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PV roofs as the first step towards 100% RES electricity production for Mediterranean islands: The case of Cyprus

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ABSTRACT

The challenge of integration of large scale RES to islands seems infeasible when the islands have isolated energy systems without primary fuel sources, with limited sources of RES and without energy storage systems. Cyprus island is one of these cases, which covers 93% of the energy demand using imported fossil fuels. Building sector is the second biggest energy consumer accounting for 19% of the final energy consumption. A net-metering scheme is introduced recently to promote the installation of small PV systems in buildings. This paper therefore takes the approach of analyzing various scenarios for installation of PV roof systems in existing and future households of Cyprus island until 2050. The goal is to achieve 100% renewable energy production to cover the needs of the households sector. Results show that the electricity demand of the domestic sector can be 100% covered when over 70% of the existing residential stock install 3 kW roof PV system. Even if 50% of the existing residential stock install a 3 kW PV system the required capacity from other applications (eg. PV parks) to make domestic sector 100% renewable is 191 MW, which is feasible. To ensure a smooth transition to 100% renewable energy in all sectors, significant actions should be taken for the development of renewable energy systems, sector coupling, smart grid system planning and storage technologies. The present study examines only the potential of the further use of net-metering scheme in the domestic sector and discusses the barriers to full energy transition as well.

1. Introduction

Climate change affects the whole world increasingly during the last years. For this reason, there is an urgent need to implement worldwide policies and take actions towards the mitigation of greenhouse gas (GHG) emissions by the introduction of a transition of the energy sector towards renewables.

The Energy Efficiency Directive (2012/27/EU) of 2012 [1] introduced a set of obligatory measures to help the European Union (EU) to reach its 20% energy efficiency goals by 2020. This means that overall EU energy consumption should be no more than 1483 million tons of oil equivalent (Mtoe) of primary energy or 1086 Mtoe of final energy. This Directive specifies that all EU countries are required to use energy more effectively at all stages of the energy production and use, comprising energy generation, transmission, distribution and end-user consumption. The 2030 Climate and Energy Framework comprises EU-wide targets and policy measures applied for the period 2021–2030 [2]. The main targets for 2030 are; at least 40% reductions in greenhouse gas emissions (from the 1990 levels), the use of at least 32% of the energy coming from renewable energy systems and a minimum of 32.5% improvement in energy efficiency.

Lately, many countries or regions set targets for 100% renewable energy production. In 2019, Hansen et al. [3] presented the general perspectives for the use of 100% renewable energy systems (RES). The same group of authors studied also the energy system transition of Germany towards 100% renewable energy [4]. Their analysis demonstrates that this transition can be achieved from a technical and economic perspectives and that some measures are vital towards the achievement of this goal in a cost-effectively. The most significant challenge in this transition is considered to be the resource potentials, especially with respect to the use of biomass.

Currently Germany is leading the world with respect to renewable energy production - in fact during just the first half of 2018 it produced enough electricity to power all households of the country for the whole year [5]. Germany also set an ambitious

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Abbreviations

CS	Current Systems
EX	Existing systems
F	Future systems

target to cover 65% of its electricity needs from renewables by the year 2030. Because of its unique geography Costa Rica which is a small country has produced 95% of its electricity from renewables such as hydro, solar, wind and geothermal during the past four years. Moreover, the government of Costa Rica aims to be entirely carbon-neutral by 2021 [5]. Another good example is Uruguay, which is now almost 100% powered by renewables achieved after about 10 years of intensive effort. A new world record is achieved in 2017 by Denmark which produces more than half of its electricity from wind and solar power with 43% of its electricity consumption coming from wind parks – the highest fraction of wind power achieved worldwide so far. The country aims to be 100% fossil-fuel-free by 2050 [5].

A study performed for Ireland by Connolly et al. [6] presents the first steps to achieve a 100% renewable energy-system for the country. Aghahosseini et al. [7] studied the feasibility of 100% RES for the MENA (Middle East and North Africa) region until the year 2030. Kiwan and Al-Gharibeh [8] studied the 100% renewable electricity system in Jordan. In their work, a 100% renewable electricity supply scenario is considered and compared with three other scenarios, which contain a mix of various energy sources like, natural gas, nuclear, shale oil and renewable energy. This study considered techno-economic feasibility, security of supply, and CO_2 emissions and all scenarios considered were found to be viable. Kilickaplan et al. [9] presented an energy transition pathway for Turkey so as to achieve 100% renewable energy powered electricity, desalination and non-energetic industrial gas demand sectors by 2050. Sadiqa et al. [10] also studied the energy transition roadmap towards 100% renewable energy and the role of storage technologies for Pakistan by 2050. Weiss et al. [11] studied the 100% RES scenario for the isolated power system of Israel. Blakers et al. [12] studied the case of 100% renewable electricity in Australia declaring that energy storage and stronger interconnection between regions is necessary for stability.

The role of storage technologies for the transition to a 100% renewable energy system in Europe is studied Child et al. [13]. The same group of authors [14] studied also the transition pathways towards a 100% renewable energy power for Europe by 2050. They concluded that this is economically competitive, technologically feasible, and consistent with targets of the Paris Agreement. Zappa et al. [15] examined seven scenarios for the European power sector conversion by 2050, based on 100% renewable energy sources, by considering different levels of future demand and technology availability, and compare them with a scenario which includes low-carbon non-renewable technologies. Garcia-Olivares et al. [16] presented the various technologies and systems that are proposed or are proven as alternative to fossil-fuel based transportation They examined also their prospects for use in the post-carbon era, from both technological and energetic viewpoints.

For small islands the pathway to replace fossil fuels with RES up to 100%, so as to economically achieve energy security and limit temperature rise to as close as possible to 1.5 °C is presented by Chen et al. [17]. For this analysis, Jamaica was used as an example and it is shown that the introduction of intermittent renewable energy to the island's grid, which is electrically isolated, relying totally on itself for backup, causes serious frequency fluctuations and load shedding. Thus, they have carried out simulations to investigate the use of battery energy storage systems using Li-ion batteries. Other studies for 100% renewable island are carried out by Meza et al. [18] and Alves et al. [19] who declared that the integration of RES in islands is critical to achieve improvement of their economy allowing them at the same time to be energy independent. The latter study also considered an assessment of the impact of the grid interconnection of two small islands concluding that although these islands can increase significantly their RES penetration with lower costs, the complete elimination of fossil fuels' use can only be achieved by the interconnection.

It should be noted that in islands high RES integration presents opportunities but also constraints, because usually islands dependent exclusively on imported and costly fossil fuels to satisfy all their energy requirements [20]. Additionally, islands have isolated energy systems thus RES integration reveals also issues related to their variability and intermittent nature especially with respect to grid stability problems and mismatch between demand and supply. These become more critical as RES share increases. Alves et al. [19] investigated the potential of 100% renewable energy production in isolated islands Pico and Faial in Azores. The Energy Plan model is used and the scenario investigated was based on the interconnection between the two islands, which allows a complete elimination of fossil fuels in both islands. Thellufsen et al. [21] presented a methodology to design smart energy cities within the context of 100% renewable energy at a national level. The city examined with this methodology is Aalborg. Xiufeng et al. [22] developed a whole-system approach and explores optimal pathways towards 100% renewable energy by 2050 for Ireland. Various scenarios were examined and results showed that focusing on renewable penetration without considering carbon capture options is less cost effective in carbon mitigation compared to decarbonization targets.

Duic et al. [23] examined the case of Porto Santo, to increase renewable energy supply. More specifically, the study describes the H_2RES model optimization of integration of hydrogen usage with intermittent renewable energy sources. It is shown that the use of renewable energy sources can increase significantly, with relatively high cost, and in combination with hydrogen storage technology. Two years later, Duic et al. [24] presented the RenewIslands methodology for the assessment of alternative scenarios for energy resource planning. The methodology was applied to several islands and helps choose energy and resource flows integration based on the island needs, resources and applicable technologies. While all previously mentioned studies worked on the various scenarios to the 100% renewable energy production target, Stanek et al. [25] examined the thermo-ecological cost of electricity from renewable energy sources. It was concluded that biogas power plants cause lower environmental impact than wind and photovoltaic technologies.

The purpose of this study is the investigation of the perspective and feasibility of a 100% renewable energy production scenario for the households' sector of Cyprus by 2050 as the first step to the biggest target for 100% renewable energy production for total energy demand. It should be noted that Cyprus has an isolated energy system with no indigenous primary sources of energy, and lack of research concerning renewable energy locally. The electricity production depends exclusively on imported fuels, mainly heavy fuel oil. Thus, the investigation of the feasibility of such a scenario will open the road for discussion to exploit the high solar energy potential of the island and will be the motivation for the government to invest on this target and collaborate with other parties to create guidelines for the achievement of the target in the future. Initially in this study, the current energy situation of Cyprus and the renewable energy resources assessment of the island are presented. Then the energy efficiency measures for the buildings sector in

Cyprus applied in the last years are presented and the net-metering scheme is explained. Based on the characteristics of the net metering scheme, various prospective scenarios were examined for PV roof systems on various percentages of the total amount of buildings concerning existing and future residential stock. Finally, suggestions for Cyprus to reach the 100% RES target in all sectors are presented together with the existing barriers to achieve this target.

It is known that the large scale integration of RES into existing energy systems should meet the challenge to coordinate the renewable energy production fluctuations with the rest of the energy system. This challenge becomes harder when the reference case country is an island, with isolated energy system without interconnected grid system and with low share of RES at embryonic state of adoption in all sectors. Several issues need to be considered examining a case like this, since there is lack of documentation regarding energy production and demand, no availability of energy storage technologies and no national funds and promotive programs for the adoption of large scale RES.

One of the most used softwares widely used to examine different energy systems in terms of their ability to integrate RES on a large scale is EnergyPLAN and it is used widely in the literature [6,26,27]. However, in a case like Cyprus with limited options regarding renewable sources available and limited capabilities to manage their fluctuations of production, EnergyPLAN is an unlikely option. In the literature, the case of Denmark with the adoption of large scale RES to the energy system is very popular, using the EnergyPLAN software. However, it is clear that the Danish energy system is suitable for analysis of large scale integration because it has already a relatively high share of RES. The study carried out in 2003 from Lund [28] presents excess electricity diagrams and the possibility to integrate RES into the electricity supply in Danish energy system takes into consideration all the benefits of the geographic location of Denmark and the advantages to have high wind energy potential, options to use excess electricity to transportation, and most important the advantage of the very good transmission line capacities to its neighboring countries. For the case of Cyprus, or other islands with Mediterranean climatic conditions and isolated grid systems, these options do not exist. The integration of RES must be done in stages, starting from the investigation of the type of RES that could be utilized in the island and then study the possibility to start promoting RES firstly with the adoption of small systems like household installations.

Another methodology which is easier to be applied for the case of Cyprus, is the RenewIslands methodology developed by Duic et al. [24] which is based on a four steps analysis approach concerning cases of islands. The first step is to map the island needs, second to map the island resources, third to devise scenarios with technologies that can use available resources to cover the needs and last model the scenarios. In most of the islands examined with this methodology, resources in step two include the locally available ones like wind, sun, geothermal energy, ocean energy, hydro potential, water resources, but also imported ones like grid electricity, piped natural gas, oil derivatives etc. Coming back to our reference case, resources are limited to sun which is abundant, wind which is moderate, and maybe hydro which is quite hard to consider due to the lack of infrastructures. For this purpose, the investigation of the perspective of the households sector to become 100% renewable in Cyprus, has been studied entirely in terms of solar energy in small systems. **This paper therefore takes the approach of analyzing various scenarios for installation of PV roof systems in existing and future households of Cyprus island until 2050.**

As mentioned before, various countries have set high level goals to mitigate emissions from fossil fuels burning for the production of energy and they work on smart energy plans to use renewable energy systems for their energy demand. Most renewable energy systems have two important requirements, the resource availability and the area availability. In most countries, there are limited areas for ground RES. Thus, it is important to exploit the available areas to integrate RES, which are the buildings. It is important to integrate PV modules into existing, already exploited and impervious surfaces, especially on buildings, in order to avoid additional land use. The higher the buildings, the more relevant the façade area becomes. This applies for high rise buildings where the roof is usually used for the installation of HVAC systems, and the façade surface becomes increasingly relevant with the height of the building. Ali et al. [29] carried out a feasibility study on roof mounted solar PV panels in the Maldives and concluded that the system has significant potential for reducing diesel generator use and fuel imports, minimizing energy generation costs and helping to ameliorate the energy crisis.

Building integrated photovoltaic (BIPV) systems represent a promising solution for clean electricity production on site. In BIPV systems the PV panels should replace a construction product of the building's envelope and if the integrated PV modules are dismounted, they should be replaced by an appropriate conventional construction product. Nevertheless, there is one more type of PV system classification named building attached photovoltaic (BAPV) products that are not BIPV, or it is uncertain regarding how the product is mounted. However, what is important here is the fact that both BIPV or BAPV systems have certain relevance for the decarbonization of energy systems both concerning general energy systems or buildings energy demand. In the literature, there are numerous studies investigating the performance of BIPV systems in different configurations [30–35], but there are less studies concerning scale up investigations on building level. Kuhn et al. [36] presented different technological design options for BIPV systems and Kyritsis et al. [37] studied the performance of a BIPV system in a building under the Net Metering Scheme. The use of BIPV systems as a significant step toward green buildings is studied by Kant et al. [38]. Aristizabal and Paez [39] investigated the performance of a 6 kW BIPV system on a university building and concluded that the annual savings for the university due to the operation of this PV system was 1022 USD. Schardt and Hessen [40] investigated the performance of roof top PV systems in Netherlands, Belgium, Luxemburg, Germany, France and Italy. BIPV systems have important advantages such as the exploitation of available surface areas on the building facades or roofs, replace a building component so costs can be counterbalanced, power is generated on site and replaces electricity that would otherwise be purchased, and when system is grid connected it ensures security of supply and high cost of storage is avoided.

Tan and Chow [41] carried out a comparative study on FiT and net metering schemes in Malaysia, considering a 100 kWp solar PV system for the UCSI University campus. The analysis is based on a simulation model and it was found that the monthly energy bill cost saving for FiT and net metering are 4.91% and 3.51% respectively and the return of investment of solar PV system implementation for FiT and net metering are 11.5 and 16.1 years respectively. Another comparison between FiT and net metering schemes, and also net purchase is presented by Yamamoto [42]. Moreover, Eid et al. [43] studied the effects on cross-subsidies, cost recovery and policy objectives evolving from different applied net metering and tariff designs for a residential consumer. Shukla et al. [44] carried out a design and economic analysis of a standalone rooftop solar PV system for a hostel building in India. It was concluded that the annual final yield value of 2.86 kWh/kWp is a good indicator that standalone system installations in India are technically viable energy solutions even for urban areas, government buildings and hostels. Additionally, it was concluded that although the initial installation of the system is high, it is beneficiary and suitable for long-term investment as the system life expectancy period is about 25 years. It is also suggested that governments should provide financial support in terms of subsidy above 25% for procurement and installation of rooftop solar PV systems, make it a popular choice and propagate this energy solution. Another study regarding a roof PV system in India is performed by Kumar et al. [45] in terms of performance, energy loss and degradation prediction. The system is estimated to operate with a yearly capacity factor, performance ratio, and energy losses as 16.72%, 77.27%, and −26.5% respectively. Brito et al. [46] investigated the potential of facades for the photovoltaic potential of a Mediterranean city. The annual analysis shows that roof and facade PV potential exceeds the local non-baseload demand, and can contribute to 50–75% of the total electricity demand and the payback period is below 10 years when only roof PV systems are considered. Sedghisigarchi [47] investigated both technical and financial aspects of a residential solar system and Shivalkar et al. [48] carried out a feasibility study for the net metering implementation in rooftop solar PV installations. It is shown that the payback period of a 15 kWp system is 4.63 years and regarding CO_2 savings results showed 19575 kg of CO_2.

2. The case of Cyprus

2.1. Current energy system and renewable energy resource assessment

The main electricity producer of the island is the Electricity Authority of Cyprus (EAC). The EAC power production system includes three Power Stations with a total installed capacity of 1478 MW and net electricity production is around 5000 million kWh every year. As mentioned earlier, Cyprus depends entirely on imported fuel for electricity generation, mainly heavy fuel oil and gasoil. The current energy condition in Cyprus and the renewable energy systems can be found in another paper of the authors in Ref. [49]. From 2010 the government started the promotion towards renewables by issuing licenses for PV installations on buildings, solar parks and wind parks. Table 1 shows the number of renewable energy systems in Cyprus and their nominal installed capacity by type of system in 2020. The majority of the capacity corresponds to wind parks followed by the PV parks whereas the share from roof PV systems and biomass systems is smaller.

EAC is the public authority which is engaged to help in the integration of RES plants in the Cyprus power generation system. Accordingly, in 2010 EAC published the Strategic Action Plan for the period of 2011–2020. The action plan included also the involvement of EAC either by the installation of its own RES plants or its collaboration with private firms.

The total electricity production from RES in Cyprus from 2004 to 2017 is shown in Fig. 1. As can be observed, the biggest production comes from the wind systems. Particularly, regarding the year 2018, 52.45% of the total production from RES comes from the wind systems while 44.29% and 3.26% from PV systems and biomass systems respectively.

Table 1
Installed R.E.S in Cyprus in 2020.

Type	Number of Systems	MW
PV parks	1868	86
Roof PVs	12053	47
Wind parks	6	157.5
Biomass systems	14	9.7
Total		**300.2**

The total load of the island in 2020 is shown in Fig. 2 while the total production is shown in Fig. 3 including production from fossil fuels, wind parks (Fig. 4) and PV roofs (Fig. 5). As can be observed, the contribution of currently installed PV roof systems is very small in regards to the total load or total production.

To set targets to 100% RES energy production, apart from the current energy production situation, the energy consumption in various sectors of the economy should also be taken into account. The domestic sector is the second largest consumer after the commercial sector and before the industrial sector. More specifically, in 2017 households consumed 36% of the total electricity consumed and this proves that the sector requires major attention (Fig. 6). The last 10 years, domestic sector consumes on average 1,580 GWh of electrical energy every year. Statistical Service of the Ministry of Finance data show that the household sectors accounts for 19% of the final energy consumption and another 13% accounts for the commercial buildings, hotels and services (mainly office buildings).

Cyprus is the third largest island in the Mediterranean, located at 35° latitude and 33° longitude. Thus, Cyprus is located in a hot zone near to the Sahara sun belt and is predicted that in the near future it will face significant temperature rise and substantial drop of rainfall. Thus, important negative effects of climate change are expected in the next decades in various sectors including energy. In one study, Zachariadis [50] examined the impact of climate change on electricity use, based on the assumption that average temperature in the Eastern Mediterranean by the year 2030 is expected to rise by about 1 °C. Although Cyprus contributes a negligible amount of emissions to global warming, it is likely to suffer considerable climate change impacts because of its location in one of the most vulnerable regions in the planet. Therefore, the formulation and implementation of a strategy on adaption to climate change is *sine qua non* for the country [50].

The general climatic conditions of Cyprus are mainly very sunny and the daily average horizontal solar radiation is about 5.2 kWh/m^2. In the cloudiest months of the year December and January, the mean daily global solar radiation varies from about 2.3 kWh/m^2, and is about 7.2 kWh/m^2 in July. The weather is generally sunny and a typical year includes more than 300 full sunshine days. The total annual solar irradiation on horizontal surface is about 1,727 kWh/m^2. Of this amount 69.4% reaches the surface as direct radiation and the rest (30.6%) as diffuse radiation, corresponding to 1,199 kWh/

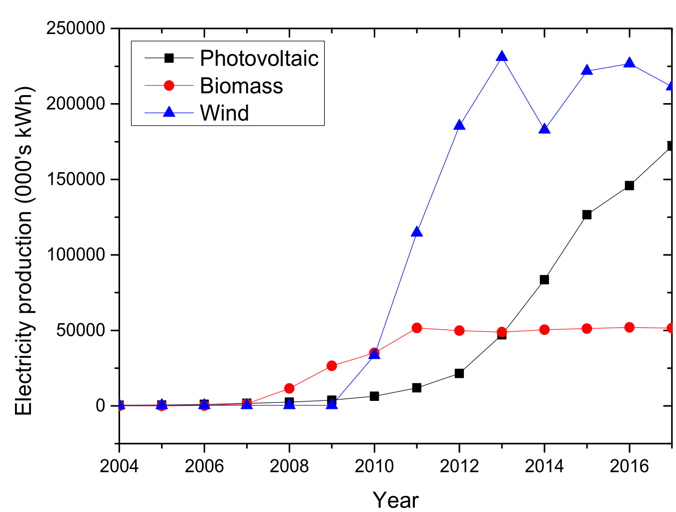

Fig. 1. Production of electricity from RES from 2004 to 2017.

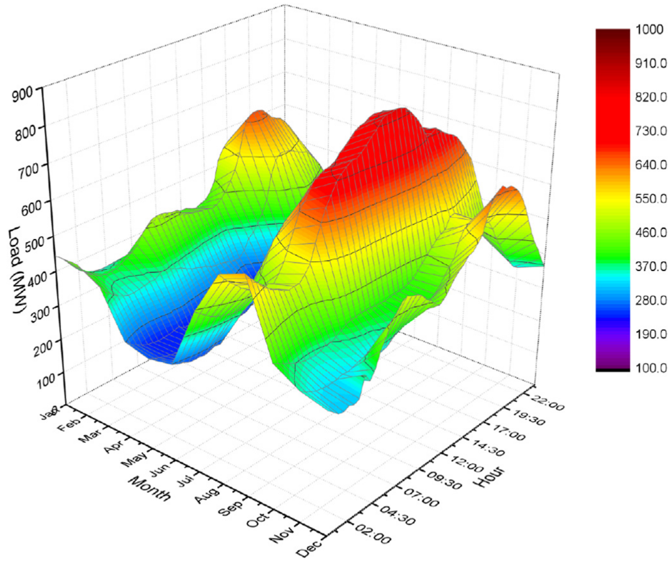

Fig. 2. Total island's load for a typical day for each month.

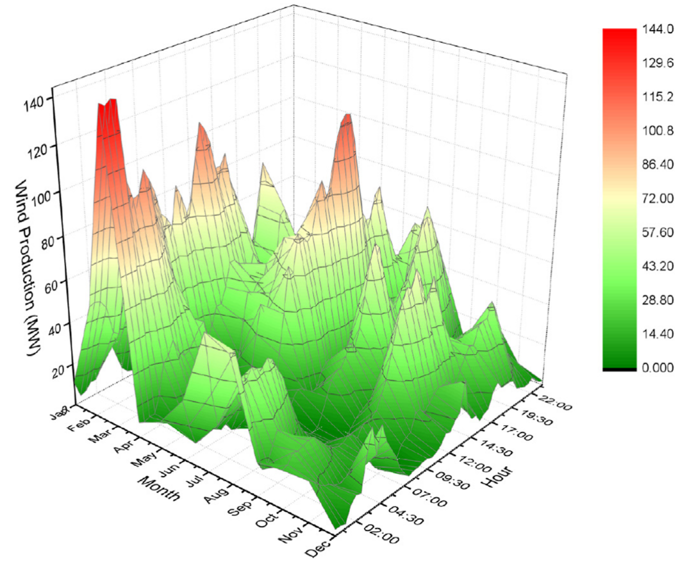

Fig. 4. Wind production for a typical day for each month.

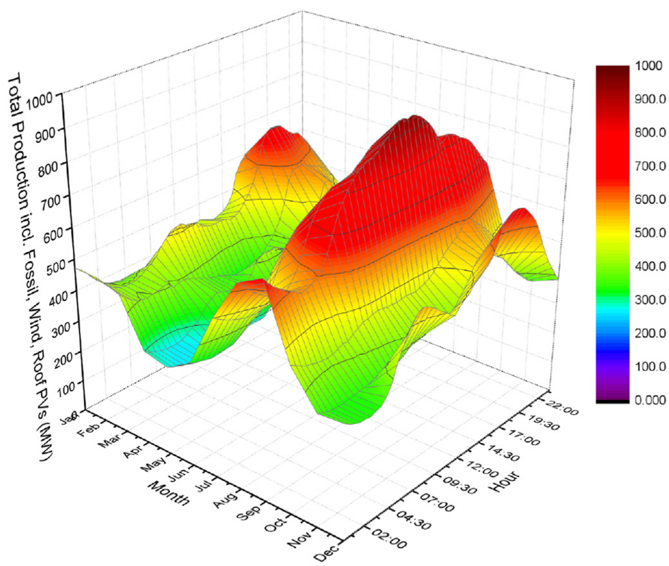

Fig. 3. Total production for a typical day for each month including fossil fuels, and currently existing wind and PV roofs.

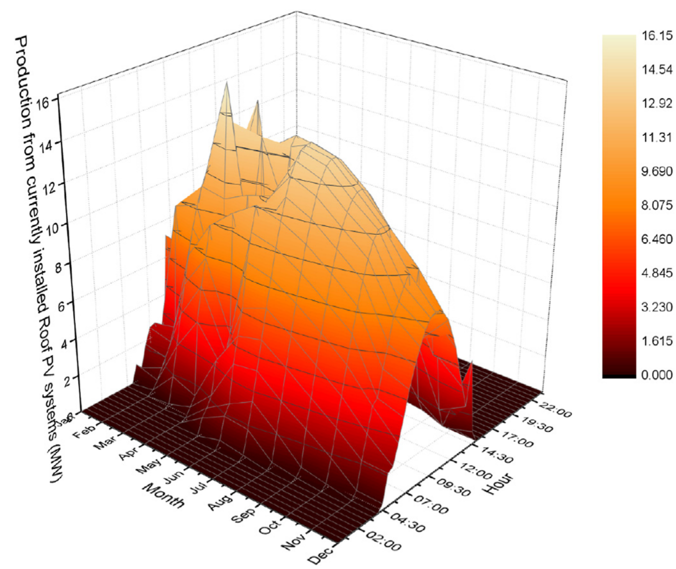

Fig. 5. Production from the currently installed PV roofs for a typical day for each month.

m^2 and 528 kWh/m^2, respectively. The global horizontal irradiation map in Cyprus is shown in Fig. 7. Therefore, it is clear that the island has excellent solar potential throughout the year as the cloudy days are not more than three continuous days. During the last few years and in order to be able to achieve the EU targets of 2020 and 2030, Cyprus started to invest in Renewable Energy, with solar energy being the most important source, as it is almost always available. Experience shows that the solar water heating and photovoltaics systems installed in Cyprus have a low payback time and because of the good resource potential, can cover a significant thermal and electricity demand respectively.

With the exception of solar energy, Cyprus has no other resources of its own and relies heavily on fossil fuels imports. There are no indigenous energy sources except about 2% of the total primary energy consumption generated from solar thermal and biomass contribution. This figure however applies for the contribution of RES before 2010. The energy import dependency therefore reaches 98% [51]. The 2% energy from solar contribution is used mainly in the domestic sector (93.5%) for the production of hot water. Based on the strong dependence of Cyprus on imported energy, the future energy policies involve further promotion of modern energy technologies and equipment for rational use of energy, maximum exploitation of renewable energy sources and probable use of clean coal technologies. The high amount of solar radiation enables the island to exploit the solar energy systems as much as possible. The photovoltaic power potential map of the island is shown in Fig. 8.

Concerning the other renewable sources, Figs. 9 and 10 show the mean annual wind speed and the available amount of solid biomass from agriculture respectively. As can be seen, there is not so high wind energy potential as the mean wind speeds are rather low. In fact, the current wind parks are installed in the few areas marked with yellow indicating the area where the mean annual wind speed

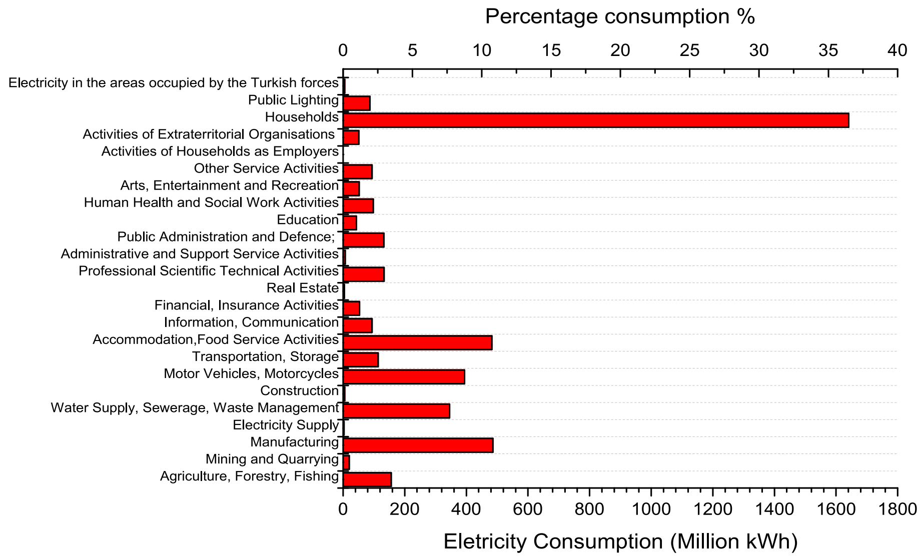

Fig. 6. Percentage of energy consumption by sector obtained by the electricity consumption balance for 2017.

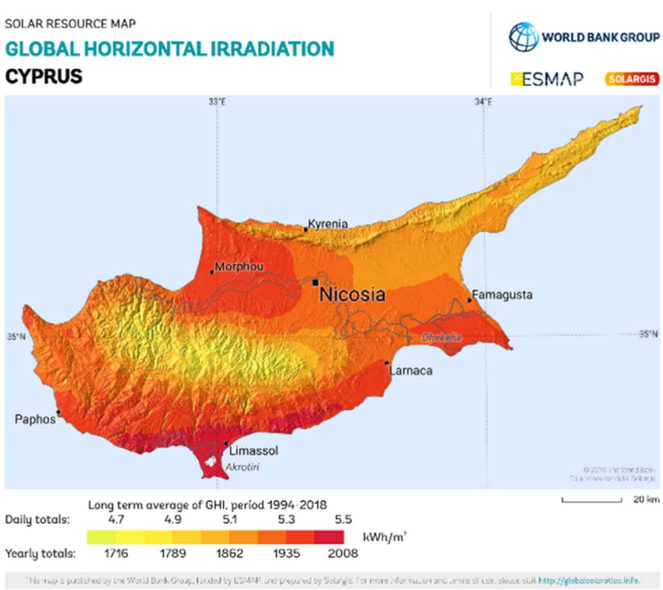

Fig. 7. Global horizontal irradiation in Cyprus [52].

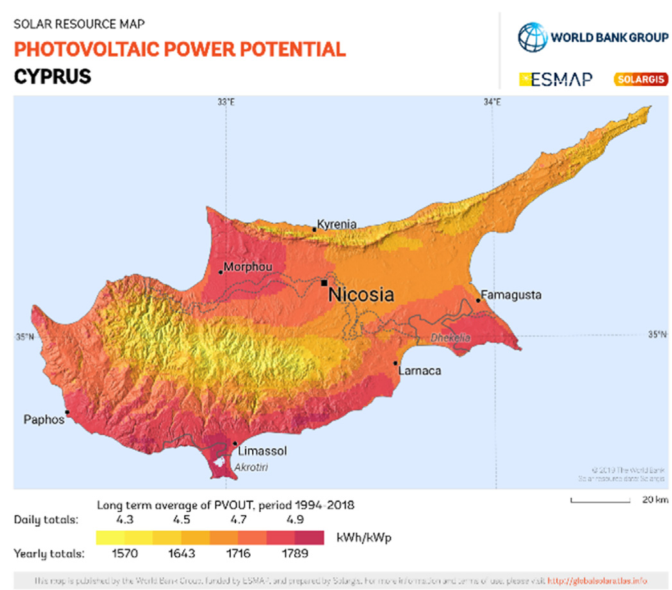

Fig. 8. Photovoltaic power potential in Cyprus [52].

is higher. The animal produced sewage biomass energy is high in most areas of the island.

In addition to the renewable energy resource, another important source of energy that can be used in Cyprus, is the waste treatment. With low effort from the people, it is believed that waste treatment can support substantially the energy production. This area requires the attention of the government to set procedures to the proper disposal or use of the municipal solid waste or biodegradable waste to produce heat. Fig. 11 shows the municipal solid waste from 2004 to 2017 and as can be seen most of the generated waste was disposed to landfills, a very small amount of waste is recycled and a lower amount is composted. Today no waste incineration plants or other plants to utilize the generated waste to produce energy exist.

2.2. Building's sector: energy efficiency measures and the net-metering scheme

Until 2007 Cyprus did not have any compulsory building energy performance requirements. Since then and after the implementation of the new legislation, the requirements have been intensified twice and it is estimated that new buildings now consume around 50% less energy than the similar ones that were built before these requirements [55]. The main legal tool for transposing the requirements from the EU Performance of Buildings Directive (2010/31/EU) into Cypriot Law is the law on Energy Efficiency of Buildings (No. 210(I)/2012), established in 2012. This is a recent update of the first law regulating the performance of buildings that was adopted in 2006 (No. 142(I)/2006) and amended in 2009 (No. 30(I)/2009). The final update in 2012 include also new requirements concerning qualified experts for the inspections of boilers and air-conditioning systems. Specific performance requirements have been set by

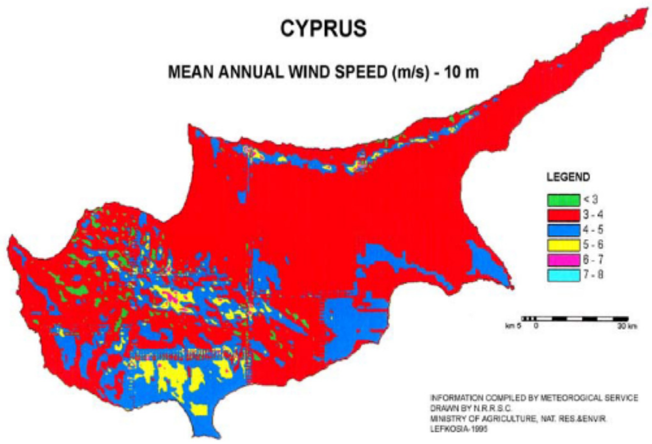

Fig. 9. Mean annual wind speed in Cyprus [53].

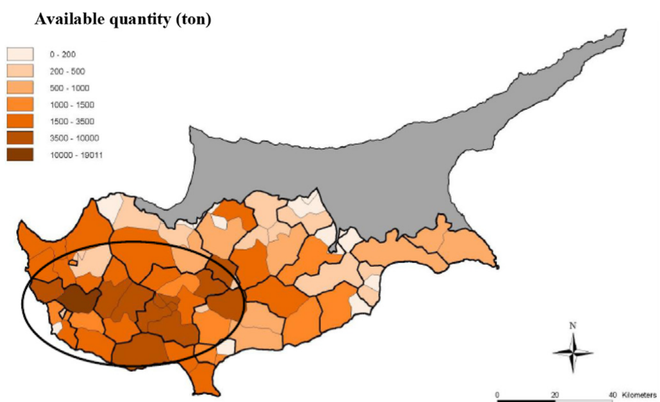

Fig. 10. Available energy from solid biomass from agriculture in Cyprus [54].

various ministerial decrees in different time periods as shown in Table 2 [55].

According to the Directive 2010/31/EU on the energy performance of buildings Member States are required to introduce Energy Performance of Building Certificates (EPCs) to be issued for buildings at either the time of construction, sale or renting or when a building is undergoing major renovation. It has been transposed through a series of laws and regulations with the Law No. 210(I)/2012 on Energy Efficiency of Buildings, mentioned above to be the main legal tool. The EU Directive 2010/30/EU on "indication by labelling and standard product information of the consumption of energy and other resources by energy-related products" is also known as the EU Labelling Directive, which requires that all household appliances must have an energy label, with standardized information, which must be given to the consumer. This EU Energy Labelling Directive has been transferred into the Cyprus national law through a series of ministerial decrees covering various appliances.

The requirements and characteristics of nearly-zero energy buildings (NZEB) have also been implemented through a ministerial decree in 2014. Accordingly, U-values are set for energy class A, a maximum consumption of primary energy is specified and a requirement is added specifying that at least 25% of the demand should be covered by RES. These requirements apply for both new and existing renovated buildings.

According to Ref. [56], energy efficiency in the buildings sector of Cyprus has improved steadily since the adoption of energy performance standards for new buildings in the mid-2000s, and as a result of the implementation of all relevant EU legislations. Still, energy consumption of buildings continues to grow as a result of the increasing number and size of dwellings, which outweighs energy efficiency improvements.

The statistical services of Cyprus for the construction and housing statistics [57], show that a total of 152,487 building permits were issued from 2000 to 2016 and that a total of 78,551 houses were completed during these years and most of them are located in Limassol district. Additionally, 70% of the total dwellings in the private sector are for houses and the rest 30% are for apartment buildings.

It is expected that the combination of the NZEB regulations for the energy performance of buildings regarding the U_{value} of the various building construction elements, and the obligatory use of RES so as each building generates its own energy requirements from on-site production, will help the household's sector to minimize its energy consumption from the EAC grid, which is based on fuels burning thus the carbon footprint of the household sector is reduced and at the same time.

For the promotion of small residential photovoltaic systems in Cyprus, the net metering scheme was introduced in 2013. The net metering is a policy that targets prospective producers/consumers, those who both produce and consume electrical energy [58]. Under this scheme the producer/consumer offsets the electrical energy consumed with the one produced by the PV system. The producer/consumer is then charged based on the net energy for a specific billing period [58].

The net metering is a billing arrangement where consumers who generate electricity on their residential premises with the use of PV system may export the excess of this to the electric utility grid and use it to offset electricity imported from the grid to the premise during the applicable billing period. In case that the consumption exceeds the production, then the consumer will be billed the difference, while in the opposite case, the production surplus is transferred to be used in the following (forthcoming) two-month billing period. The final clearing will be stated on the last bill of the financial year (February–March). Any surplus may not be transferred to the next billing year. In cases of Residential Consumers, the metering may contain the electrical consumption of Storage Heaters if it is requested.

It is important to mention that net metering is the only measure that applies for buildings for the case of Cyprus since 2013. Other governments are sponsoring the BIPV systems by implementing a Feed in Tariff (FiT) systems. This concept allows selling back excessive power to the grid at a higher price than the grid price of the electricity [38].

Poullikkas [59] made a comparative assessment of the net metering and feed-in-tariff schemes for residential PV systems. The comparison revealed that the net metering is financially more appealing than feed-in-tariff for the PV owners. Christoforidis et al. [60] showed that PV systems working under the net metering achieve a lower Levelized Cost of Energy (LCOE) and they are likely to generate higher savings, which leads to a quicker pay-off.

Several European countries use the net metering scheme such as Belgium, Cyprus, Italy, Greece and Portugal. The net metering scheme in Cyprus had initially supported the installation of small PV systems with power up to 3 kW in 5,000 households. A total of 15 MW is set as limit for the installed PV capacity under this scheme. This scheme is still in operation, but the capacity of the PV systems is upgraded to 5 kW. The optimum installation parameters of a PV system according to the geographic location of Cyprus, is South oriented with inclination of 28°–30°. Any divergence from these parameters affects the system output negatively resulting to the relevant divergence on the optimum economic return. The net

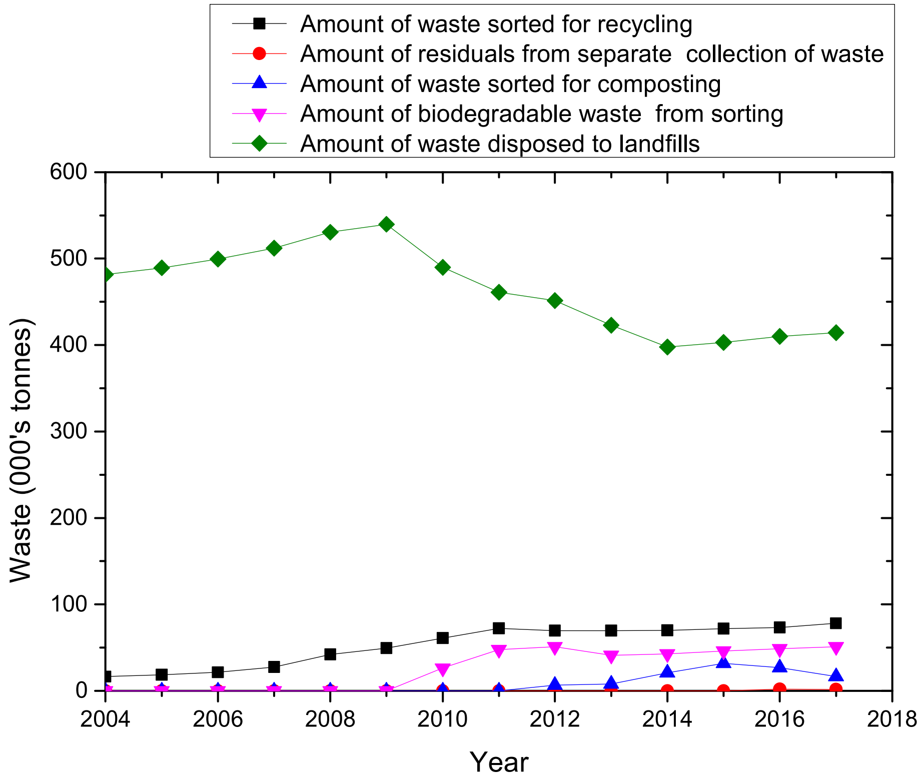

Fig. 11. Municipal solid waste in Cyprus for the years 2004–2017 by type of waste.

Table 2
Evolvement of energy performance requirements in Cyprus.

Requirement	Since January 2010	Since December 2013	Since January 2017	Since August 2014 for NZEB
Energy class according to the EPC	B	B	B	A
U_{value} for walls (W/m^2K)	0.85	0.72	0.4	0.4
U_{value} for floors and roofs (W/m^2K)	0.75	0.63	0.4	0.4
U_{value} for windows (W/m^2K)	3.8	3.23	2.9	2.25

area required for a PV installation of 3 kWp – 10kWp is approximately 25 m^2–80 m^2 if installed in a tiled roof or approximately 45 m^2–150 m^2 if installed on a flat roof/terrace [61]. The installation is subject to the orders in force of the relevant House Planning Department. The average annual energy yield of a PV System with capacity of 10 kWp, over a 20-year period, reaches 16600 kWh, equivalent to €3320 compensation in electricity bills, based on the EAC residential tariff (€0.20/kWh).

The Net Metering Contract with EAC is valid for 15 years for Residential Consumers and 10 years for Commercial Consumers. PV modules have a written 10-year warranty by the manufacturer that the respective PV module is free of material defects. Moreover, manufacturers of PVs provide a 25-year performance warranty guarantee on every module. Solar inventers have a 5-year warranty by the manufacturer with extension right from 10 up to 20 years.

The producer/consumer pays an annual fee to the Supplier of €47,23 + VAT per kWp, to offset the belayed/deferred production and consumption of power in the house. These charges are paid by the producer/consumer in six equal instalments and are included in the supplier's invoice, i.e., €7,87 + VAT per kWp of the PV system [61]. This fee is subject to future variations according to the rules and regulations published by the Cyprus Energy Regulatory Authority (CERA). The payback period of the initial investment is usually less than 5 years. Any individual falling in the category of vulnerable consumers according to the relevant order of the Ministry of Energy, Commerce, Industry and Tourism, or any recipient of the Single Parent Families Subsidy with annual gross family income €39,000, who is also a permanent resident in the domestic unit in which the Photovoltaic (PV) System is installed has the right to apply for funding as an eligible applicant. In this case the applicant is funded with €900 per kWp installed, with a maximum amount of €2,700 paid when the system is installed and permission is obtained [62].

3. 100% renewable energy production in the households sector

3.1. Methodology

The way to manage the production of energy form the convectional and the RES systems includes initially the prediction of the electrical energy production from all energy sources including the RES systems (photovoltaics and wind turbines) as well as the next day energy demand. From these the program of operation of the conventional production units is established based also on various technoeconomic parameters (e.g., scheduled maintenance). Generally, the policy is to give priority for the energy produced by the RES systems and the conventional units to complement the production deficit according to the demand. The current grid system is shown in Fig. 12.

The current energy demand is covered from both RES and energy from the power stations:

$$E_d\, f(E_{PS}, E_{RES})$$

$$E_d = E_{RES} + E_{PS} \cdot i \tag{1}$$

Where E_d is the energy demand, E_{PS} is the energy from the power stations, E_{RES} is the energy from renewable energy systems and i is the percentage of energy supplied by the power stations in conditions where $E_{pr} < E_d$.

In case that in real time the production exceeds the demand, then the daily production program is adjusted, by reducing the production from the conventional units so as to give maximum benefit to the renewable energy production which to continue to produce energy seamlessly. The readjustment of the conventional units is done according to their various technoeconomic parameters including the fuel price required by each unit to operate and its response time. For example, gas turbine units have a very small response time, but their operation is expensive because of the type of fuel used (diesel oil). When the readjustment of the production from the conventional units has reached its limits and the production continues to be more than the demand, then the operator starts to cut proportionally the production from the RES systems. This can only be solved in the future by the development of appropriate storage systems. When the production exceeds the demand, priority is given to the RES:

$$\text{If } E_{pr} > E_d \text{ then } E_d = E_{RES} \cdot k + E_{PS} \cdot j \tag{2}$$

Where *j and k* are the percentages of energy supplied by the power stations and renewable systems respectively in conditions where $E_{pr} > E_d$.

All the above coordination is done from the Manager of the Transmission System of Cyprus (MTSC) whereas the production department of the Electricity Authority of Cyprus (EAC), any other current of future electrical energy producers of private interests as well as the Distribution System Manager of the EAC are responsible to perform the instructions of the MTSC on the planning of the electrical energy production.

The building sector is expected to play a key role in the achievement of the national targets for the energy saving targets. This paper aims to show the potential of the households sector to be autonomous in terms of electricity, under different hypothetical scenarios. A huge potential exists since 91% of all buildings (94% of residential buildings and 83% in the service sector) were built before the introduction of the mandatory energy performance requirements and about 50% of the buildings do not include any kind of thermal insulation.

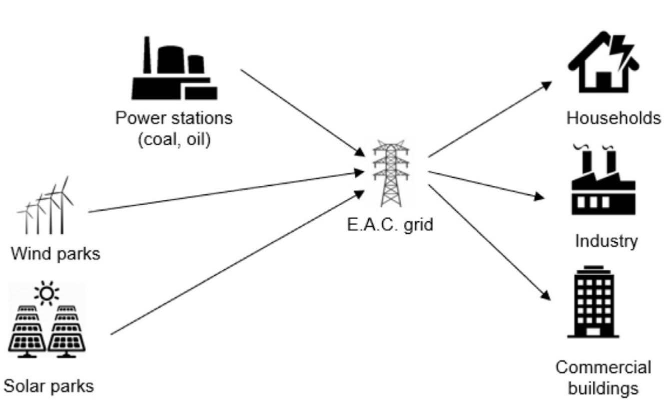

Fig. 12. Today's grid system in Cyprus.

The idea of this study is the enhancement of the net metering scheme, to a grade that the households sector can be 100% renewable. For this purpose, the current energy system with the power stations and existing renewables is combined with roof PV systems under the net metering scheme as shown in Fig. 13. The suggested grid plan combines existing and future installation of RES for the coverage of the building's sector energy demand. More specifically, the plan focuses on installing PV roof systems in the residential sector. As mentioned earlier, under the net metering scheme, the surplus electricity from each PV system cannot be transferred to the next year and thus owner does not benefit from it in any way. Thus, during daylight the households with PV roofs will be powered from self-production while at night they will be powered by the grid. The excess energy that may be produced during the day will be transferred to the grid since it is the only way of distribution. Accordingly, increasing the number of roof PV systems under the scheme will not only cover the energy demand of the buildings with PV roofs but will also feed the grid with their surplus energy which can be then used to cover the needs of the whole building's sector including the buildings without PV roofs, industrial buildings and commercial buildings (sector coupling). The storage of electricity is very important when large scale integration of RES is planned since energy from RES cannot always be provided at the time that is needed due to low solar radiation or nighttime. In the reference case however, the PV roofs will be supported by the energy from the grid when fluctuations occur and thus the grid itself and distribution network will be the 'battery' of the PV roof systems which can store or supply electricity when required and when is possible respectively.

Here it is important to mention that all domestic users using the grid are charged 0.028 €/kWh thus both users with PV roofs and without are paying the same fee for using energy extracted from the grid. One can expect that the future increased number of PV roofs may change this fee and the users without PV roofs may have to pay more, but the methodology behind the net-metering will hardly lead to that outcome since the PV roof users will continue to pay for the use of the grid every night where their PV system does not produce energy and they actually purchase energy from the grid.

The building stock in Cyprus comprises of 431,059 residential buildings and 85,198 non-residential buildings [63]. Almost half of the residential buildings are single-family houses and 22% are apartments. The majority of dwellings (67%) are occupied by their owners and a large portion (78%) is located in the coastal and low land areas. Based on the plan presented above and the data from the construction and housing data by Ref. [57] various scenarios for installation of PV systems on the households roofs were examined for existing and future residential stock (Fig. 14). Considering that 78% of the existing residential stock is family houses and the rest 22% apartments, here we only consider family houses stock for the estimations, which includes 336,226 houses because apartments may not have an adequate amount of roof space to install a PV system. Scenarios for installing roof PV systems from 100% to 10% of residential stock, excluding apartments, were investigated subsequently for the existing and for the future houses. The idea is to examine the contribution that the PV roofs in households can have to their electrical energy demand and the contribution to the total electrical energy demand of all sectors. The reason that different percentages of the residential stock are accounted for the investigation is to be able to identify the potential of the 100% renewable energy production target from ideal extreme case scenarios to most pragmatic and realistic scenarios. The different examined scenarios

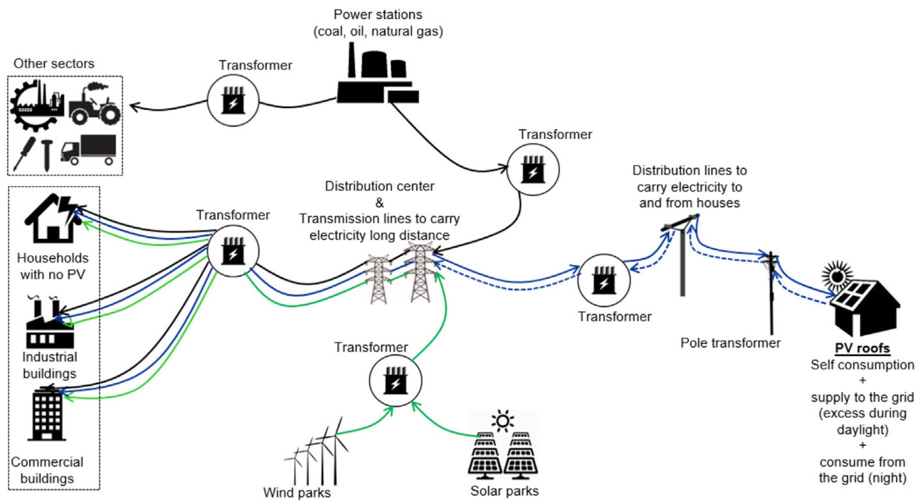

Fig. 13. Proposed sector coupling grid plan for increased PV roof installations.

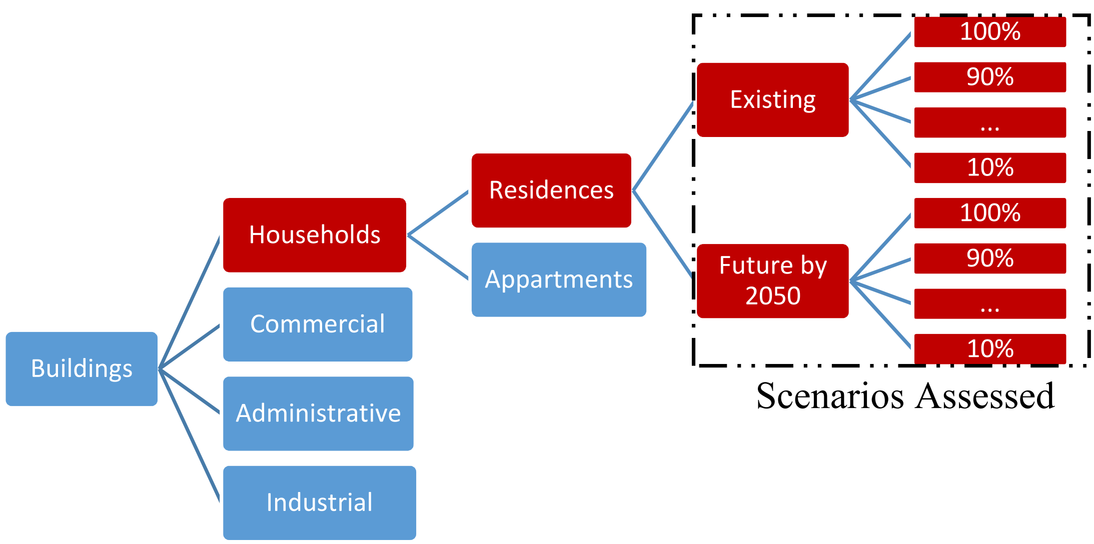

Fig. 14. Buildings assessed in the analysis and scenarios for installation of PV systems on existing and future residential stock.

include both hard-applicable or difficult to apply scenarios (e.g.100% of the stock) and also realistic scenarios (e.g.70% of the stock). For example, considering the 100% of existing residential stock to install PV systems it is known that it is a hard applicable scenario or not applicable, because it does not take into account geographical restrictions, orientation of the roofs, age of the building, technical characteristics and economical situation of the owner to afford the installation of a PV system.

For the estimation of the future residential stock the trend of completed residences for the last 20 years was analyzed (Fig. 15). The substantial drop in the years after 2008 is attributed to the economic crisis that affected all economic sectors of the island.

The following steps were carried out for the methodology to assess the target of 100% renewable energy production in the household's sector:

1. Identify the existing residential stock
2. Estimate the future residential stock by 2050
3. Investigate which net metering scheme is applicable for existing and future residences
4. Selection of scenarios on the percentage of residences to install PV roofs through net metering
5. Calculations for each scenario
6. Combine scenarios to identify realistic solutions
7. Suggest actions to reach the realistic solutions and identify barriers

The following assumptions were made for the calculations:

- Average annual electricity demand is around 1,582 GWh based on data from 1960 to 2017. This load is assumed in the following analysis and it is considered that it will not increase because any use of renewables in buildings need to be combined with energy conservations measures.
- The energy production from PV systems is estimated using a capacity factor of 18% for PV systems in Cyprus (~1,570 kWh/installed kW) [64,65].
- Install 3 kW roof PV systems in existing residences.
- Install 5 kW roof PV systems in future residences.

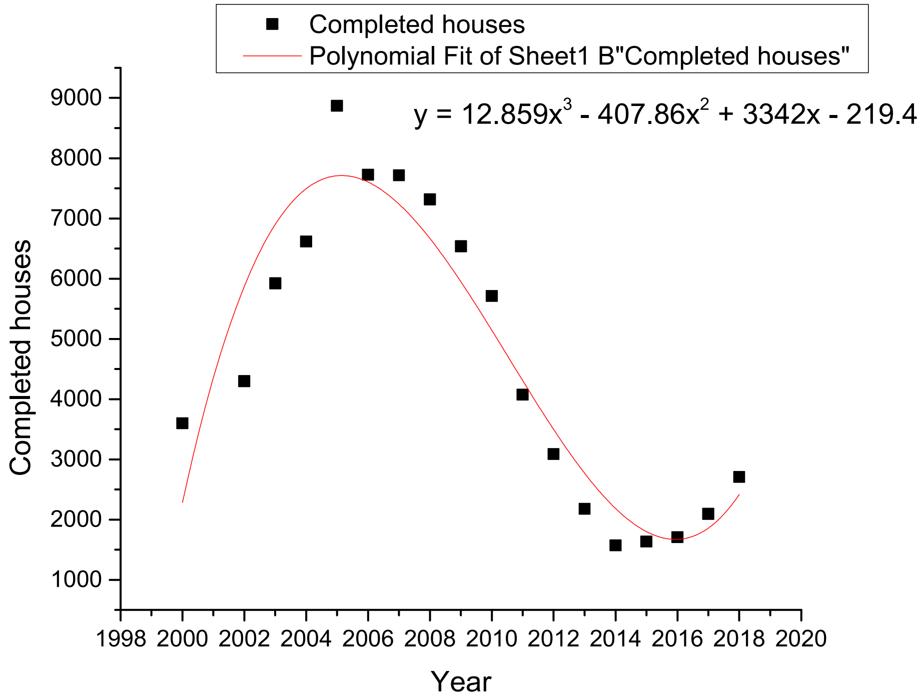

Fig. 15. Trend of the completed residences the last twenty years in Cyprus.

- Current installations of RES and conventional energy production systems are taken into account in combination with all examined scenarios.
- All PV roof systems considered will feed the grid and supply existing residential stock.

Table 3 shows the existing installations of energy production systems in Cyprus including RES as shown before in Table 1, and conventional systems from the EAC. Considering that the average annual electricity demand is 1,582 GWh, and 485.61 GWh are already produced by RES, the required energy to cover 100% the domestic sector's demand from RES is 1,096.56 GWh. If we consider that this demand will be 100% covered from the PV roofs, this translates to 695 MW PV capacity. Additionally, considering that 7,768.37 GWh are produced by the three power stations from EAC, and assuming that RES produce 485.61 GWh, the remaining energy to cover the total demand is 7,282.75 GWh. These data were in all cases combined with the scenarios mentioned above.

3.2. Hypotheses assessed

As mentioned before, the assessed scenarios for installing roof PV systems consider from 100% to 10% installation of roof PV systems at the residential stock, for the existing and for the future houses. Thus the analysis that follows presents the estimated data for application of PV roofs to all existing and future residential stock, which is 100%, and reduced in steps of 10%. Codes of scenarios are shown as 'EXnnn' where 'nnn' is the percentage (%) of residential stock considered to have PV roofs and 'EX' demonstrates the existing residential stock while 'F' demonstrates the future residential stock. For example, EX50 means that 50% of the existing residential stock is assumed to have PV roof system of 3 kW.

Fig. 16 shows the contribution of PV roofs of the scenarios of the existing residential stock, on the domestic sector's electricity demand and on the total electricity demand of all sectors. All cases include the contribution of the current systems (CS) of RES in Cyprus, shown at the beginning of the graph. Considering that all existing residences install a 3 kW PV roof system, we see that the domestic sector's electricity demand can be covered by 130%, i.e., 30% surplus energy. The electricity demand of the domestic sector can be 100% covered when over 70% of the existing residential stock install 3 kW roof PV system.

Fig. 17 shows the energy production from RES based on the scenarios of the existing residential stock, and the electricity demand required from the power stations to cover the total electricity demand for all sectors and the required energy needed to cover the

Table 3
Existing installations of RES and conventional energy production systems in 2019.

Systems	Number of Systems	Installed Capacity (MW)	Energy (GWh)
PV parks	1,868	86	135.60
Roof PVs	12,053	47	74.11
Wind parks	6	157.5	238.14
Biomass systems	14	9.7	37.76
Energy from RES	-	-	**485.61**
Conventional systems			
EAC (3 power stations)	–	1,478	7,768.37
Energy demand from power stations (excl. RES)	-	-	**7,282.75**

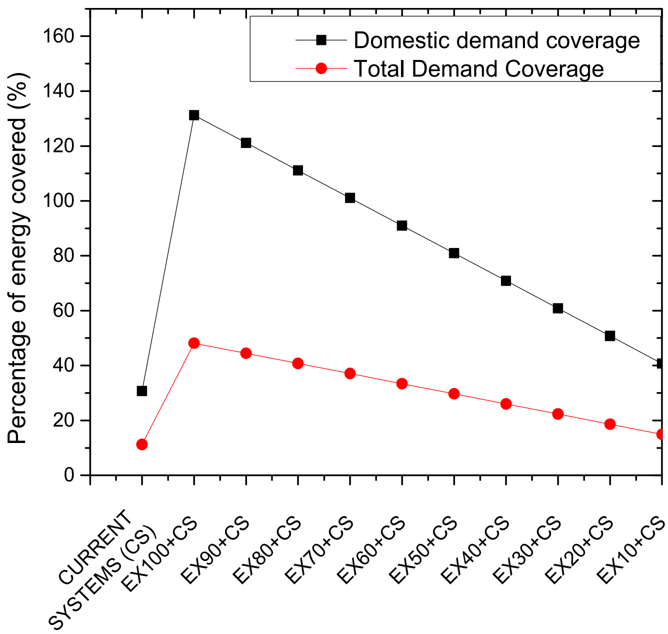

Fig. 16. Contribution of PV roofs of the scenarios of the existing residential stock (EXnnn, nnn = % covered), on the domestic sector's electricity demand and on the total electricity demand of all sectors. All cases include current systems (CS).

domestic sector's demand from PV systems. It can be seen that while with the current systems the required energy to cover domestic sector's electricity demand is 1,096.56 GWh, if all existing residences install 3 kWp roof PV the total coverage is 130%, indicating that these could produce more energy than the amount required by the sector. Additionally, to cover fully (100%) the demand of the sector only, 70% of the existing residences need to install 3 kW roof PV systems, which is quite feasible. Energy demand from power stations does not seem to approach zero values since it is estimated based on the total required energy from all sectors and not only the domestic sector, however the energy coverage just from the PV roofs covers a substantial part of the requirement.

The required energy to cover the domestic sector's demand from PV systems corresponds to PV capacity shown in Fig. 18. While currently with the existing systems, 695 MW of PV capacity is required to cover 100% the domestic sector's electricity demand, as can be seen in Fig. 14, even if 50% of the existing residential stock are equipped with a 3 kW PV system the required PV capacity from other applications (e.g., PV parks) to make domestic sector 100% renewable is 191 MW, which is feasible since it can be translated to 63,666 existing households with PV roof. If only 40% of the existing residential stock are equipped with a roof PV system, the required capacity for the domestic sector to be 100% RES, a total of 291 MW from other RES would be required, which is also a possible scenario.

A more detailed analysis of the daily data shows that the contribution of the PV roofs can be significant with the expansion of the net-metering scheme. Comparing the current contribution of the PV roofs to shown earlier in Fig. 5, it is clear from Figs. 19 and 20 that the contribution of the scenarios EX50 or EX70 is much higher. The proposed grid plan shown in Fig. 13 suggests the use of the excess produced energy from PV roofs for the coverage of the domestic sector's needs but when there is excess energy to transfer it to the rest sectors continuously, maintaining a sector coupling system.

Fig. 21 (a), (b) and (c) show the contribution of PV roofs for the scenarios of the future residential stock, on the domestic sector's electricity demand and on the total electricity demand of all sectors for the years 2030, 2040 and 2050. The estimations for the future scenarios include the current systems (CS) already installed since 2019. Fig. 21 (d) shows a summary of the estimated results in the next three decades if all future houses (Case F100) install a 5 kW PV system. Concerning that no more PV systems are added to the existing residential stock and accounting only on the future residential stock, it can be seen that if all new residential houses install

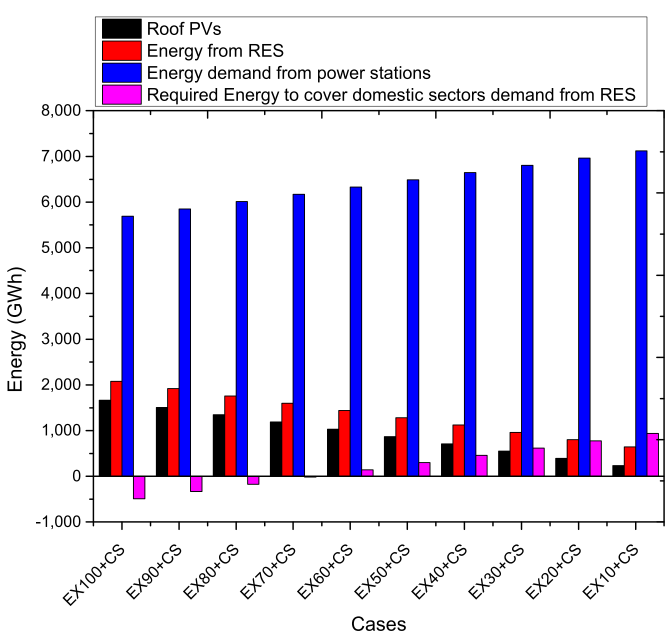

Fig. 17. Energy production from roof PV systems based on the scenarios of the existing residential stock (EXnnn, nnn = % covered), energy production from all RES, the electricity demand required from the power stations to cover the total electricity demand for all sectors and the required energy needed to cover the domestic sector's demand from PV systems. All cases include current systems (CS).

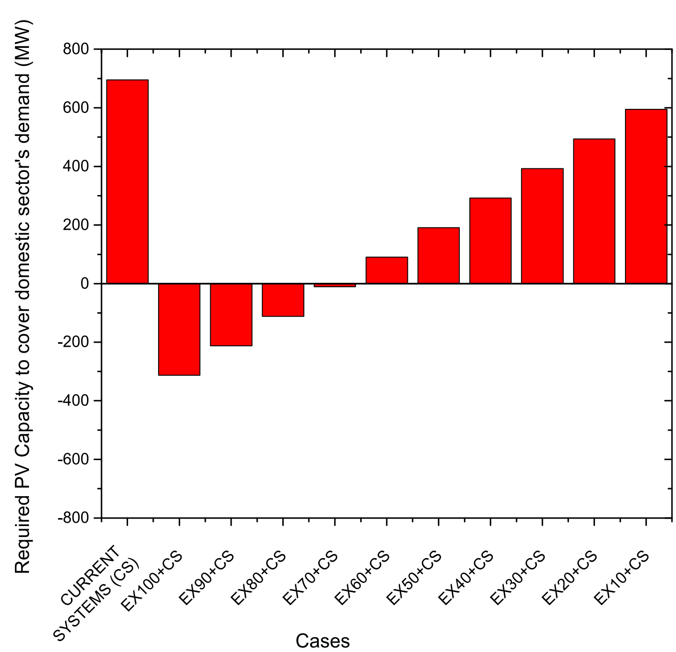

Fig. 18. The required PV capacity to cover the required energy needed to cover the domestic sector's demand from PV systems for the scenarios of the existing residential stock (EXnnn, nnn = % covered). All cases include current systems (CS).

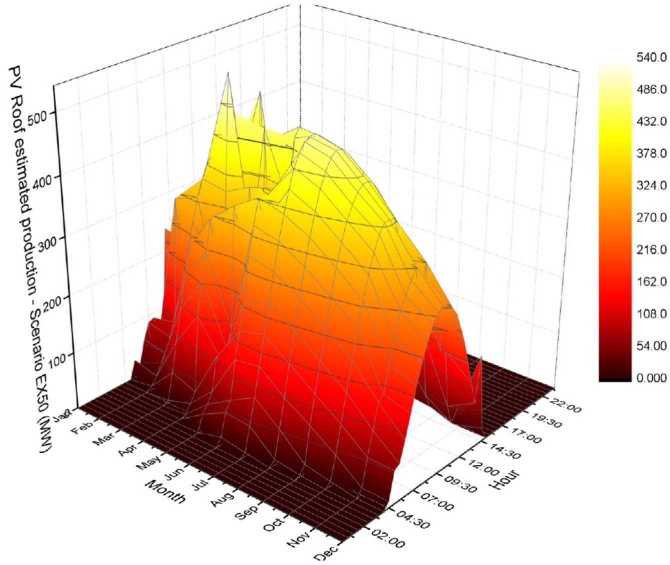

Fig. 19. Contribution of the hypothetical scenario EX50 for a typical day for each month.

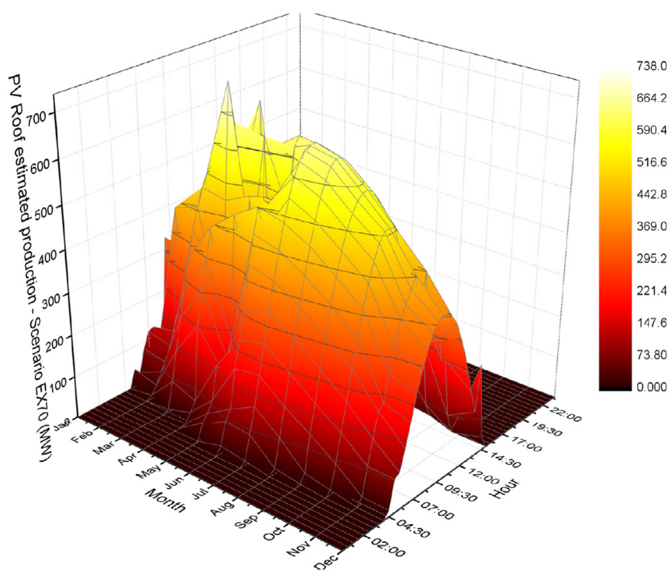

Fig. 20. Contribution of the hypothetical scenario EX70 for a typical day for each month.

5 kW roof PV systems the domestic sector will be 80% renewable in 2040 and 108% renewable in 2050. It is important not to ignore the contribution to the total electricity demand from all sectors, which can be covered by almost 40% in 2050 if all new houses install 5 kWp PV system which is an important contribution.

As mentioned before, the reason that different percentages of the residential stock are accounted for the investigation is to be able to identify the potential of the target from ideal scenarios to most pragmatic and realistic scenarios. In order to find possible combinations of the examined scenarios that will lead to more realistic and more applicable solutions, various combinations are investigated as well. Fig. 22 shows the energy production from roof PV systems based on combined scenarios of existing and future residential stock, the total electricity production from all RES, and the required energy needed to cover the domestic sector's demand from PV systems. As can be seen, there are some cases with negative values of required energy from RES to cover domestic sectors from RES, which means that these cases can achieve 100% RES for the domestic sector and the negative is the surplus energy which can be used in other sectors.

3.3. Barriers and radical actions suggested

Currently a 3 kW system costs between 4500 and 5800 Euro and a 5 kW system between 5600 and 6700 Euro which are not prohibitive to a consumer to pay as his electricity bill will be zeroed and the payback time is around 5 years. This means that after this period substantial amounts of money will be saved, which makes the system quite justifiable. Although upfront investment cost seems to be an important barrier to small PV investors, for the case of Cyprus, the upfront investment cost is the less important barrier since there are other issues with frameworks, regulations, bureaucracy etc., that actually prevent people from installing PV systems. Table 4 shows the pros and cons of the suggested grid plan which promotes the expansion of the net-metering scheme.

From the side of the state, the aim should not be to reduce its overall share in the support of the energy efficiency interventions, but primarily to drive the public financial resources to more cost-efficient support mechanisms and types of energy efficiency interventions with a higher influence. In the household/residential sector, while not undermining the acceleration of the requirements for new buildings any new tool must be designed to be cost-attractive and implementable in market terms. The following political support measures could accelerate the energy transition:

- Compensate PV owners if they produce more energy that they use because they will be actually feeding the grid with their excess energy.
- New feed-in Tariff laws should be adopted to enable investments from decentralized actors to be involved, such as small and medium enterprises, cooperatives, communities, farmers and citizens.
- Introduction of carbon and methane taxes.
- Incentives should be created to help the growth of renewable energy technologies, such as legal privileges, direct subsidies and tax exemptions.
- Finally policies and frameworks should be adopted which promote education, research and information sharing on renewable energy and zero emission technologies.

4 Full energy transition to 100% renewable energy in all sectors

For the case of an isolated grid system, a full energy transition to 100% renewable energy is not a pragmatic scenario with the net metering scheme dissemination only. Even in the best case scenarios for 100% of the residential stock installs roof PV system, the coverage of the total demand does not exceed 40%. The target for 100% RES for all sectors can only be achieved when other measures are taken in combination with the net metering scheme and when the various barriers overcome. Here in this section, the barriers to this aspect are discussed and some radical actions are suggested in order to present the important actions needed to be done. There are lot measures that needs to be taken in order first to reach the EU targets and then the 100% RES targets. According to Ref. [66], to approach a full energy transition to 100% renewable energy in all sectors, the whole energy system should be redesigned. This includes merging of the various energy sectors and identification of a more fuel-efficient and lower-cost solution compared to the traditional approach of individual sectors.

To exploit the considerable potentials to produce more energy from renewables than conventional sources in the different sectors

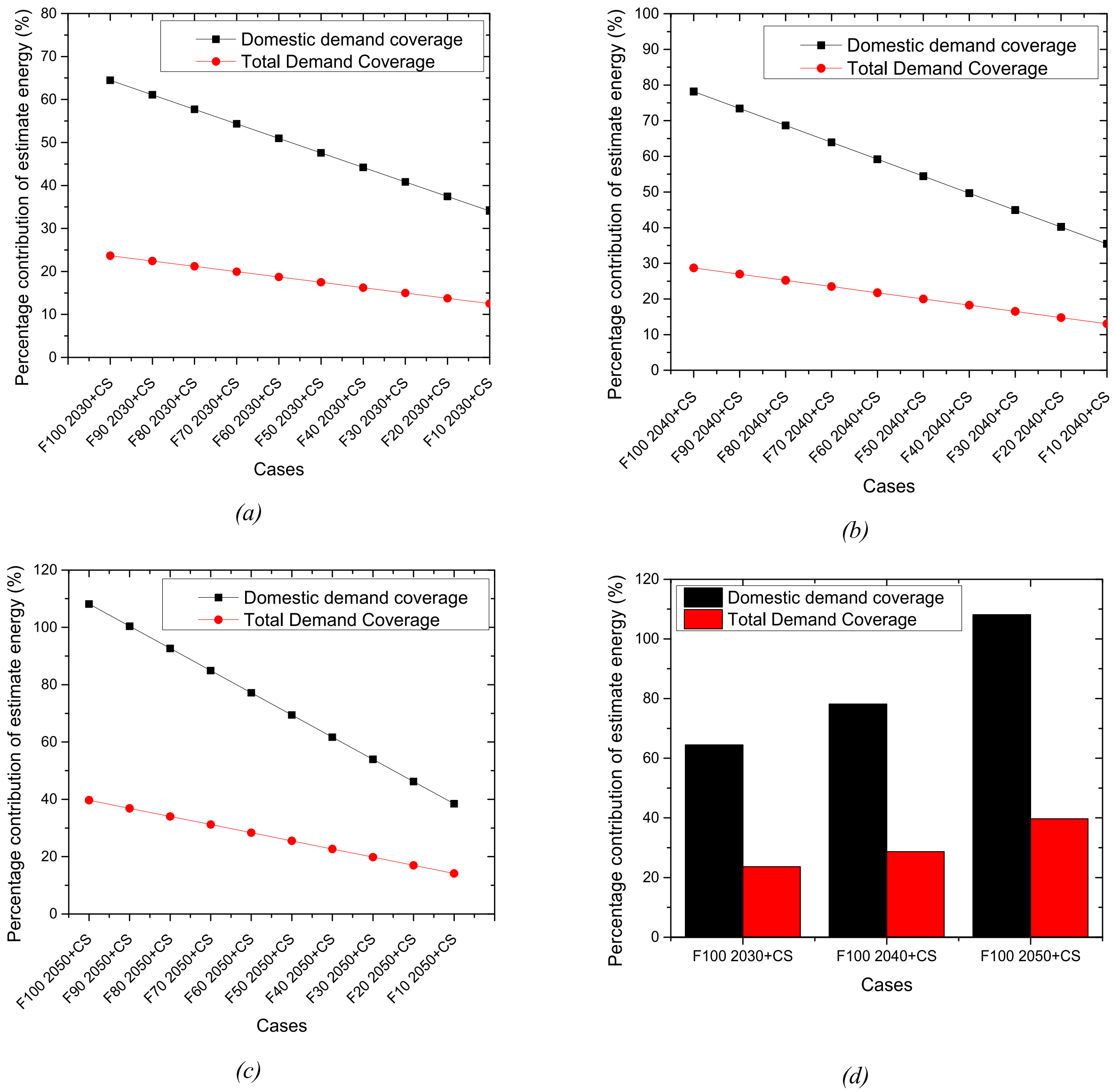

Fig. 21. Contribution of PV roofs of the scenarios of the future residential stock (Fnnn, nnn = % covered), on the domestic sector's electricity demand and on the total electricity demand of all sectors for (a) 2030, (b) 2040 and (c) 2050 and (d) the percentage contribution at the three decades of 2030, 2040 and 2050. All cases include current systems (CS).

of the economy, the main barriers preventing a wider uptake of energy efficiency measures, the limited financial support and the interest of final consumers, should be sufficiently addressed. The first barrier is the emergent state of the energy service market of Cyprus because of the existing underdeveloped regulatory framework. Attention should be given on topics related to standardization of energy services offered, the performance of the services and the procurement issues related to the operation in the public sector [63]. For the successful tackling of the existing mainly market-related barriers it is important to adopt standardized tools and procedures and to develop appropriate databases and communication platforms. The existing regulatory facilities regarding the building codes and the Energy Performance Certificates, should be further simplified and enhanced in terms of monitoring procedures and increased market value so as to create a sustainable regulatory framework for Energy Efficiency.

The low-hanging benefits in terms of energy efficiency interventions are still not fully exploited and further emphasis should be given to public awareness and training of personnel which ease the achievement of significant energy savings. One of the most severe barriers for the achievement of savings is the limited budget available for this kind of interventions. Over the years, the private sector has been accustomed to being more responsive when significant public subsidies are available, while the public sector demands full upfront capital coverage. Therefore, the change to a more market-oriented financial supportive scheme, will be a challenge requiring careful planning and adoption of appropriate financial and market tools.

Additionally, a balanced mix of mandatory obligations and voluntary targets for the energy consumers and suppliers should be introduced. This needs to be done in a careful way especially when going beyond the minimum mandatory instruments foreseen under the current energy efficiency directive (2012/27/EU) in order not to generate market failures or uneven burden for any of the end-users or market participants. Furthermore, the of energy audits instrument should be utilized more in the future by both the service and industry sectors and should be directly linked with any kind of state financial support instruments.

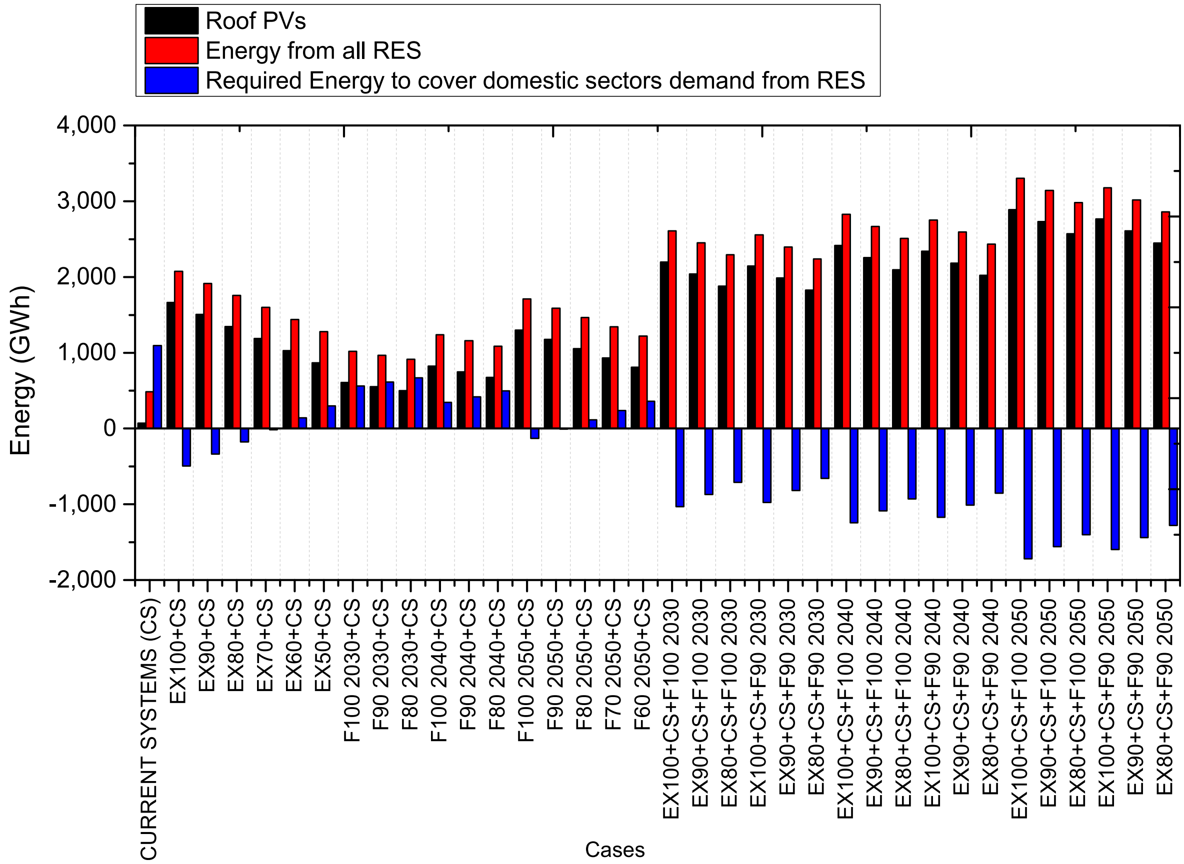

Fig. 22. Energy production from RES based on combined scenarios of existing and future residential stock, the electricity demand required from the power stations to cover the total electricity demand for all sectors and the required energy needed to cover the domestic sector's demand from PV systems.

Table 4
Advantages and disadvantages of the suggested grid plan with net-metering scheme expansion.

Pros	Cons
Electricity for self-consumption	No option to store electricity for later use (Except autonomous systems far away from the grid).
Low payback period, money saving	The users pay for the electricity usage from the grid at night.
The grid (other sectors) can be benefited from the excess production	The users do not get paid for feeding the grid when they produce more than they consume.
Does not require large field areas for PV installation since there are many building roofs	Not all existing and future buildings have the required roof space, orientation, topography to install a roof PV system.
Easy to adopt scheme which does not require dramatic actions to the grid system or support from the government	A combination with other measures and actions is required to achieve a full transition to 100% renewable energy in all sectors

From the perspective of public, it needs to be addressed that Cypriots are very familiar in the use of renewables in buildings, as proved by the very large coverage of buildings with solar water heating systems. Furthermore, because of the high solar radiation energy that falls on the islands solar energy systems have a very high rate of success as the resource is almost always available. However, for the electricity generation from RES it needs to be stated that as Cyprus has an isolated and small electricity system, substantial changes need to be implemented by the EAC concerning the distribution circuit including also electricity storage which is the most important parameter when considering 100% RES. When we talk about “100% renewable” it generally means that we can produce the same amount of renewable electricity as the electricity that is consumed in a year but not necessarily at the same time as it is consumed. Because electricity is delivered during the sunshine hours, operating the power grid reliably requires supply to equal demand, every second of every day [67], which can only be achieved with the introduction of some kind of storage of the electrical energy, either directly (as electricity) or converted in another form of energy. This means that the main challenge of achieving a 100% renewable electricity grid is not only a question of how much renewable energy systems are built, but rather whether renewables can supply electricity when the consumers can use it or whether an electricity storage system is feasible. To ensure a fast, cost-effective and smooth transition to 100% renewable energy in all sectors, the government must adopt national legislative actions that will guarantee the swift uptake in the development of renewable energy, sector coupling, smart grid systems planning and storage technologies. The various frameworks should include favorable investment conditions for all actors, including businesses and communities.

The following political support measures could accelerate the energy transition but significant actions from the government should be taken to upgrade the grid system and invest in storage technologies:

- Simplification of application/certification procedures. Currently these take more than 2 years to complete and this time needs to be reduced substantially.
- Policies and instruments dedicated to sector coupling enabling direct private investment in renewable energy or other zero emission technologies.
- Substantial actions should be done to the grid in terms of interconnection strategies and electricity storage.

4. Findings discussion – conclusions

The aim of this study, was the investigation of the perspective and feasibility of a 100% renewable energy production scenario for the households' sector of Cyprus by 2050 as the first step to the biggest target for 100% renewable energy production for total energy demand. The current energy situation of Cyprus was analyzed and the renewable energy potential of Cyprus was assessed. As a result, various possible scenarios with percentages of building stock to install roof PV system are investigated, in order to make a step forward to the target of 100% RES in the domestic sector. As it is shown, both the existing and the future buildings have important role to achieve this target. The scenarios for the existing buildings must be supported by the government since there are not any energy efficiency regulations applied for this type of buildings by the time this investigation is carried out. Thus, the government has a very important role to achieve the target as well. It is believed that the findings presented in this paper could be helpful to other similar island-states with isolated grid system and good potential for using renewable energy.

The most important outcomes of this study are summarized below:

- PV roofs can have an important contribution to the electricity demand of the island.
- The electricity demand of the domestic sector can be 100% covered when over 70% of the existing residential stock, excluding apartments, install 3 kW roof PV system.
- If 50% of the existing residential stock install a 3 kW PV system, the required PV capacity from other applications (e.g., PV parks) to make domestic sector 100% renewable is 191 MW, which is feasible.
- Concerning that no more PV systems are added to the existing residential stock and accounting only on the future residential stock, it is estimated that if all new residential houses install 5 kW roof PV systems the domestic sector will be 108% renewable in 2050, i.e., producing more than what is required.
- In addition to the use of the existing roof PV systems, for the year 2050 to produce energy equivalent to the current domestic demand corresponds to the application of a 5 kW PV roof system to 90% of the future houses, or for the combined case, the application of 5 kW PV roof systems to 80% of the future houses and 50% of a 3 kW PV roof system to existing houses. Of course for this case a number of other combinations are possible but this is considered a realistic scenario.

After analyzing the potential to transform the domestic sector to 100% renewable energy sector, the full energy transition to 100% renewable energy for all sectors is discussed, addressing the barriers and suggesting radical actions to support the target. As mentioned, there are lot measures that needs to be taken in order to firstly reach the EU targets for energy savings and then the 100% RES targets. A combination of the various measures and actions should be taken in order to reach the 100% renewable energy production for all sectors. All actions need to be supported with a smart energy storage system to take care of the variability of the energy supplied by RES. The existing regulatory tools regarding building codes and the energy performance certificates should be further enhanced especially in terms of monitoring processes and increased market value so as to create a sustainable regulatory framework for Energy Efficiency. The government must adopt national legislative acts to ensure a smooth, fast, and cost-effective transition to 100% renewable energy across all sectors, that will ensure the swift uptake in the development of renewable energy, sector coupling, smart grid systems, electric vehicles and storage technologies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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