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Solar energy for Sicily's remote islands: On the route from fossil to renewable energy

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Abstract

Following first attempts in the early 1980s that provided useful information on the reliability of the photovoltaic energy generation, Sicily's remote islands share a number of pioneering achievements in the utilization of solar energy. This study aims to assess progress and the remaining gaps in the large-scale adoption of renewable energy in said numerous islands. We identify the most advantageous technologies and suggest pragmatic actions, so as to allow new stakeholder commitment for further progress in the forthcoming transition from fossil to renewable energy.

Keywords: Solar energy in minor islands; Islands' sustainable development; Photovoltaic energy; Distributed generation

1. Background and introduction

Sicily, the most solar irradiated Italy's region (Šúri et al., 2007), has 14 remote islands: three (Favignana, Levanzo and Marettimo) comprising the Egadi Islands archipelago off the coast of western Sicily; seven (Alicudi, Filicudi, Panarea, Salina, Vulcano, Lipari and Stromboli) making up the Eolian Islands off the northern coast, another off the west northern cost (Ustica), and three off the southern cost, between Sicily and Tunisia (Lampedusa and Linosa comprising the Pelagie archipelago; and Pantelleria: the largest among Sicily's remote islands).

Blessed with plentiful sunshine, selected islands have hosted some of Italy's most significant first attempts in the study toward large scale utilization of solar energy. For example, Vulcano hosts since 1984 a large photovoltaic (PV) field that in the subsequent three decades will show remarkably stable performance (see below).

Like in the rest of the world, interest in renewable energy technologies remained idle until the late 1990s. A revival of attention started in the late 1990s and early 2000s when the European Commission financed a number of joint studies in which Sorokin in Italy and co-workers from other EU countries undertook and published a number of pioneering studies on renewable energies in the Mediterranean islands (Giampieri and Sorokin, 1997), that in the subsequent two decades will provide useful guidelines to a number of the Mediterranean islands now approaching 100% renewable energy supply (see below).

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A new work investigated grid control systems (Tselepis et al., 2000) for PV energy introduction in Greek, Italian and French island grids (Tselepis et al., 2001), and the opportunity of introducing PV modules on the roofs of Italy's minor islands when the price of solar modules was still greater than €7/W (Sorokin et al., 2002).

At the end of the first decade of the 2000s, the cost of both photovoltaic and wind electricity approached and then went below the so-called "grid-parity". Suddenly, the idea of a full transition from fossil to renewable power in remote islands became a serious topic of discussion and field of action both in Italy (Sorokin, 2014) and worldwide (United Nations, 2014). The Mediterranean El Hierro Island in the Canary archipelago, for example, now generates 100% of its energy from a mix of renewable sources to supply power needs for its approximately 12,000 residents, saving over 40,000 barrels of oil and 1.8 million euros each year, by foregoing importation of fossil fuel (Morales Clavijo, 2015).

Being located in areas with an abundance of wind, sunshine and water, as well as relatively small, remote islands have geographically ideal conditions for almost all forms of renewable energy (Gilchrist, 2014).

Currently, Sicily's islands import fossil fuels, mostly diesel, to meet their significant energy demand. Electricity, indeed, is not used only to power residential buildings, hotels and small and medium enterprises (SMEs), but also to desalinate seawater to meet the demand of fresh water. This has led to rapidly surging energy costs in the course of the first decade of the 2000s, during which the price of oil surpassed the $100/barrel threshold.

Like in many other remote islands in the world, this has caused a renewed interest to diminish reliance on expensive and difficult to transport fossil fuels using renewable energy. In a few years, the use of solar water heaters became a common practice in most Sicily's islands, translating in significant fossil fuel and financial savings, as most inhabitants of these islands continued to use electricity to generate hot sanitary water.

Unfortunately, Sicily's restrictive regional regulation *de facto* prevented a similarly rapid adoption of PV energy as building owners are usually required to receive explicit permit from regional authorities.

This study aims to assess progress and the remaining gaps in capillary penetration of solar energy in Sicily's remote islands. We identify the most advantageous technologies, and suggest pragmatic actions, in order to allow new stakeholder commitment for further progress in the forthcoming transition from fossil to renewable energy.

2. Achievements in using solar energy

Sicily's remote islands share a number of pioneering achievements in the utilization of solar energy. Installed and connected to the island grid in 1984 in Vulcano, part of the Eolian archipelago, the 180 kW PV plant comprised of 9% efficient monocrystalline silicon PV modules (Fig. 1) has shown remarkable stable performance.

Thorough measurements of energy generation are carried out by Italy's researchers every year since its installation. After 21 years since its installation the PV array had lost only 6% of its original production capacity (CESI,

Figure 1. Two PV fields (80 kW the one on the right; 100 kW the other) comprised of different crystalline silicon solar modules installed in the island of Vulcano, Sicily.

Figure 2. 100 kW photovoltaic field in Ginostra, an isolated fraction in the island of Stromboli, Sicily, now electrified with a hybrid PV-diesel system powering also a desalination plant.

2005), namely about one half of the assumed degradation rate median value of 0.5%/year (Jordan and Kurtz, 2013).

In 1992, in the village of Ginostra on the island of Stromboli, 30 houses were electrified by Italy's public utility using individual, stand-alone PV generators coupled to lead batteries (Eyras and Lorenzo, 1993). In 2004 the same village was equipped with an hybrid power system (HPS) relying on a 100 kW photovoltaic field equipped with three inverters, lead batteries (3000 Ah, 400 V), and a diesel generator (160 kW) for emergency generation, both connected in parallel to a newly built small grid serving all Ginostra's 140 homes with alternate current (Viglianesi et al., 2003).

The system was sized for the energy demand of the summer months when the population goes from about 40 during the winter months up to a maximum of 600 people in July and August. This results in the production of excess PV energy that remains unused from October to May (see Fig. 2).

To better use the production capacity of the HPS, a desalination system has been installed as periodical load to store water during the low occupation period and meet the water peak demand in the summer (Figà Talamanca, 2012).

The desalination system now provides a local source of fresh water replacing periodical water deliveries by a tank ship, through the use of as much excess PV energy as possible via an energy management system running the desalinator with the smallest possible amount of diesel energy, and with the largest possible amount of PV excess energy (Scrivani, 2005).

Frequent malfunctioning of the HPS has been due to failure of the lead batteries (Gazzetta del Sud, 2013). Indeed, the same utility is now switching to Li-ion batteries for analogous projects in another Italy's islands (Ventotene).

Lipari, the largest of the Eolian islands, hosts one of the world's largest PV plants installed so far in remote islands. Built in 2013 to supply at least 20% of the electricity needed by the new desalinator, the PV field has a 1120 kW nominal power (Fig. 3). Seawater desalination indeed is carried out not only in Lipari, but also in Pantelleria, Lampedusa, Linosa, and Ustica (ProDes, 2010).

3. Water desalination

The use of seawater desalination in five out of fourteen Sicily's remote islands (Fig. 4), has partly solved significant issues of water supply traditionally met by water transportation with tank ship, with an estimated cost of €10–12/m^3 and a very poor quality of the shipped water.

Figure 3. 1.12 MW photovoltaic field in the island of Lipari (circled in red), currently supplies most of the power needed by the new reverse osmosis desalination system installed close to the PV field. [Image obtained by the Authors with Google Earth.]

Figure 4. Delivery of the last module of the new RO desalination system in Pantelleria (March 2015). [Reproduced from protecnosrl.it, with kind permission.]

Initially, all the islands used the old, poorly efficient mechanical vapor compression (MVC) desalination technology. Most recently, all are switching to the 3 times more energy efficient reverse osmosis (RO) technology (5 kWh/m^3 vs 15 kWh/m^3).

In detail, Pantelleria (Fig. 4), Lampedusa and Linosa now host efficient RO modules with a fresh water production capacity of several thousand m^3/d.

Lipari too now hosts a new, large RO desalinator with a first module delivered in mid 2014 capable to supply 3600 m^3/d of drinking water. Once completed, the new RO system comprised of several modules will have a capacity of 450 m^3/h. Remarkably, and relevant to this study, the first module installed has suffered from numerous failures in the subsequent months (Leone, 2015), regularly taking place during nighttime when there is no supply of PV energy from the close PV array.

The advantages of using renewable energy to power desalination plants are now well established (El-Nashar, 2002). The complementary nature of wind and solar energy resources, for example, makes the use of wind-solar systems ideally suited to drive a desalination plant (Charcosset, 2014).

The cost analysis that led to the decision to install the 1.12 MW photovoltaic field readily shows that the main driver for the operational costs paid by Sicily's regional Government was the cost of diesel fuel for power production, with the cost of maintenance and salaries keeping constant, and even diminishing, in the period 2005–2008 (Viola and Francipane, 2012). The unit cost of potable water produced with the old MVC system, in detail, was close to 6 €, one of the highest in the Mediterranean islands, with an average energy input of 15 kWh/m^3.

4. Barriers to overcome

The main barriers to overcome to cause sustained and significant penetration of renewable energy in Sicily's islands are two: (i) the subsidies paid by Italy's Government to the utilities for each kWh of electrical energy produced burning diesel fuel, and (ii) the poor regional regulations that almost forbid the adoption of PV and wind energy systems in these islands.

Since the early years after World War II, to lower the electricity bill paid by the inhabitants of Italy's remote island, Italy's Government pays a subsidy to the local utilities burning diesel fuel transported at high cost with ships. A compensation fund is continuously fed with extra money paid by every average electricity user in Italy. Paid by the Cassa Conguaglio per il Sistema Elettrico, the average tariff in 2013 was about €0.31/kWh (Codegoni, 2013).

Under these conditions, that were clearly identified by Sorokin and coworkers already in the late 1990s as the main barrier to RE in all Italy's remote islands (Giampieri and Sorokin, 1997), one might argue that renewable energy sources will never become competitive with subsidized fossil electricity. Yet, the dramatic fall in cost of solar PV and wind systems is leading to rapid and somehow unexpected changes.

The cost of the electricity bill paid by the inhabitants of the island is starting to become unbearable. For instance, in 2013 citizens in Lampedusa publicly complained (Giovanilampedusa.it, 2013) to pay 51% of their expensive energy bill (about €0.31/kWh) for "energy dispatch service", rather than for energy itself.

Clearly, today's low cost distributed generation (DG) with PV modules in which solar electricity goes from the panels straight home, eliminating the additional costs associated with energy dispatch, makes solar electricity much cheaper, while the solar system, having no moving parts, requires very little maintenance.

What continues to delay massive adoption of PV distributed generation in Sicily's islands is the old regional regulation which demands every building's owner willing to install solar modules to undergo a tedious authorization route with authorities in Sicily's mainland. Officers at these regional authorities (Superintendency of Arts) lack guidelines that dictate proper building integrated photovoltaics guidelines (Pagliaro et al., 2010). We have recently analyzed elsewhere the reasons that those strict regulations were created in the first place (Ciriminna et al., 2015). In brief, the strong opposition to the development of distributed solar energy generation was due to the action of public officers concerned that having solar panels at rooftops might affect the esthetics of buildings.

What happens in practice is that every single permit request undergoes slow review by the few available officers. Outcome is most often a denial. The mayor of Lipari, for example, announced in early 2013 his will to undertake action to reform these rules and promote widespread adoption of photovoltaic DG in both Lipari and Stromboli (Codegoni, 2013).

What is ironic is that related regional legislation smoothly allows the installation of conventional water solar heaters whose visual impact is certainly worse than BIPV systems now elegantly integrated in all sort of historical buildings in Italy and abroad.

When a project is approved, however, home and building owners can install their solar PV systems with outcomes that are such as those shown in Fig. 5, showing a 800 year old mill, winery and olive orchard in Pantelleria supplied with solar electricity and solar-heated water since April 2010 through a 7 kW stand alone PV system connected to a 1250 Ah battery pack (a 10 kW diesel generator is installed only for backup), and abuilding integrated solar thermal plant providing all energy needs (Sustainable Design and Product Management, 2011).

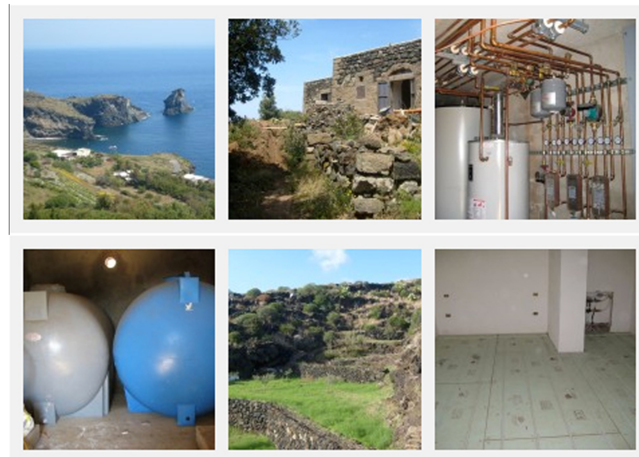

Figure 5. Images of an historic home refurbished in 2010 in Pantelleria, whose energy needs are met using solar energy. Solar hot water provides the domestic via a radiant floor heating, with ground water collected from the dome shaped roof and stored in a cistern built in the 12th century. [Reproduced from sustainabledesignpm.com, with kind permission.]

Pantelleria, an island between Sicily and Tunisia, is a volcano that 45,000 years ago was entirely covered in a searing-hot layer of green glass as a cloud of hot gases and volcanic dust spread radially out from the erupting volcano in all directions. Incandescent rock fragments suspended in the all-enveloping volcanic cloud were so hot, molten and sticky that they fused to the landscape forming a layer of glass, over hills and valleys alike (Williams et al., 2014). The need to respect and reduce the impact of human activities on such a peculiar ecosystem is obvious.

What is perhaps barely known to officers, local administrators, engineers as well as to sales professionals and management of solar companies is that even the roof of the Pope's audience hall next to St. Peter Dome, in Rome, since 2008 hosts a perfectly integrated large (220 kW) photovoltaic system (Squires, 2008).

This leads us to the foremost important need, namely to provide a renewed, better education in solar energy and energy efficiency both to suppliers and users of the new energy technologies.

5. New energy technologies education

The transition to the solar economy of Sicily's remote islands, we argue, requires better education of both suppliers and users of renewable energy technologies. It is somehow reassuring, in this respect, that Broman (co-founder in 1990 of the International Association for Solar Energy Education) recently reported that renewable energy education and training at university, school and professional training level is still far from being satisfactory in many countries (Kandpal and Broman, 2014).

Scholars at Sicily's Solar Pole have developed an intensive course for effective renewable energy education that includes the integrated and multidisciplinary study of technology, resources, systems design, economics, industry structure and policies.

The aim of the course is to fill the gap of human resources with required knowledge and skills needed for accelerated dissemination of economically viable and environmentally responsible renewable energy technologies in these islands. Eventually, students ending the course will be able to increase public perception of renewable energy as an intrinsically reliable and cost competitive energy source to produce electricity, low temperature heat and useful white light for ideal illumination of all sorts of buildings.

The course will dispel a number of myths surrounding renewable energy, transmitting new knowledge and new skills. The final objectives are clear: ending the combustion of fossil fuels for all energy user needs – artificial light, electric power, low temperature heat, cooling and transportation – replacing said combustion with clean electricity and clean solar energy to produce low temperature heat required in buildings.

Students, for example, learn the route that led to one of the first islands with a significant population (11,000 inhabitants) to achieve almost energy self-sufficiency.

Between 1990 and 2000 Europe held a clear leadership position in renewable energy research and industry. In those years, and still in the early 2000s, the European Commission financed much of the research carried out across Europe to bring renewable energy to Europe's remote islands.

As mentioned in the introductory section, Spain's El Hierro island now generates almost the entire energy needed by the island's 11,000 residents, summer tourists, and (three) water desalination plants from a mix of renewable sources which includes a 11.5 MW wind farm consisting of 5 turbines and a 11.3 MW hydroelectric plant.

Surplus wind power is stored as water potential energy by pumping water up 700 m to fill the crater of an extinct volcano. When winds are calm or when demand exceeds supply from the wind generators, water is released from the crater to generate 11.3 MW of electricity, filling an artificial basin created at the bottom of the extinct volcano (Fig. 6). Water in the lower basin is then pumped back up again to the upper reservoir when there is excess wind power.

It is less known that the original project had been devised in 1999 by an Italian energy technology company (Ansaldo) along with other research partners such as the Instituto Tecnológico de Canarias (ITC), to be deployed in the Greek island Ikaria in the Aegean Sea (European Commission, 2001). When the Italian company decided not to go ahead with the project, the ITC rescued the idea and brought it to El-Hierro where it was adapted to the specific geography of this nice volcanic island, showing incidentally the general validity of the renewable energy transition.

6. Economically viable technologies

The energy end users in Sicily's islands willing to switch to renewable energy to meet their energy needs are interested in learning which specific technology to adopt. Yet, available information is often poor, obsolete and fragmented. Yearly surveys show that people in Italy greatly welcome photovoltaic energy, with 84% of the panel preferring energy independence and considering to switch to solar distributed generation (Fondazione Univerde-IPR, 2015) and welcome photovoltaic energy, but they can barely tell the difference between a solar thermal (collector) and a photovoltaic panel.

Writing the present study at the end of 2015, when the grid parity in Sicily has since long been achieved (Meneguzzo et al., 2016), requires to start from this very societal demand. In other words, rather than opting for a "push" approach in which several renewable energy technologies are presented with their own advantages and limitations, following Seddon we opt for a "pull" approach (Seddon, 2005) in which the technology offer is based on

Figure 6. Five wind turbines (left) coupled to an hydroelectric plant using an artificial basin at the bottom of the extinct volcano (right) and the volcano's crater, now provide almost the whole energy needs of El Hierro island, in the Canaries archipelago. [Reproduced from technocrazed.com, with kind permission.]

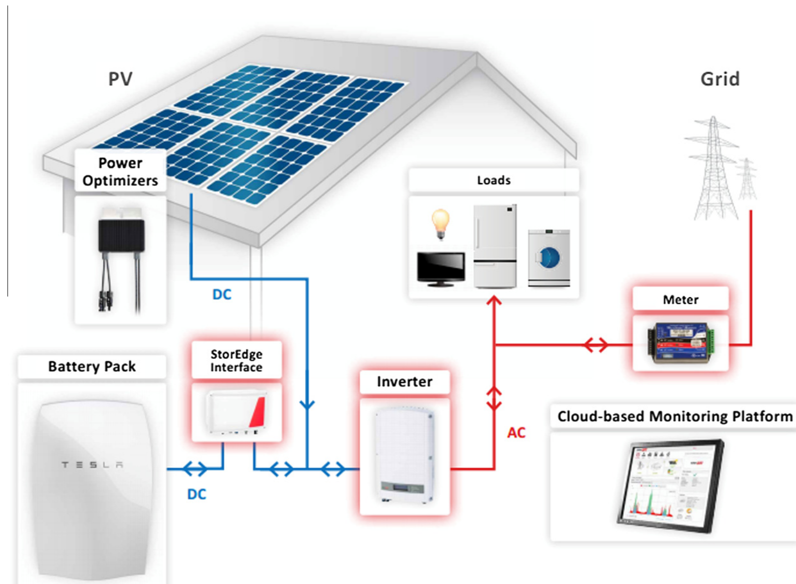

Figure 7. BIPV energy generation coupled to power optimizers and energy storage in Li-ion battery allows home owners to maximize self-consumption and reach energy independence. The solution is based on a single inverter for both PV and storage. [Reproduced from solaredge.com, with kind permission.]

said demand: low cost distributed generation with no impact on the environment and the landscape.

It follows from this assumption that the two main technologies meeting these requirements are BIPV and solar thermal. The former technology will be used along with inverters equipped with Li ion batteries (Fig. 7) and power optimizers that adjust the power output from each PV module on the roof allowing to recover 25% more energy compared to conventional PV technology, combined with energy management software. Unused PV power is stored in a battery pack and used when needed to maximize self consumption. The local users, in other words, will be accustomed with state of the art, advanced solar technology, and not with solutions developed two decades ago turned into inevitable obsolescence.

The latter technology will use newly developed solar thermal water heaters of no visual impact, such as the one with a 26 cm thick boiler painted with the same color of the roof; as well as the elegant solar air technology integrated into facades (Fig. 8) to quickly generate hot air plentiful in oxygen during the winter season thereby freeing homes and building of all sort from the high relative humidity that characterizes most buildings of remote islands, including those of Sicily's sea.

Getting to the next step, and willing to achieve massive penetration of renewable energy, larger energy generators will be required. Five wind turbines each with 2.3 MW nominal power are enough, coupled to similar power hydro generation, to power El Hierro.

What is the visual impact of the wind turbines displayed in Fig. 6? One might even argue that clean technology renders the slopes even more elegant.

Pantelleria (from the Arab for "*the wind daughter*") has similar size, 8000 inhabitants, two desalination plants, a seasonal touristic peak during summer and constantly blowing wind. The southern side of the island, with plenty of space and low home density is ideally suited to install 5 or 6 wind turbines. Backup could use hydrogen generated at low cost from fresh water of the desalination plant (Pagliaro and Konstandopoulos, 2012). The diesel generator would then be replaced by a series of PEM fuel cells generating electricity when the supply from the wind turbines is insufficient, further progressing the approach chosen for El Hierro.

Figure 8. Sicily's home heated with solar air. Relative humidity went from >80% to an average 55% in less than 4 days. Since then, the home has never suffered from high relative humidity again. [Photograph of Mario Pecoraino.]

7. Managing externalities

When assessing the sustainability of renewable energy development, it is important to take into account the influence of external (and potentially unpredictable) factors to understand for example how vulnerable are the local renewable energy enterprises to potential disturbances of external factors, and what could be done to minimize the impacts of those disturbances.

For example, renewable energy looked favorable when oil price was $100/barrel in the early 2000s, but at the writing of this study oil price has fallen to around $30–$40/barrel. Yet, as mentioned above, the price of solar PV modules has reached such a low value (<$0.50/W) to make solar electricity economically viable even in countries where oil is practically free such as Saudi Arabia or other Middle East countries. Specifically, a watt of solar photovoltaic capacity dropped in price by a factor of about 2330 between 1956 (about $1910 in 2013 dollars) vs. $0.82 in 2013, with cost of PV modules decreasing at an average rate of about 10% per year since 1980 (Farmer and Lafond, 2016).

We have also mentioned above that energy consumers in Sicily's islands still rely on subsidies from Italian Government. It is not inconceivable that those subsidies could decrease if oil prices remain low, or if political situations change in Italy beyond the control of people in Sicily. In any case, it is the high and increasing cost of the "energy dispatch service" mentioned above (Giovanilampedusa.it, 2013) that is making the cost of the electric kWh in Sicily's islands ever more expensive, beyond the cost of oil-derived fuel used to generate electricity, reinforcing the case for distributed renewable energy generation.

As another example, with climate change, a future change in cloudiness over the region might affect the net available solar power as climate is constantly changing due to anthropogenic processes. Yet, in the near term, the impact of the greenhouse-gas forcing is relatively minor (10% over one century in the US; Saenz and Huang, 2015) such that the estimate of solar power potential using present-day climatology will remain useful in the coming decades.

8. Conclusions and recommendations

This paper surveys the regional development of renewable (particularly solar) energy in the Sicily islands region over multiple decades. The study adopts a "big picture" approach that synthesizes many aspects of the development – technical, environmental, economical, and more. The study focuses on Sicily, but the value of its findings is general. Readers, for example, may discover that the use of excessive energy for water desalination is an innovative design that could be adopted by other regions in the world.

The study further identifies the barriers to the transition from fossil to renewable energy resources, in order to suggest solutions to accomplish this transition using economically viable solar energy technologies in an environmentally responsible way.

All stakeholders will have to play an important role.

Sicily's policy makers will review and update existing legislation establishing clear guidelines for solar and wind energy in these islands, in order to ease the adoption of clean energy with no threats to the beauty of these wonderful natural resources whose economy is largely based on tourism.

Local policy makers, as is already happening with projects such as "Egadi sotto le stelle" and many others, will take part in EU-funded programs to boost the use of clean energy and energy efficient technologies, including electric vehicles. Local policy makers will assume a leadership role to foster the systematic partnerships between governments, businesses, educational and research bodies, citizens, and environmental groups needed to support the transition to the solar economy.

Local energy users, i.e. families and small companies, will select and purchase the most economically viable and reliable technologies for distributed generation, namely photovoltaics and solar thermal.

Suppliers of renewable energy and energy efficiency technologies will strive to meet the large demand of economically viable solutions for self-making energy through a flexible offer based on quality of the technical solutions, accessible prices and quick installation from qualified installers.

Engineers and architects will make an effort to update their knowledge studying the building integration of solar technologies, as well as the new smart technologies to optimize clean energy utilization. Finally, local utilities rather than perceiving renewable energy as a threat to survival, will strive to transform themselves from suppliers of fossil electricity to suppliers of distributed generation systems, and suppliers of clean electricity through the existing grid.

Along the route to become energy self-sufficient communities, these islands will increase their attractiveness to their own citizens and to the rest of the world. Inhabitants, firms and public bodies will stop paying ever-increasing energy bills giving place to a flow of wealth systematically leaving the island.

The environment will greatly benefit, with the end of polluting emissions, the end of costly and hazardous fossil fuel delivery via tank ship, and the environmental remediation of sites where the old thermoelectric power units were installed.

The economy will largely improve because the transition to low cost, renewable energy will liberate resources that will be used to lower prices and expand the touristic offer from the summer central months to the whole year. Hopefully this study will provide further guidelines on how to accomplish this transition.

Acknowledgments

This article is dedicated to Alex Sorokin (InterEnergy, Italy), eminent energy engineer who pioneered the use of renewable energy in Italy's islands and mainland when most engineers and administrators barely believed it could cover more than a tiny fraction of energy needs.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijsbe.2016.04.003.

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