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Autonomous Buildings with Electricity by Renewables

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Abstract – *This work reviews autonomous buildings that have been designed to cover electricity requirements by Renewable Energy Source (RES). Not only naturally installed systems but also theoretical presentations (simulations) are included in this study in order to clarify their feasibility and their general behaviour under different weather conditions in several locations. Authors judge on- and off- grid connection, while energy buffering with or without eco-friendly character is also discussed. Finally, the necessity of a relative optimization process is presented, in order to assure the feasibility of off-grid projects, implemented in remote areas with totally "green" technologies.*

Keywords: *Hybrid System, Renewables, Simulation, Zero Emissions*

I. Introduction

Energy supply is essential for the welfare of households and generally for human life in developed and developing countries. Electricity production currently depends mainly on fossil fuels which are costly and characterized in general by pollutant emissions during their life cycle. Improving access to RES-based electricity production is an important target for each country towards its development. During the last two decades, the energy sector has changed drastically. Fossil fuel deposits have been reduced thus their acquisition costs have increased. Conventional energy sources are characterized by high transportation costs (from source to energy stations), while their efficiency during energy production is not high enough to overcome their pollutant character. Therefore, the attention of many countries has shifted to the development of renewable energy options. In Europe, several factors contribute to the demand for an eco-friendly electrification. European Union has also decided to follow a common line to reach specific targets with positive consequences on climate and human health by the year 2020, as follows [1]:

- Greenhouse gas emissions should be reduced by 20% compared to 1990.
- The share of RESs in final energy consumption should be increased to 20%.
- Energy conversion efficiency should improve by 20%.

Each EU country has set a specific target in accordance to the above three pledges. Fig. 1 shows the progression of greenhouse gas emissions in Greece, compared to the European average, with 1990 set as the reference year [1]. Fig. 2 presents the increasing percentage of renewable sources in the EU and the 2020 target. Fig. 2 also shows, as an example, the RES share obtained in Greece during the same period, while similar targets have been set specifically for each EU country under a very strict deadline [1].

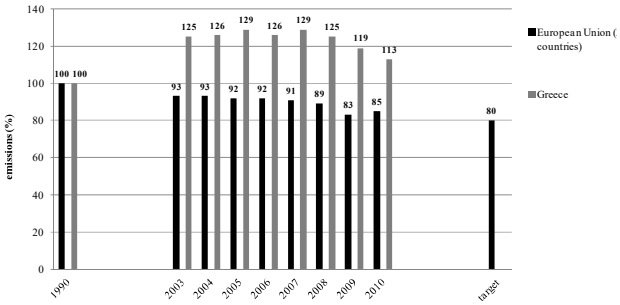

Fig. 1. Greenhouse emissions in Greece compared to the European average [1]

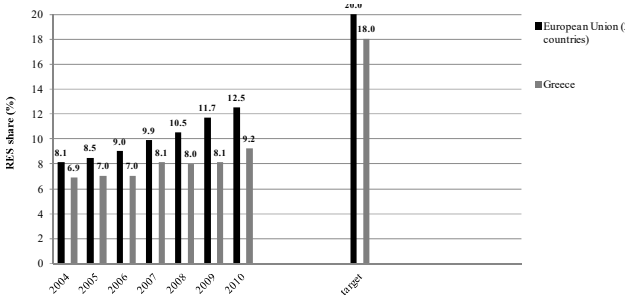

Fig. 2. RES share in Greece compared to the European average [1]

Finally, Fig. 3 presents the percentage of energy savings of fossil fuels. A reduction below 100% throughout the years, as shown in Fig. 3, reveals that fewer fossil fuels are used during energy production, and these fuels are being progressively replaced by renewables, in accordance to the evolution of RES-based energy production systems [1]. All the above presented data indicate a relatively low involvement of "green" energy in everyday life slow due to poor acceptance of RES based systems, despite the existence of numerous scientific studies that show quite the contrary. Beyond

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the targets set by the EU, great interest in RES seems to be a global phenomenon with different characteristics per specific occasion. In Africa, interest in renewable energy is currently driven not only by the recent increases in oil prices as well as currencies exchange rates, but also by the rapid population growth in megacities and the rate of urbanization [2].

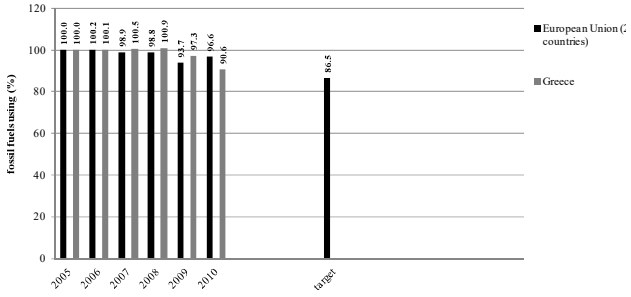

Fig. 3. Energy savings in Greece compared to the European average [1]

Petroleum imports as a percentage of export earnings has almost doubled in the last decade for the majority of the African countries [3]. The second most important development that increases interest in renewables in Africa is the crisis faced by most power utilities in several countries due to limited extension of the national grid which is affected by the territorial and climatic characteristics of the region, as well as by politics. These countries face power supply limitations which, in turn, affect their economies [3], [4]. Asia has been also facing a power crisis for almost a decade. The power generation capacity cannot meet the demands of the population for extended electrification, while only 20% of the total population is connected to the grid [5]. Deposits of natural gas, which is the main commercial primary energy source, are limited and Asian economies are not strong enough to sustain large fossil fuel imports.

Although some Asian economies rely heavily in fossil fuels, a significant share of energy use can be traced to combustible renewable and waste such as solid and firewood. It is important to note that in many Asian countries, less than 5% of energy consumed came from renewable sources [6]-[8]. The satisfaction of consumers' demands can be achieved by national investments in large scale RES based projects that support the already existing grid, such as hydropower or biomass applications [9]-[11]. Hydropower applications remain by far the widest acceptable of the renewables for electrical power production worldwide (providing 19% of the planet's electricity), they can only be established near rivers or lakes with enough water, being therefore of limited interest [12], [13]. Similar difficulties are also faced in the use of biomass as an energy source, because such installations occupy large land areas, thus prohibiting domestic use [14]. In accordance to the globally accepted approach of using grid as energy buffer, the producers have to provide their energy to the grid while all consumers have to satisfy their energy demands through the grid. For instance, when coal is used to produce electricity, it is obvious that a connection path (grid) is necessary to transport the energy from the production location to each consumer. Furthermore, the centralized transport of electrical energy allows political forces that have access to and control the grid, to obtain higher political power through the threats about supplying power or not and the ability to exclusively define pricing policy. Fortunately, RES do not have such limitations since electricity is produced by the individual consumer and in-situ, i.e. in the same place where the consumption occurs. It is important to note that a solution where any consumer would independently cover his own energy requirements by producing electricity locally using RES based systems does not appear feasible, because of the inevitable gap between production and consumption rates. This gap can be attributed to: a) the stochastically dependence of RES based productivity on unpredictable local meteorological conditions, b) the evolution on innovative storage technologies has been grave [15]-[18] and c) the unstable energy demands (loads) with unpredictable high peaks [19]. A potential option towards the efficient management of energy excesses and requirements could be found in the use of smart micro-grids for autonomous small-scale electrification [20]. A micro-grid is an energy logistics system based on the concept of "community", and whose members are simultaneously energy producers and energy consumers. Each consumer provides their excess energy to the community and, in turn, the community provides the amounts of electricity required to cover each consumer's energy demands when necessary. This distributed production scheme by-passes the national grid, thus avoiding the installation, maintenance and operating costs of such a system. At the same time, the political factor is absolutely different, since the processes of energy production and provision are locally managed under well-established social parameters, thus avoiding the effects of centralized control. With this in mind, subsidized financial programmes for small scale domestic RES projects should be promoted worldwide to encourage individuals to use RES to cover their own power requirements.

These applications can be supported by the use of solar and wind energy in combination with mature buffering technologies for micro grid optimization. One of the advantages offered by renewable energy technologies is their potential to provide electricity in areas not served by national power grids. This prospect leads to RES based, hybrid, and autonomous systems.

Problems such as supplying electricity to remote villages, which usually requires large investment and leads to power losses associated with transmission and distribution networks, can therefore be overcome.

Several scientific approaches exist for already established or simulated systems based on RES technologies to cover the electricity demand problems of isolated islands [21]-[23] and remote communities located far from national grid, especially in poor countries [24]-[26]. Such systems, which include wind

and solar parks or hydropower technologies and meet huge electrical loads, are included in large scale projects and are out of the scopes of this particular study. This paper deals with the feasibility and worldwide development of small scale, RES based, stand alone electricity production systems for use either by typical and country households or by small enterprises. In the first part of this study, on-grid RES based hybrid systems will be examined in terms of feasibility and efficiency, regarding every aspect of such an investment. The evolution of these projects will be concentrated on autonomous systems. The last part will focus on the actions and scientific studies regarding simulation and optimization of already stand alone installed systems.

More precisely, it is investigated whether RES based systems could be a feasible solution for electrical load coverage for everyday domestic use.

II. On-Grid Hybrid RES Based Systems

The first step towards the integration of renewable sources in energy production is made through on-grid systems. On-grid systems are designed to use "green" energy through the renewable technologies in combination with the one offered by the grid, as supplementary source, when the peak load is high during the day to assure total coverage of the electrical needs, in accordance to each scenario. For this reason, such an on-grid concept based on "green" technologies does not constitute an innovative process during its final design and establishment. It is important to underline here that this type of grid connection is quite different than the widely accepted analogous practice: in this case, the grid is used only to offer the extra power needed when the renewables seem insufficient, while the commonly accepted concept is to use grid connection for energy buffering purposes by selling the production to the grid and buying the demands by the grid. However, it is necessary to describe and discuss some of these in this section, and specifically the most well known, in order to clarify the usefulness of RES based technologies on the electricity production in our everyday life. Hydrogen And Renewable Integration (HARI) project is one of the most disseminated projects in the world that uses different renewable technologies supplying electrical power to domestic and office loads [27]. It is installed at West Beacon Farm, Leicestershire, United Kingdom (UK). The project comprises wind turbines, photovoltaic panels and micro-hydro turbines because is located near a river. Concerning buffering, hydrogen technologies via electrolysis and a battery bank are also used. All these components are connected in a high voltage DC bus which cooperates with an AC bus from the national grid.

It has been shown that this is not an optimized system because throughout the day it is supported by and consumes energy from the grid even though it can operate as a standalone system under a specific timetable [28]. Simple and less costly renewable systems exist, operating in combination with the grid and can cover a significant portion of the energy consumed during whole year. Such systems are based exclusively on solar energy, can be integrated into a building's design without destroying its aesthetic concept, being characterized as "small scale" because they operate autonomously to cover the building's demands [29], [30]. Another scientific simulated research in Andalusia, Spain, revealed that the energy from photovoltaic panels mounted on rooftops can satisfy 78.89% of all energy needs [31]. The energy consumption for uses related to residential housing in Andalusia was 12,320GWh/year [31]. If photovoltaic arrays were installed on all the available building rooftops, the benefit in terms of energy has been calculated at 9,730GWh/year. This means that the national grid would have a backup role and if energy efficiency was increased in combination with a reduction in energy consumption, this Spanish community would be a totally green and autonomous area with its own electric micro grid [31].

III. The Evolution of RES Based Systems: Off-Grid Systems

The main aim of RES based systems is to reduce dependence of the population from fossil fuels to satisfy its demands on energy production in an eco-friendly manner. Given the aspects for autonomous systems discussed earlier, RES based systems should be considered as an important option for the coverage of electricity demands. Several studies exist on single and hybrid projects that prove the feasibility of such a scenario (Fig. 4) [19], [32]-[36].

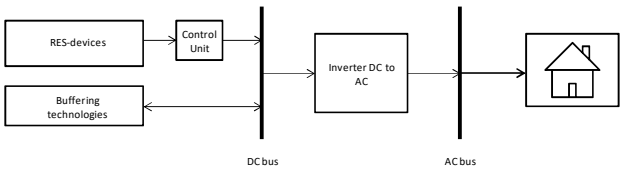

Fig. 4. A typical off-grid RES-based hybrid system

Many small tourist lodgings in Australia are remote and supplied by stand-alone power plants [32]. The eco-friendly primary sources used for energy production of the already established power plants are the wind and solar potential comprising either diesel generators or electrochemical batteries as back-up energy sources. A feasibility analysis of renewable energy supply and several simulations took place, providing optimistic results for small to medium scale tourist operations (less than 100 beds) towards a decrement of the dependence on fossil fuels. The comparison among different scenarios demonstrates that an entirely eco-friendly RES system is both technically feasible and economically viable, compared to diesel energy supply scenario for small to medium scale investments. In the same study, hydrogen technologies were tested as an alternative option to batteries for energy storage, but found not economically viable in the case studies concerned, due to

the current high cost of components, especially compared to the existing situation of the diesel generators [32].

Another study, which reveals the importance and feasibility of RES based autonomous systems, was undertaken in the extreme climatic conditions of Antarctica [33]. This study presents a range of small scale energy efficiency and renewable energy deployments within Antarctic research stations and field camps. The management of large amounts of fossil fuel under extreme environmental conditions involves severe environmental risks and further complicates the life conditions of the scientific staff in the most remote area of the world. Therefore, with the technological evolution of RES based equipment, the desire to run entire stations or field camps on totally "green" energy is increasingly common and feasible. The electrical requirements of Antarctic research stations are small compared to urban installations on other continents. If renewable energy efficiency of a feasible level can be achieved there, then the deployment of RES based autonomous systems should be more widespread and encouraged on other continents [33]. Similarly to the previous study, another one presents an extensive review of RES technologies and the research work conducted under cold climatic conditions [34]. These conditions include mountainous, continental, cold oceanic and polar climates and in general, all climates where below zero temperatures are common during the winter. The use of solar energy under such conditions is described from various aspects: greenhouses, buildings and housing, heat pumps, heat storage, PV panels, solar thermal and PV/T, high-latitude issues, cooling, and policies. Both environmental and economic aspects are considered and the zones covered more or less intensively are Central and Northern Europe, North America, Turkey, Iran, China, Japan, the Andes and Antarctica. This analysis has proven that, for most cold climatic conditions, it is worth implementing solar energy technologies for certain uses, however, many parameters must be carefully considered before concluding on the relevance of a given technology [34].

In some specific cases, the governments of poor countries take advantage of renewable sources to develop small scale projects to supply electricity to remote rural communities and improve livelihoods and reduce poverty. Solar panels can meet these demands while specific research on the PERMER project in Argentina concluded that small standalone systems based on PV electricity provide better quality lighting, reduce indoor air pollution levels, and extend social life. This RES based equipment would be installed in homes, schools and public buildings sponsored by a range of public and private sources [35]. Another study examines the relationship between renewable and living conditions of poor rural households in developing countries with a particular focus on Cameroon. Its goal is threefold: first, analyzing the energy situation of the country and the living standard of its rural households, second, promoting renewable usage and third, formulating consolidated policy recommendations to foster the diffusion of profitable, renewable structures [36]. This work tries to encourage decision-makers to increase the share of renewable in country's energy mixture and to integrate into their development policies the concept of sustainable development.

IV. Comparison of the Two Categories and System Optimization

This section focuses on a major issue arising from the above-mentioned studies.

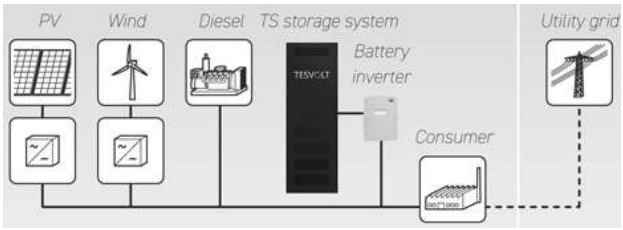

Fig. 5. Comparison between on-grid and off-grid systems

Most case studies concentrate on whether renewable energy technologies are cost effective compared to the extension of a national grid. In a relative study, where the electrification of rural households in the Kingdom of Bhutan was simulated, it has been showed that a wind-battery hybrid system is the best option, among other not totally green projects, to meet the electricity demand of these rural off-grid areas [37]. Renewable energy technologies, such as PV-battery and wind-battery hybrids, could be considered as alternatives to grid connection. A similar result was found by another research group for Western Australia, where it has been concluded that small scale standalone RES based systems (less than 6kWp) are cost-effective and demonstrate very promising financial results when installed in remote locations far from the electricity network, mostly displacing diesel capacity [38]. Researchers also study evaluated the potential and cost effectiveness of off-grid PV systems at Indonesia for each province and indicated the appropriate provinces where these systems are most cost-effective, giving the higher return on investment [39]. In other cases, research shows that renewable energy sources cannot compete with grid electricity generated by fossil fuels in large urban centers but that each citizen should be encouraged to invest in RES systems and participate in eco-friendly governmental programs, since it could be a method of saving energy and reducing emissions at national level [40], [41].

Higher shares of RES offer many new opportunities for amending and improving the existing grid charges in ways that were not originally considered by economists or policy-makers [42]. Other publications, including processes simulations, present the comparison between off-grid projects using different combinations of storage systems and, in some cases, use fossil fuel as a backup energy supply via diesel generators. Mbaka, et al. presented a comparison between photovoltaic-diesel,

standalone photovoltaic and standalone diesel systems, which fail to satisfy specific financial criteria because these are designated in a poor area of north Cameroon [43]. This project, which includes different combinations of storage banks, can meet the existing electrical demands, while the photovoltaic-diesel system is confirmed as the most economically viable and characterized by an energy cost in a range of 0.692-0.785 €/kWh. At this point, optimization can play an important role by adjusting the system's characteristics, accordingly to several parameters that differ in each specific case. Mamaghani, et al. presented an application of photovoltaic (PV) panels, wind turbines and diesel generators in a standalone hybrid power generation system for rural electrification in three off-grid villages in Colombia with different climatic characteristics. The configurations and the optimal size of the components proposed in this study, can be effectively employed to provide electricity for these communities in the most economically convenient way [44]. For every established system that takes advantage of RES technologies, an integrated study of operation, design and optimization has to be performed. Specific research studies pointed out that, prior to construction of a complex small-scale project, it is necessary to perform a systematic design analysis, based on economic and other operational criteria to select the finally installed equipment. Different variables of power management strategies should be examined before final decision [45], [46]. Although a very powerful tool, optimization of power plants has gained research interest only during recent years. For example, the established HARI project in Leicestershire was optimized only recently, where simulations have been used to identify the most economical and efficient scenarios for the generation of electricity to cover the desirable load on an annual basis [28]. This process revealed an off-grid system with a totally eco-friendly character and with minimal investment costs. Using the same concept, three typical loads were selected to be covered by RES based systems for electricity supply in four different Greek islands. The optimization shows that even if off-grid systems cover the desirable load, they are not economically feasible. The grid connection is used for selling the excess electricity and not as a backup energy source, thus increasing the financial profits of the investor and minimizing the period for the project abbreviation [19]. Furthermore, another project was simulated for the case of a 30 chalet island resort in Malaysia, under two different RES based scenarios [47].

The concept was to fully cover the electricity demands of the resort by using (a) a totally green pv/wind/FC/battery system, instead of (b) a diesel generator supported scenario [47]. This research study revealed that an eco-friendly autonomous system with zero emissions can be feasible after serious optimization and can achieve better financial results than fossil fuel based systems [47]. Moreover, for the electrification of remote households in north Cameroon, a standalone diesel generator system, a standalone PV system and a hybrid photovoltaic system were also simulated and evaluated using Net Present Value and zero emission techniques [48]. Throughout this process, the hybrid PV system was evaluated as the most efficient by moderating the desired annual number of generator hours to cover each desirable load in several cases [48].

V. Conclusion

In the present work, several different small-scale projects with different combination of RES based equipment have been reviewed, under the major criterion to cover building scale electric loads in remote locations.

The combined use of different "green" technologies with an electrical grid has been investigated as an alternative to fossil fuels, due to their increasing price, where the grid connection is not found to be necessary, and at the same time the total cost of using renewable sources found comparable to that of a central national grid. Finally, fossil fuels have been proven inessential for an autonomous system throughout the optimization process, which is considered as a crucial part of an off-grid project design. These results indicate that a different approach towards the solution of the global energy problem is possible, in the direction of environmentally friendly and financially efficient systems based only on RES technologies.

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