to generation technology, transmission and end use efficiency will greatly attribute to a sustainable environment apart from fulfilling our international obligations. In order for this to be achieved, there has to be a broad understanding of what the mechanisms for addressing it entail, continuously backed up by political will and scientific

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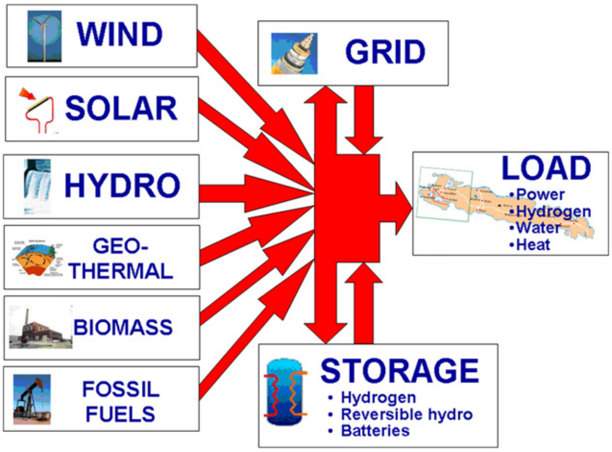


Fig. 1 – H_2RES model v 2.6.

findings. In its Green paper on efficiency, *Doing more with less* [2], the European Commission together with the Directorate-General for Energy and transport stresses the importance that ''An energy-efficiency initiative has wider implications'', one that ''constitutes a major contribution to reduction of our energy dependency on third countries''.

2. H_2RES model

The H_2RES model (Fig. 1) [3] is designed for balancing between hourly time series of water, electricity, heat and hydrogen demand, appropriate storages and supply (wind, solar, hydro, geothermal, biomass, fossil fuels or grid).

The main purpose of the model is energy planning of islands and isolated regions which operate as stand-alone systems, but it can also serve as a planning tool for single wind, hydro or solar power producers connected to bigger power systems. Wind velocity, solar radiation and precipitation data obtained from the nearest meteorological station are used in the H_2RES model. The wind module uses the wind velocity data at 10 m height, adjusts it to the wind turbine hub level and, for a given choice of wind turbines, converts the velocities into the output. The solar module converts the total radiation on the horizontal surface into the inclined surface, and then into the output. The hydro module takes into account precipitation data, typically from the nearest meteorological station, and water collection area and evaporation data based on the reservoir free surface to predict the water net inflow into the reservoir. The biomass module takes into account the feedstock information, the desired mix of feedstock, conversion processes (combustion, gasification and digestion) and desired output production (power, heat or

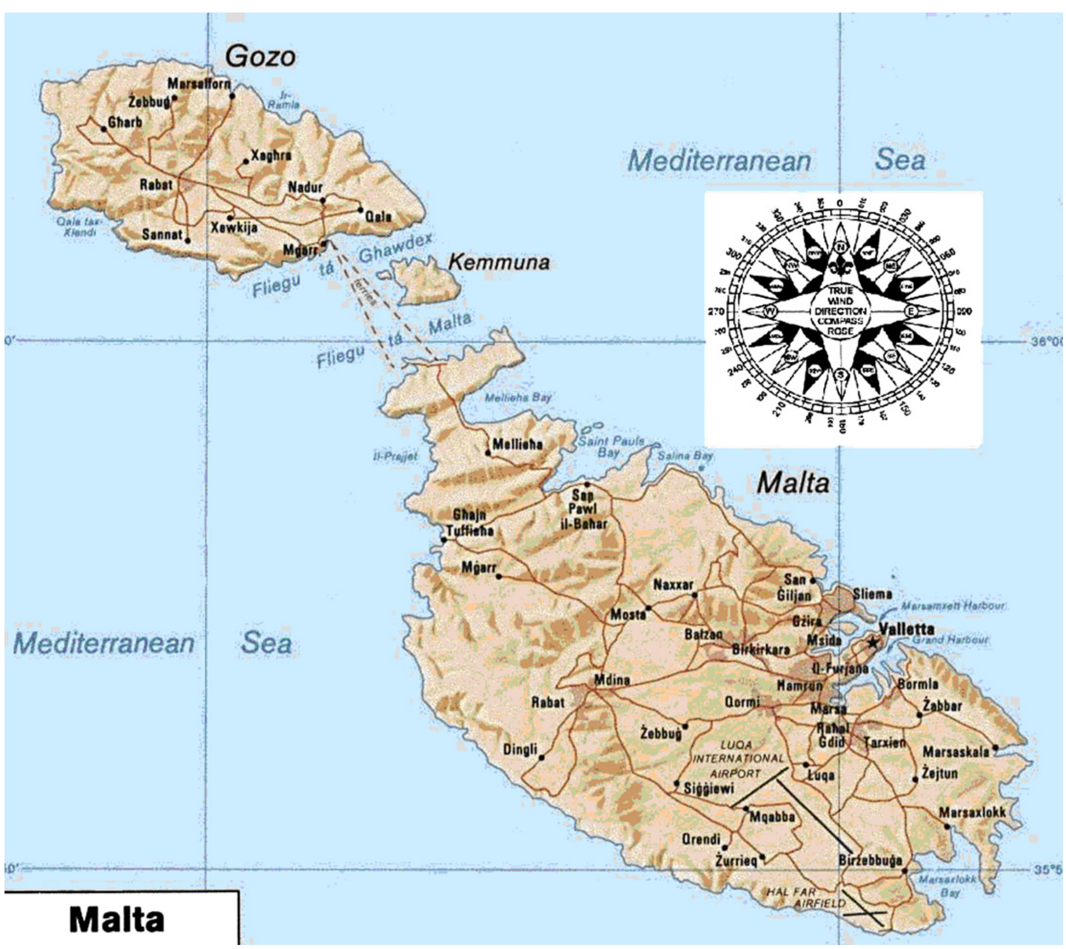


Fig. 2 – Maltese archipelago main islands.

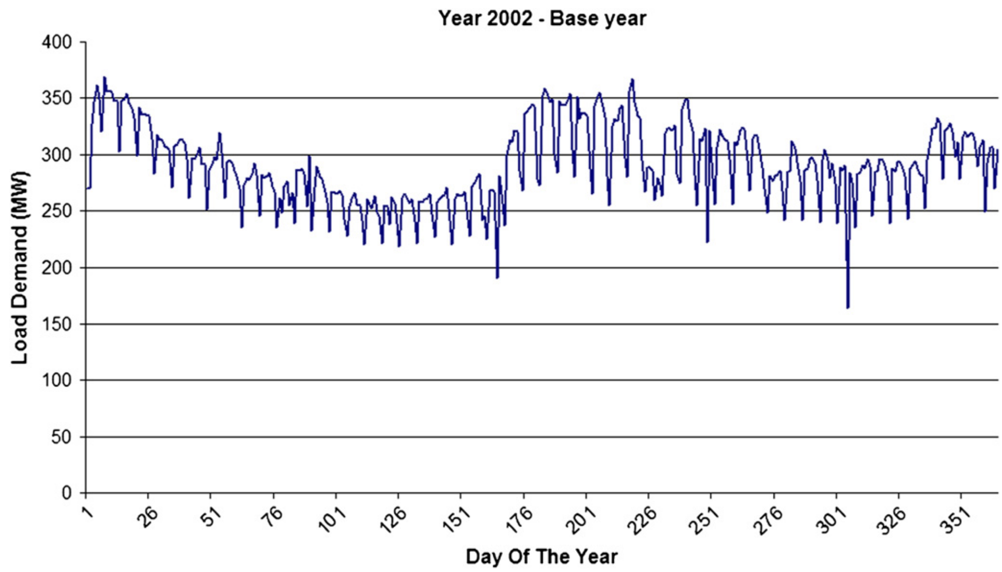


Fig. 3 – Daily load variation.

combined heat and power). Biomass module is set to follow the heat load and it generates electricity as by-product. This module has ability to calculate the minimum and maximum potential energy outputs in order to make optimization of production according to unwanted shutdowns. The minimum is a factor between the installed capacity and the minimum load factor. This assures that the unit never goes below minimum design. If the available energy is below this, it shuts off. The maximum also depends on the available energy but it is reduced based on the guaranteed production days. The geothermal module functions in continuous, where the installed power generates electricity for the system continuously, except when it is in maintenance. The system primarily uses the electricity produced from geothermal source in detriment of the other power sources, because this is a safe source, not intermittent. H_2RES allows managing the amount of electricity produced from geothermal that enters in the grid and the one that goes for storage. This becomes very useful when intending to use the geothermal potential for hydrogen production for transport. The load module, based on a given criteria for the maximum acceptable renewable electricity in the power system, integrates a part or all of the available renewables output into the system and discards the rest of the renewable output. The excess of renewable electricity is then stored either as hydrogen, pumped water or electricity in batteries, or for some non-time critical use. The energy that is stored can be retrieved later and supplied to the system as electricity or hydrogen for transport purpose. If there is still unsatisfied electricity load, it is covered by fossil fuel blocks or by the mainland grid where such connection exists. The model can also optimise the supply of water and hydrogen demands.

The order of sources in supplying of demand could be easily set up according to criteria. In most cases, geothermal energy is first taken, then biomass and then the rest of renewables. Currently, the model does not support the automatic choice of sources according to minimal cost of electricity or according to minimal environmental pollution.

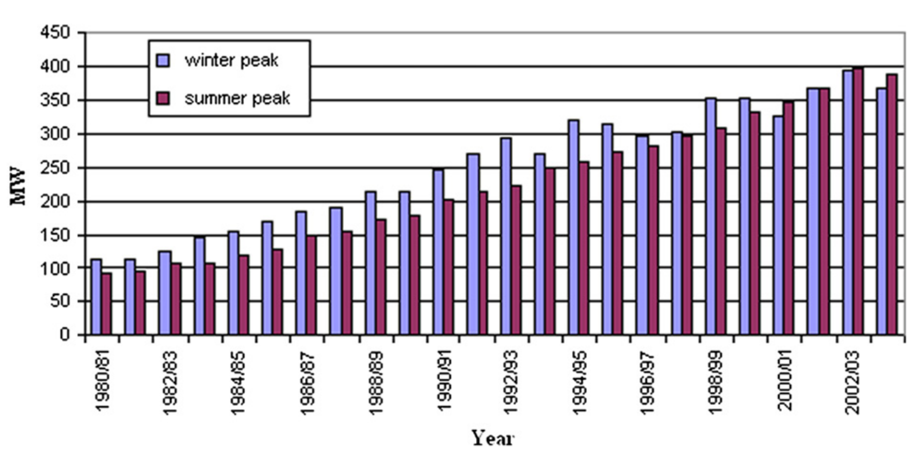


Fig. 4 – Winter and summer yearly peaks.

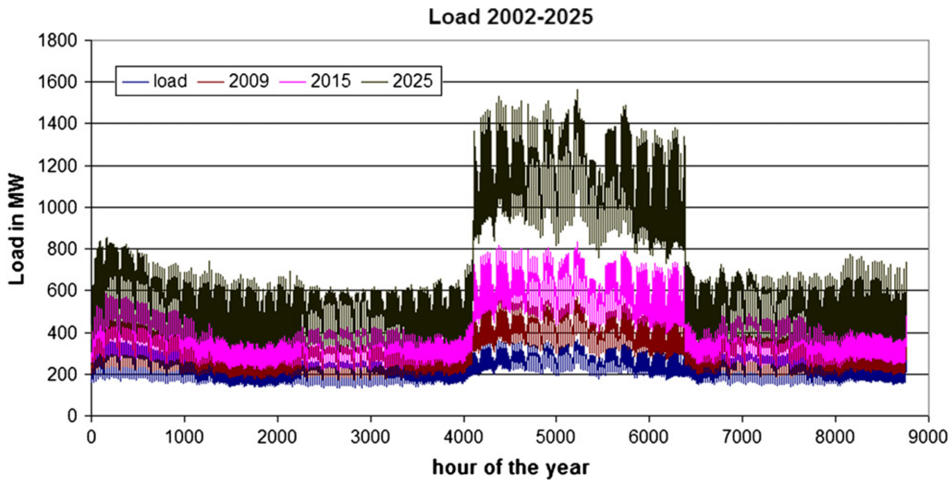


Fig. 5 – Load projections.

There are two abilities of H_2RES that make it specifically suited for islands: it can manage the water supply and consider hydrogen load for other than power supply. The hydro module allows managing potable water demand and excess energy storage at the same time, using pumping as a deferrable load and considering pumped potable water as storage for reversible hydro power. Hydrogen has been seen as a new energy vector and can be specially suited for islands and remote regions, when produced in a renewable way, because it increases the security of supply and opens the renewable market for other areas, as for instance transport.

For islands lacking fresh water, there is the possibility of developing a new module based on desalination to be associated to the hydro module. In the current version desalination can be treated as deferrable load, but there is no link between it and water storage module.

3. Malta

The Maltese archipelago is centrally located in the Mediterranean Sea and comprises six small islands. The main islands are Malta, Gozo and Comino (Fig. 2) all of which are inhabited, while the islets of Filfla, Cominotto and St. Paul's Islands are uninhabited.

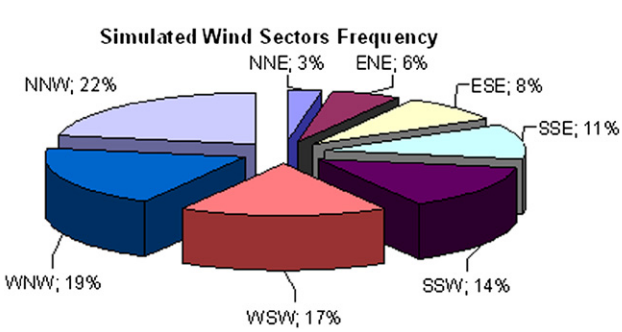


Fig. 6 – Frequency of the simulated wind directions.

The Maltese islands cover a total area of 320 km^2 with a total coastline perimeter of approximately 140 km. Malta's geographic co-ordinates are 35 50N and 14 35E. Malta is 93 km south of Sicily and 290 km north of the African Continent. Malta's land area totals 246 km^2. The general topography of the island can be described as a series of low hills in the northern area which give way to terraced slopes and plains as one moves to the south. It is mostly low, rocky, flat to dissected plains and with many coastal cliffs. There are no mountains or rivers.

Gozo is the second largest island and lies about 6 km northwest of Malta. The total land cover is about 67 km^2 with a coastline perimeter of 43 km. The topography is similar to that of Malta [4].

With a current population of almost 400 000 Malta has one of the highest national population densities in the world. The present population growth rate is in the range of 0.75% according to UNFCC report [5]. This small annual increase in the net population is primarily sustained by high life expectancy and a low emigration rate. Furthermore, population density is accentuated by the annual inflow of tourists, which is equivalent to about 30 000 additional residents mainly during the summer months.

The climate of the Maltese archipelago is normally described as typically Mediterranean, with moist, mild winters and dry, hot summers. The average annual precipitation is about 530 mm and is mainly restricted to very short periods in the autumn and winter. The air temperature generally ranges between 9.5 °C and 33 °C. The hottest period of the year runs from mid-July to mid-September and the coldest months are January and February. The sea temperature varies in conformity with the air temperature, with a yearly mean of 20 °C.

Agriculture accounts for about 3% of the GDP and employs 2% of the total workforce whilst fishing plays a very limited role in the Maltese economy. Possessing few indigenous raw materials and a very small domestic market, Malta has based its economic development on the promotion of tourism and labour-intensive exports.

Malta has no indigenous conventional energy sources. The production of primary energy in Malta is fossil fuel based. The

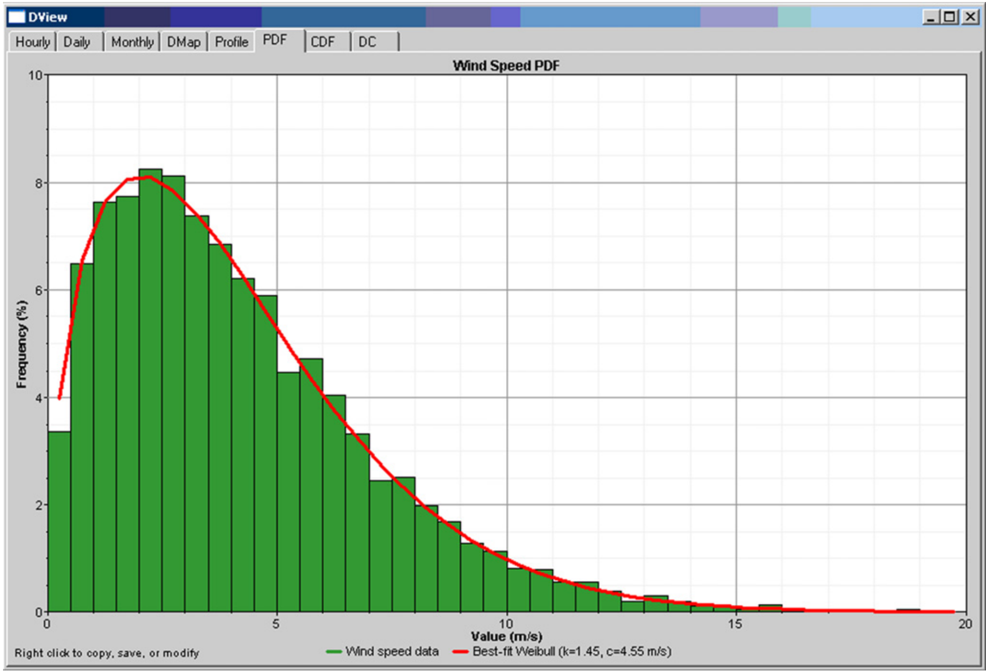


Fig. 7 – Wind speed distribution function using Homer software.

Maltese national electricity grid is an isolated one and is not connected to any other electrical network. Therefore, all the electrical energy that is required is generated in Malta. This is carried out by Enemalta Corporation (EMC). Electricity is generated by two inter-linked power stations, one at Marsa on the eastern part of Malta and a more recent plant at Delimara on the southern coast with a total combined nominal installed capacity of 571 MW (2004). The generators operate at different levels of efficiency. The main user of electrical power is the domestic sector (36%), followed by the commercial sector (30%), the industrial sector (25%) and the water production sector (9%) [5]. The cost of imported fuel for energy represents most of the country's total domestic exports. Therefore, it is obvious that energy is of vital importance to the island's economy and that the cost of imported energy is and will continue to be an increasing burden on the economy of the country.

The daily electricity demand for the Maltese islands exhibits a profile that is typical of the Mediterranean area. Peak demand in winter is during the evening and is therefore predominantly domestic. In summer the peak demand occurs during the morning and therefore predominantly commercial and industrial. The overall yearly peak occurs in summer as seen in Figs. 3 and 4. This may be attributed to the influx of tourists mentioned earlier.

The total carbon dioxide emission for 2004 was 1 145 744 tons from Marsa power station and 875 503 tons from Delimara Power Station [6].

4. Growth rate determination and future load prediction

Projections as to future load growth are based on extrapolations of electricity demand from historic data over the base period 2000–2004. This study load projection uses a ''trend method'' technique. In this method, the variable to be predicted is purely expressed as a function of time, rather than by relating it to other economic, demographic, policy and technological variables.

Different growth rate scenarios were analysed in this paper. These varied from yearly to seasonal, daytime to night-time and working days to off days. However, after an evaluation of all the results it was decided to model the system with two growth rates, one for the summer period and

Table 1 – Recorded wind speeds

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Avg.
1961–1970	5.30	5.35	5.40	5.35	4.73	4.17	3.40	3.40	3.50	3.55	4.32	5.40	4.50
1971–1980	4.99	5.56	5.40	5.66	4.73	4.58	3.96	3.81	3.96	4.27	4.73	4.89	4.71
1981–1990	5.35	5.04	4.99	4.89	4.53	3.96	3.50	3.50	3.60	3.66	4.53	4.73	4.36
1991–1994	4.32	5.14	4.78	5.14	4.27	4.37	3.50	3.04	3.45	4.32	4.01	4.58	4.26
1961–1994	33-Years overall average in m/g												4.46

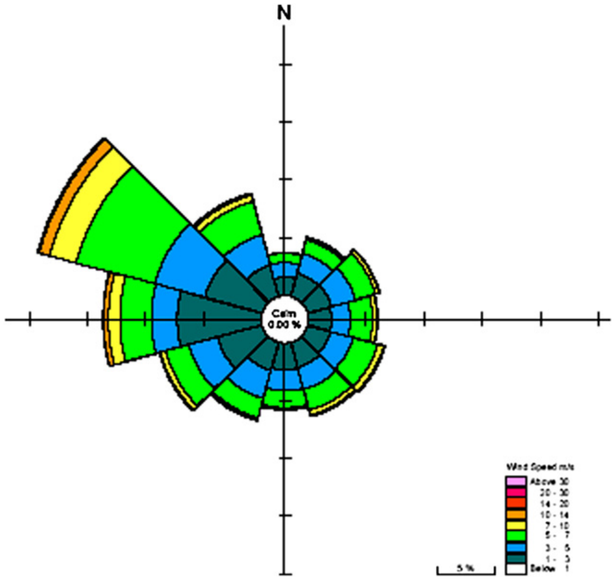


Fig. 8 – Wind rose for the Maltese islands [7].

one for the rest of the year. The yearly load growth rate demand for the coming 10-year period was set to be 6.5% for the summer period whilst that for the rest of the year was set to be 3.73%. Thus the overall annual average works out to 4.4%.

A base year in order to model the growth was chosen to be the most regular year over the last period. This was year 2002. H_2RES load module was used to extrapolate the peak load for the year and the load demand for the coming years until 2025. Projections of total demand over the period 2005–2007 are 7 478 535 MWh compared to Enemalta projections of 7 317 358 MWh [1].

Fig. 5 is the predicted load demand till the year 2025. Four years are shown, 2002 being the reference load year and the other three, 2009, 2015 and 2025 being the projected ones.

5. Assessing wind and solar energy potential

First and foremost, when deciding to introduce RES, one has to analyse the technical potential and limitations of the technology available and climatic conditions. In order to assess RE scenarios in Malta, it was necessary to analyse the wind and solar energy potential. Various organisations monitor these in Malta amongst which ''Malta Weather Services'' has the largest database and was the most willing to provide information.

Meteonorm simulation tool was used to obtain the yearly hourly data. This provides 8760 h of wind speeds and directions. After performing all the necessary simulations, the results were cross-checked and analysed. Some results are presented in Figs. 6 and 7.

Table 1 indicates the average actual mean monthly wind data for Luqa Airport obtained from Malta weather services in m/s at 10 m height at Luqa yielding to an average of 4.46 m/s over a 33-year period. It is important to consider that due to the sheltered location of the inland station, a certain attenuation results in the wind speed measurements especially the prevailing NW wind.

This average wind speed is a function of height. Thus one would expect higher wind speeds at higher altitudes.

Another very useful study is a report prepared by Scott and Wilson for Malta Maritime authority [7]. In this report: ''Malta Significant Wave height study'', the offshore and onshore wind roses (Fig. 8) are presented. The NW and WNW prevailing wind directions could be easily seen. The average wind speeds according to the wind direction are also possible to configure.

The analysis and comparison of the simulated results concluded that the predominant wind is the NW wind (Majjistral) which is due to the strong heating of the Sahara desert where the ascending hot air has to be replaced by the inflow of air masses from Europe. Its direction is nearly parallel to the geographical orientation of the Maltese islands which also

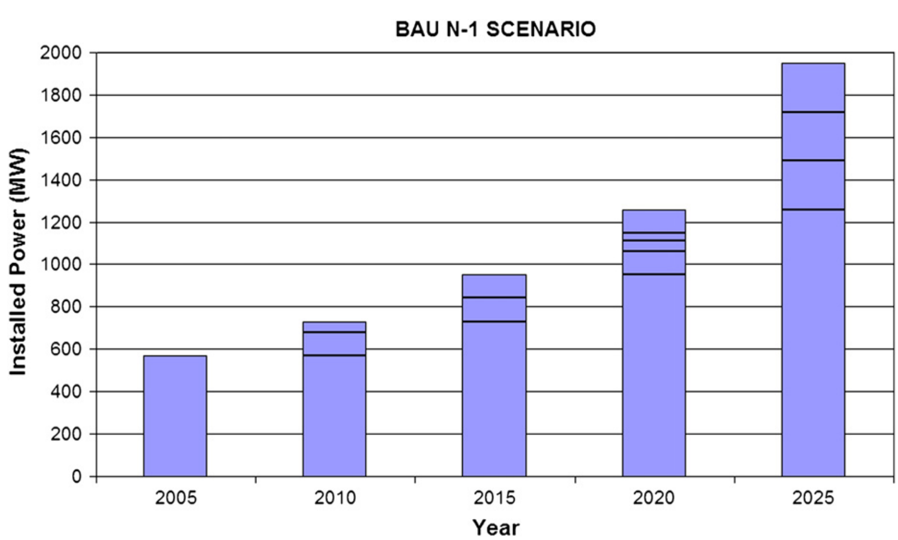


Fig. 9 – Blocks needed to be installed in a BAU N-1 scenario.

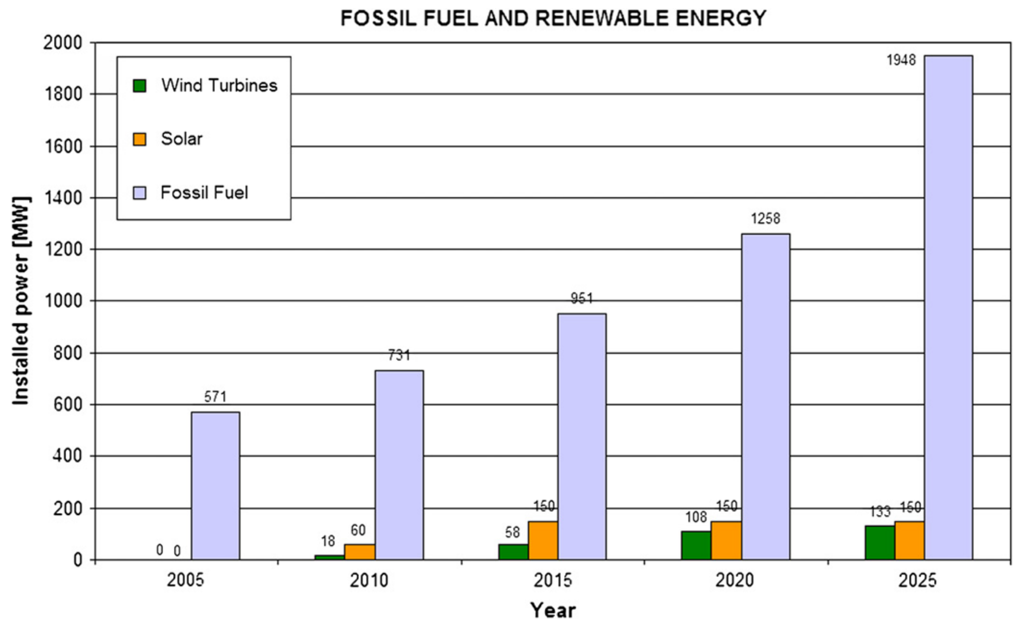


Fig. 10 – Fossil fuel and RE blocks in scenario 2.

extends from NW to SE. This wind direction is a determining factor for the best location of wind turbines. Another strong but less frequent is the North Easterly wind. The results obtained confirm the simulated wind directions in Malta. Sites having a mean wind speed of 6.9 m/s at 50 m above ground level have been identified as good locations for wind power generation [8]. This roughly corresponds to a wind speed of 6.01 m/s at 10 m height for a roughness class of 0 m/s and 5.27 m/s for a roughness class of 1.5. Simulated data and available data show an average of about 4.12 m/s and 4.46 m/s, respectively, at an inland station at 10 m height. Applying a multiplying factor of 1.15, to an average of 4.29 m/s, which is adequate to transfer inland data to coast would result in an average wind speed of 4.93 m/s. This wind average value is encouraging enough to further consider it.

6. The scenarios

Different scenarios can be simulated using the H_2RES model; however, it was decided to model three different situations varying from a practical situation to a near future situation and finally to an almost theoretical situation.

Case 1 *Business as usual scenario* is a situation guided by existing local government policies in which no change in current generation technology is used. This involves the analysis of the investment and upgrading necessary in order to cater for the load demand up to year 2025. This analysis assumes an N-1 situation in which it is assumed that at any time there will be one generating block, equivalent to the biggest block, either in maintenance or stand by mode.

Case 2 *Fossil fuel and low level penetration of wind and solar scenario*. It is correct to say that power coming from RE up to 30% will not greatly affect or disturb the synchronous operation of a generating system. A low and practical level of renewable penetration, apart from fulfilling our EU Directive on the promotion of energy produced from RE sources, also implies that there will be no excess energy produced. Thus all wind energy produced will be supplied to grid with no storage

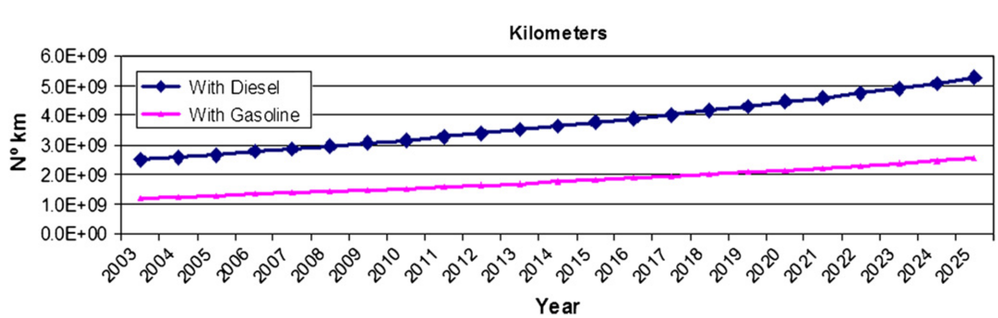


Fig. 11 – Estimated increase in km traveled by cars.

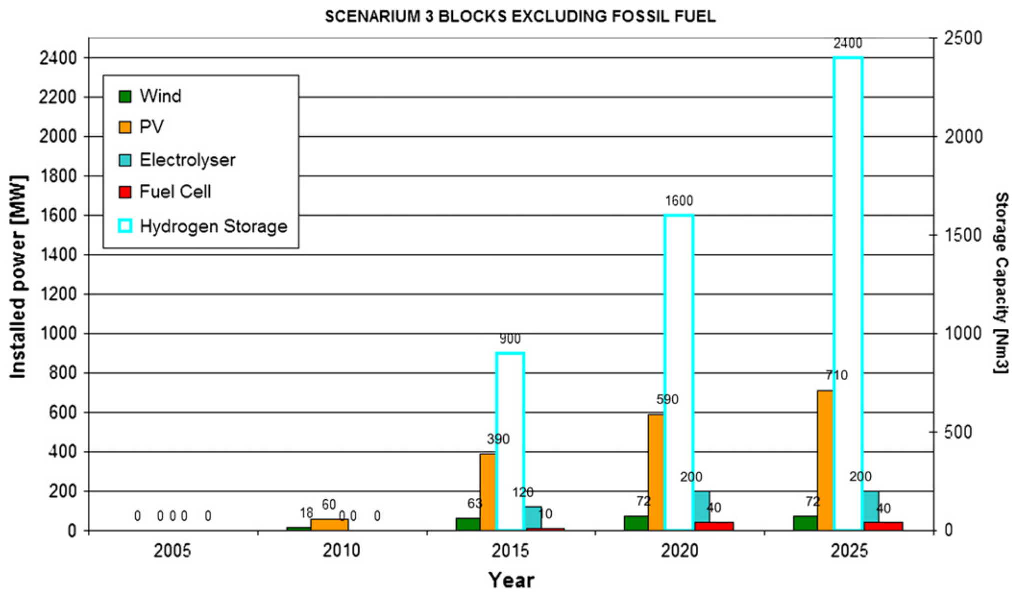


Fig. 12 – RE for transport and electricity.

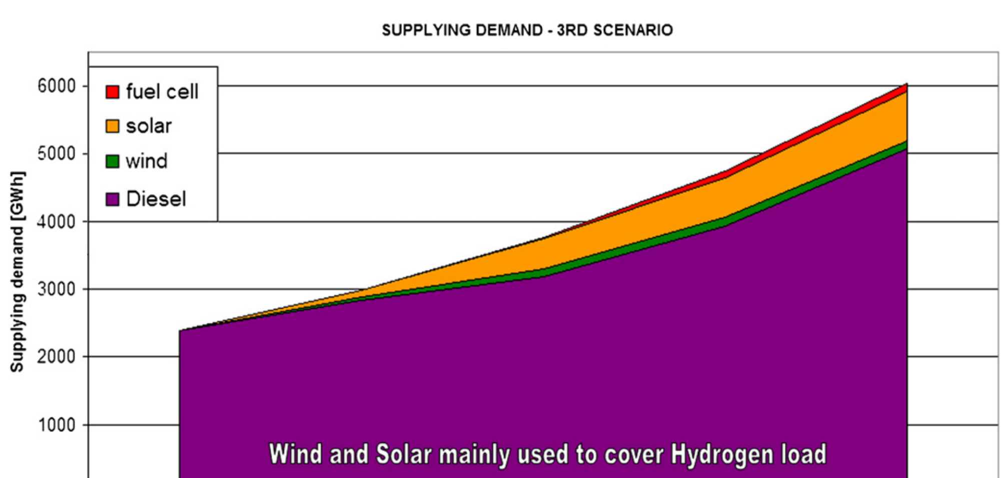
necessities. Thus, this scenario will try to meet the 5% target of electricity produced from RE sources set in the Accession Treaty of the EU Directive on the promotion of electricity from RES. This 5% is further increased above 10% by 2015 and maintained so until year 2025.

Case 3 *Fossil fuel, RE and hydrogen storage scenario for the transport sector*. This is a scenario introducing a hydrogen load to be used by road transport. This is produced from wind and solar sources satisfying a 5% transport energy demand in 2015. RE will be directly converted to hydrogen in order to cover the necessary load to be used for transport. Excess intermittent energy is supplied to grid via fuel cells provided a certain security of supply is reached.

7. Results for the scenarios

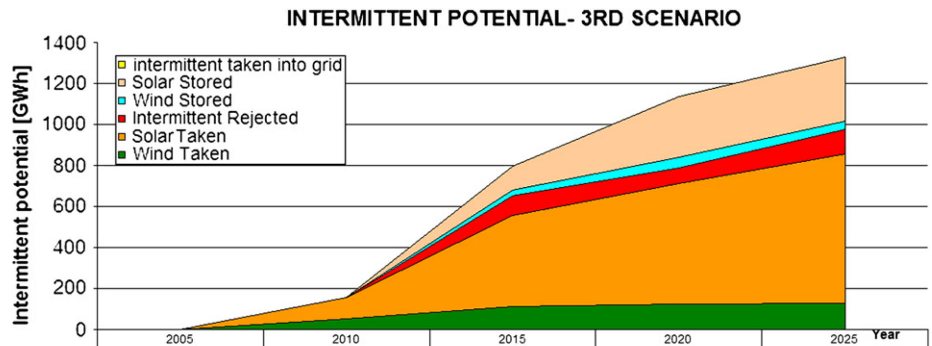
7.1. Case 1: business as usual (BAU) scenario

Results depict, with the simulated load growth demand, the necessary generation investment. A capacity shortage will start to be experienced in 2006 if no investment is effected.



Year	2005	2010	2015	2020	2025
fuelcell	0	0	13490118	103764813	104819571
solar	0	102319878	443085213.4	588289591.1	730154065.1
wind	0	51841505	113267166	123210968	126243560
Diesel	2381600345	2831815180	3188516555	3934473847	5066514882

Fig. 13 – Supplying demand for a case 3 scenario.



	2005	2010	2015	2020	2025
intermittent taken into grid	0	0	0	0	0
Solar Stored	0	0	115241186	298578927	308795324
Wind Stored	0	0	29907814	50715573	42728676
Intermittent Rejected	0	0	94419239	76161877	118104651
Solar Taken	0	102319878	443085213	588289591	730154065
Wind Taken	0	51841505	113267166	123210968	126243560

Fig. 14 – Intermittent potential case 3 scenario.

This percentage shortage will continue to grow then on upto 11.72% in the year 2015. This shortage in generation capacity, in this scenario, can be resolved by installing different fossil fuel blocks as shown in Fig. 9 every 5-year period.

Period 2005–2010 involves the installation of two fossil fuel blocks, 110 MW and 50 MW, respectively. This has to be further extended by adding two more blocks in the period 2010–2015 consisting of 2×110 MW. For period 2015–2020, four blocks have to be added consisting of 2×110 MW, 1×37 MW and 1×50 MW. Finally for period 2020–2025, three blocks of 230 MW each have to be added. Ideally these blocks should cater to best fit the situation, i.e. a bigger combined cycle gas turbine to offer higher efficiency and small-sized gas turbines to offer immediate electricity generation during peaks.

7.2. *Case 2: fossil fuel and low level penetration of wind and solar scenario*

This scenario aims to fulfil the Accession Treaty of the EU Directive on the promotion of electricity from RES, i.e. to produce 5% of total energy from renewables by 2010. This percentage is achieved by the installation of 18 000 kW of wind turbines and 60 000 kW of PV panel leading to a 2% and 3% of RE produced, respectively. This 5% is further increased to 11% by the installation of 40 000 kW more of wind turbines and 150 000 kW of PV in 2015. Great care must be taken in this respect. One has to consider the maturity of the technology used together with the levels of penetration in order not to introduce unacceptable frequency fluctuations. A 30% instantaneous penetration of intermittent renewables were used. The 2010 figures are achieved by the installation of 10×1.8 MW wind turbines and 60 000 kWp PV. This is further increased to include 20×2 MW wind turbines and 40 000 kWp PV. The Vestas V90 WT, capable of providing high output in modest winds, was used in the simulation. An overall efficiency of the PV system was set to 11%, however, this is expected to increase with current studies and research in the field. Such levels of PV percentage though at first instance might seem too much, is actually being achieved and planned. Such a project with a 62-MW PV plant is in planning process in Portugal [12]. The 2–3 MW wind turbine range technology is the most mature technology in this field and was thus chosen as the

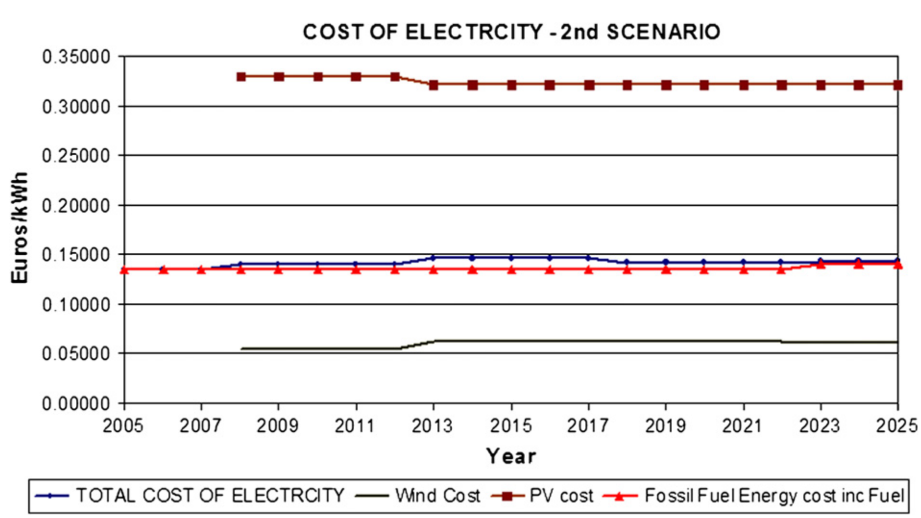


Fig. 15 – Cost of electricity scenario 2.

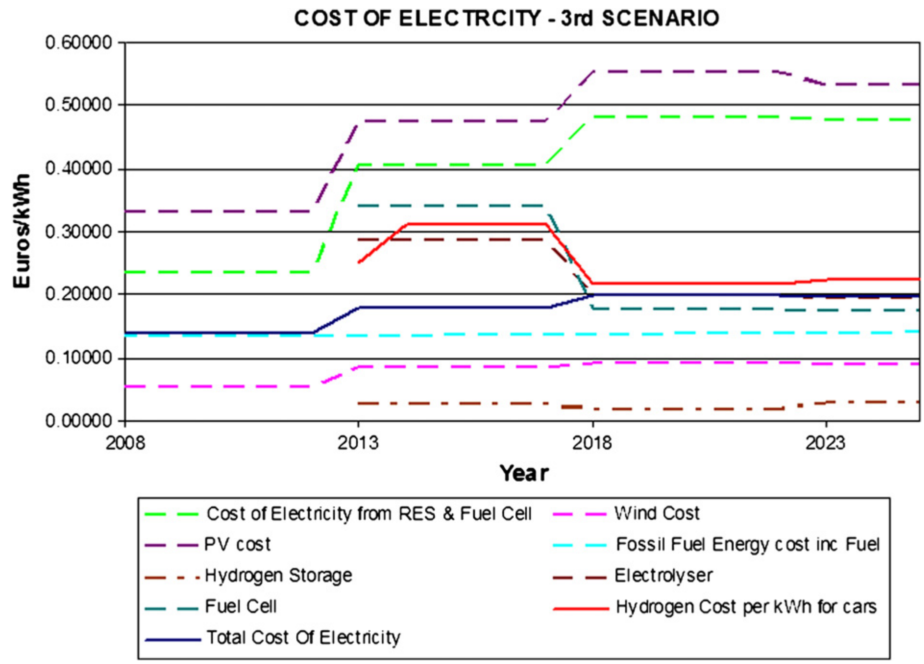


Fig. 16 – Cost of electricity scenario 3.

wind component. Period 2015–2020 involves the installation of ten 5 MW turbines which would have matured by that period and other five 5 MW turbines in period 2020–2025. No PV panels are added during these last two periods (Fig. 10).

On analysing current RE technology prices, one realises that PV panels are much more expensive than wind turbines. However, one must be aware that for such a small island like Malta with deep waters around, a higher level of PV is inevitable unless wind turbine technology matures in deep offshore installation. Furthermore, peaks usually occur in summer during which winds are not as favourable as they are during the rest of the year.

7.3. *Case 3: fossil fuel, RE and hydrogen storage scenario for the transport sector*

The necessary blocks in order to obtain 5% of transport energy from RE by 2015 and 10% by 2025 are presented in

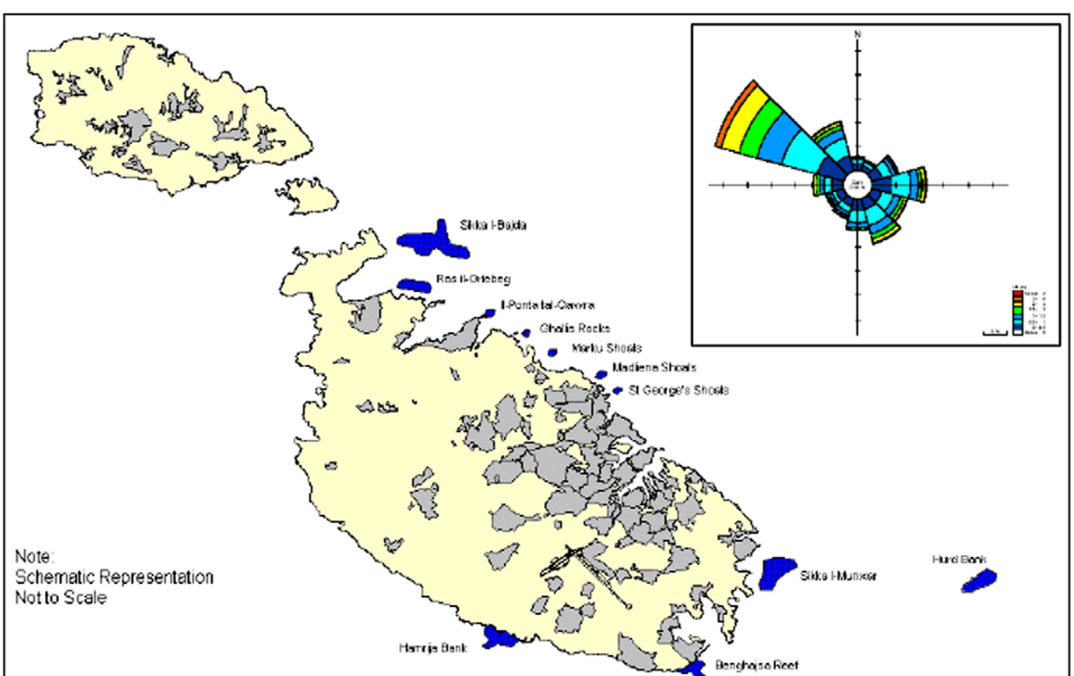


Fig. 17 – Shallow offshore sites suitable for wind energy production [11].

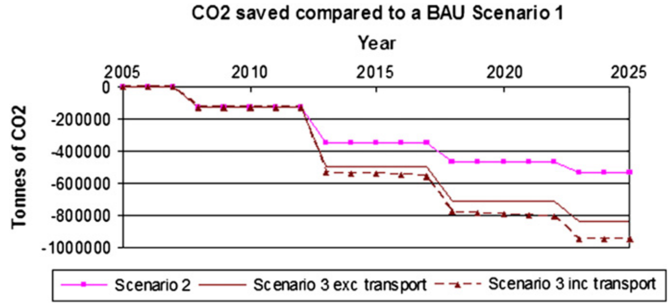


Fig. 18 – Carbon dioxide emission saved.

Figs. 12 and 14. In determining the hydrogen amounts necessary to fulfil the set targets, a growth rate was worked out using figures extracted from the 10-year period 1990–2000 [9]. This growth rate (3.4%) was then applied to the 2003 values, 90 ml of petrol and 90.40 ml of diesel (Fig. 11) [10].

In order to keep the rejected energy within a 10% bracket, fuel cell blocks had to be integrated in the system which would operate when excess hydrogen is produced, provided a security of supply of 240 h is stored. The 10-day security of supply was chosen so as to balance the need for security and the size of the storage. The net effect of the energy supplied to the grid by the fuel cells is negligible (Fig. 13), however, this was done to minimise the rejected energy. A rejected energy of less than 10% was imperative in the results. Utilising all of this energy is quite impractical when opting for a high level of RE. The blocks of fuel cells were chosen such that a minimum operation of 1500 operating hours was achieved. This ensures correct figures in wattage and numbers. Similarly, in choosing the size of blocks it was ensured that adequate period of operation was reached.

8. Financial anaysis

Different electricity generating cost models exist, the common ones being Engineering Economics Approach and Capital Asset Pricing Model. The former, being based around the time of the Model-T Ford fails to accurately quantify fossil price risk, however, the latter though widely accepted for capital budgeting and project valuation have not for a number of historical reasons been adopted for electricity planning and cost estimation [13,14].

An engineering economics approach was used in order to calculate the cost of kWh. This was applied until year 2025 for every 5-year period investment. Furthermore, this was applied to all scenarios.

The necessary additional power that had to be added every 5 years in order to cover load demand was calculated using H_2RES. This was done until year 2025, i.e. a total of five, 5-year investments starting from year 2010. The cost of the additional generating blocks together with the related operation and maintenance costs was calculated for each year using typical average cost per kWh over the economic life of the project. The resulting series of annual cash flows were discounted by a discount rate (a rate used to convert future costs to their present value). Then, a mid period investment was used. Finally, in order to be able to compare all costs, all the costs were 'levelised' to year 2005 in order to be able to compare different scenarios. The transferred value of scenario 1 to year 2005 was 5578 Million Euros, followed by 5926 Million Euros for scenario 2 and finally 7220 Million Euros for scenario 3. Further more, typical cost per kWh was calculated for each year, using the payment values, in order to give an approximate cost of the generated energy. The payment function calculates the payment for a loan based on constant payments and a constant interest rate.

Fig. 15 shows the results obtained for a typical cost of 1500 €/kW of installed wind turbines, 5500 €/kW of installed PV and 1000 €/kW of installed fossil fuel plants. Excluding the fuel and old power plants, these were estimated to carry a 2% O&M costs and the discount rate was set to 6%. The old power plants were assumed to be paid by the past operation, however, their O&M was increased to 5%.

The results show an increase in the price of electricity attributed to the investment necessary in order to cover the load demand and the introduction of renewable energy sources. This positive price gradient turns into a negative one for the period 2020–2025 since some targets would have been reached. However, from year 2025 onwards, additional investment must be made in order to replace existing generating plants. This leads once again to an increase in price. Results also show that the net cost of wind energy is cheaper than that produced from fossil fuel (with fuel), which in turn balances out the expensive cost incurred by photo voltaic. The overall cost of energy including renewable sources results slightly higher than that by fossil fuel only.

The results per technology for scenario 3 are also presented in Fig. 16.

9. Implementation

Implementing RE scenarios in Malta is considerably challenging given the small land area and deep waters around the island which limit the possibilities. Some suitable sites for wind turbines were identified and are presented in Fig. 17. The application of PV panels to generate energy, though more expensive, seems to be more practical considering the usable area varying from houses, factories' roof tops, public buildings to building facades.

10. Conclusions

The results and necessary blocks implementation were presented for each scenario. The introduction of RE in a system has still to be backed up by fossil fuel generation in order to secure electrical supply. However, in order for Malta to contribute to the reduction of GHG emissions and global warming, inevitably some RE sources have to be introduced in a particular scenario. With an average of 0.873 tons of carbon dioxide emitted per MWh of electrical energy generated, Malta will be producing approximately 2 Million tons of CO_2 in 2005 going up to 5 Million tons of CO_2 in 2025 under a BAU scenario 1. The alternatively studied scenarios project a reduction in this emitted carbon dioxide as shown in Fig. 18. Car transport emissions are based on the assumption that an average of 0.20 kg of CO_2 is produced for every km traveled by cars. Under all scenarios, Malta will still surpass the expected CO_2 limit imposed.

RE sources in Malta have the potential to leave a remarkable positive effect leading to an economic growth and traditional barriers break down. Inevitably this has to be backed up by a demand side management structure. The need for an attractive legislative and financing framework is finally considered as the governments' role of promoting the efficient use of energy and the promotion of alternative energy resources. This will reduce fuel imports which are a great drain and a significant constraint on development since this crowd out vital capital and social expenditures and inhibit the achievement of much needed growth.

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