Solar Living Lab: implementing sustainable experimentation process, responsible innovation and community engagement in a solar energy research facility.

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Abstract
The aim of our work was to investigate the feasibility of implementing a Living Lab approach into a solar energy research infrastructure, promoting open participated and sustainable experimentation processes. We pursued this goal by studying similar experiences, tackling technical, social and cultural challenges, testing innovative solutions in a real-life context, engaging stakeholders and enhancing the commitment of local communities within a broader solar-driven energy transition process and a smart specialization strategy. Furthermore, the implementation phase showed the high potential of replication of this initiative bridging to other twinned demonstrative infrastructures in the Mediterranean basin (Cyprus, Jordan, Egypt). The results so far achieved proved that an iterative innovation process has been effectively triggered, whose impact is being measured to design future development, and an overall interest has been raised by the Solar Living Lab approach, leading to new applications and to the enlargement of the local, national and international networks of the solar research infrastructure.

Keywords: *solar energy, smart specialization, open innovation, energy infrastructures, responsible innovation*

1 The energy transition scenario

The starting point of our study was to analyse distributed energy models as applied in 100% RES communities (Meiffren et al. 2015), which are experimenting energy generation from local renewable sources. The challenge that the 100% RES movement has tackled in Europe and outside is to show that: i) a different scenario for energy production and consumption is not only possible, but also economically profitable; ii) integrating energy generation and management systems into the community result into a decreased environmental impact; iii) a bottom-up approach to energy action plans could exploit local competence and supply chains, by converging the choices of policy, research, industry and citizens in the energy field; iv) benchmarking at a transnational level is not only an added value, but indeed, it is necessary to set up a transition arena able to trigger and drive change .

Energy transition, in fact, is only one piece of the game which involves resilient towns and communities, stepping up to address the global challenges by starting local with co-designed solutions for a low carbon future (Hopkins et al., 2016). Promoting community resilience in energy crisis times means “intentionally guiding the system’s process of adaptation” (Lerch, 2015): thus, increasing the share of renewables in the energy mix does not definitely help overcome the crisis, unless the territorial system develops the ability to transform and remake itself, with a change in behaviour (consumption patterns), business (energy ownership), policy (environmental impact, sustainable use of resources), science (responsible research), relationships (participation, awareness).

The United Nations are fully supporting this vision; 2030 Agenda for Sustainable Development, formally adopted in September 2015 by the UN General Assembly, has introduced a holistic and transformative vision of sustainability, to be implemented through partnership and commitment of government, research, business and civil society (UN, 2015). In particular, *Sustainable Development Goal 7 - Ensure access to affordable, reliable, sustainable and modern energy for all* (UN, 2015) calls all the actors concerned for joining their efforts to increase the renewable share in the global energy mix, to improve dramatically energy efficiency, to enhance international cooperation to facilitate access to clean energy research and technology, to promote investment in energy infrastructure and clean energy technology, supplying modern and sustainable energy services for all especially in developing countries.

The European Commission, through the Energy Roadmap 2050, has underlined that the energy system of the European Union (EU) is changing too slowly to decarbonisation and that efforts should be both structural and social, including: a joint responsibility of energy saving and managing demand; switching to RES with further technology development to bring down costs; rethinking energy markets; integrating local resources and centralised systems (EC, 2012).

The Energy Union policy document is aligned with the UN SD goals: a resilient Energy Union to give EU consumers - households and businesses - secure, sustainable, competitive and affordable energy "with citizens at its core, where citizens take ownership of the energy transition, benefit from new technologies to reduce their bills, participate actively in the market" (EC, 2015). Three years since the publication of the Energy Union Framework Strategy, the Commission has presented proposals to deliver on the energy efficiency first principle, support EU global leadership in climate action and renewable energy and provide a fair deal for energy consumers (enabling measures).

On the technical side, the Strategic Energy Technology plan (EC, 2017) has outlined the huge potential that renewable energy and energy efficiency investments have for EU economic growth and employment. By 2015, the EU has counted 1.6 million people working on renewables and energy efficiency, representing a growth of 13 % since 2010. By 2040, projections indicate that renewable energy sources will represent 60% of the European electricity mix, with solar representing half of the additional installed capacity. At the regional and cross-regional level, EC energy policies have been enforced through the Smart Specialization Strategies, applying a place-based approach characterised by the identification of strategic areas for intervention through SWOT analysis and Entrepreneurial Discovery Process (EDP) with wide stakeholder involvement. "We need to anticipate and manage the modernisation of existing economic and societal structures, bearing in mind that today, more than ever, local issues have gone global and global issues have become local" (EC, 2017). EU regions have been then encouraged to identify their specific competitive advantages, as a basis for prioritising research and innovation investment; thematic Smart Specialisation platforms, such as the one in the Energy domain, foster value chain linkages and joint investments across the regions to pool experience and resources.

2 R&I and LL in the solar energy field

Within this framework, since 2011, at Consorzio ARCA we have been pursuing the implementation of a research infrastructure for the experimentation of innovative solar systems, which could provide affordable, reliable, sustainable distributed energy services, suitable for an integration at a building, settlement and community level.

We meant to fulfil this plan not only through individual projects, but also by means of an integrated set of actions, as part of a process which could harness a systemic change to support innovation in the transition towards sustainable communities.
The most suitable approach which could allow achieving this objective was, in our view, the Living Lab concept.

Living Labs are user-driven innovation environments where users and producers co-create innovation in a trusted, open ecosystem that enables business and societal innovation[1]. Studies have explored the relationships between innovation capability, entrepreneurial orientation and performance of Living Labs as user-centred open innovation ecosystems (Krawczyk 2013).

A Living Lab takes research and development out of the laboratory and into the real world, engaging stakeholders, citizens, and end-users in the collaborative design of new services. The immediate benefits of the Living Lab approach derive from this new relationship created between people and technology (Marsh et al. 2015).

In the energy sector, this would imply providing a detailed and real time awareness of where energy comes from and where it's going, engaging citizens and the community together to explore the social and behaviour implications of new technologies and co- design new solutions.

In particular, we adopted five pillars which should govern our Living Lab operations: a) the business and societal value offered to fit users[36] innovation needs, b) the influence that users can have on innovation and development process, utilising the creative power of the Living Labs, c) the sustainability of a responsible innovation environment for future generations, d) the openness in getting different stakeholders participate in the innovation process, with multiple perspectives, e) the realism to put innovation in operation in a real- life testing setting (Ståhlbröst, 2012).

Firstly, the scenario we analysed concerned the research infrastructures based on solar technologies relevant to our study, which could show a high potential in terms of impact on local communities. Our survey started from the Archimede Power Plant by ENEL at Priolo Gargallo (Siracusa, Italy) which represents an output of an applied research community set around the Italian agency ENEA in the fied of innovative concentrating solar technologies (Donatini at al. 2007); main premises for ENEA solar technologies are in Casaccia (Rome) and Portici (Naples)

Plataforma Solar de Almería (Spain)[37], Proteas facility (Cyprus)[38], University of Evora (Portugal)[39] and CEA INES (France)[40] are among the facilities that have been investigated at this stage.

Secondly, we referred to other Living Lab experiences in the RE domain.
The Energy Living Lab (Switzerland)[41] aims to empower energy users (citizens, employees of private companies, members of the users' association, etc.) and to integrate them into the innovation process, motivating them to participate, encouraging bottom- up dialogue and

[36] http://www.openlivinglabs.eu/
[37] http://www.psa.es
[38] https://www.cyi.ac.cy/index.php/eewrc/eewrc-research- projects/energy/facilities.html
[39] http://www.en.catedraer.uevora.pt/sobre/iniesc
[40] http://www.ines-solaire.org
[41] https://enoll.org/network/living-labs/?livinglab=energy-living-lab

turning ideas into sustainable business products or services. Botnia Living Lab (Sweden)[42] supports the process of developing digital service innovations from the early exploratory needfinding phases, through the iterative process of designing the service by experimenting, piloting and evaluating in real world situations, with applications in the area of energy efficiency among others. Adelaide Living Laboratory (Australia)[43] engages stakeholders to provide pathways for low carbon living with both local and national significance across three research programs (Integrated Building Systems, Low Carbon Precincts, Engaging Communities). Coventry City Lab (UK)[44]supports users to develop and test innovations in low carbon vehicles/transport and sustainable buildings. E-zavod (Slovenia)[45] operates in four pillars of sustainable development – ecology, economy, energetic and e-business, assisting the citizens as energy users in applying innovative ICT approaches and technologies in order to optimize energy consumption. The Living Lab Green Schools in Treviso (Italy)[46] has been conceived as a mean to involve users in the energy efficiency process, based not simply on technological devices for energy saving, but additionally promoting changes in people's behaviour.

Other Living Labs either include energy innovations in a broader smart city concept or focus on specific technology application (i.e. lighting, recycling, urban mobility). It is also worth mentioning the case of the SusLabNWE – Sustainable Labs North West Europe[47] as a project of an international infrastructure of Living Labs in Northern Europe in the domain of building energy efficiency, where research is brought into a real-life setting within a design-driven process.

3 Setting the Solar Living Lab

Considering this scenario, our work has been thus centred on conveying a Living Lab approach into a solar research infrastructure characterized from accessibility, openness, innovation co-design, experimentation.

In the design phase of the infrastructure it has been decided to prioritize the experimentation of technologies that could address the energy demand in the Mediterranean solar belt, and especially the fast-growing demand of cooling services in buildings due to the expansion of the urbanized population and the effects of climate change. Within this priority, the first challenge to be addressed was the downscaling of the relevant technical experience available gained by the Italian technical community in the design of concentrating solar systems for the

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42 https://enoll.org/network/living-labs/?livinglab=botnia-living- lab#description
43 https://enoll.org/network/living-labs/?livinglab=adelaide-living- laboratories#description
44 https://enoll.org/network/living-labs/?livinglab=city-lab- coventry#description
45 https://enoll.org/network/living-labs/?livinglab=e-zavod-living- lab#description
46 https://enoll.org/network/living-labs/?livinglab=green-schools#description
47 http://suslab.eu/about/suslab-mission/

power utility market, towards the experimentation of innovative components for solar polygeneration at a scale that was suitable for local and distributed energy models. A huge growth potential in small-scale CS plants is estimated in the upcoming decades, as well as in the application of solar systems in industrial heating and cooling. Technological improvements in solar field elements, such as collectors and mirrors, reduced costs in installation and engineering, and cost reductions in specific components, too, are expected (IRENA; 2018).
At present, heavy barriers are slowing down the full exploitation of these applications of solar energy. Low awareness, lack of confidence, limited number of proven configurations and long payback periods are limiting the attraction of potential developers and customers. Low availability of finance is somehow a consequence of that, and it will become less important as the first demonstrative installations are successfully deployed.

The Solar Living Lab (SoLL) has been tackling these barriers from the beginning, promoting the potential of different technologies and plant configurations, spreading the knowledge and the discussion about the upcoming opportunities among the different stakeholders, in the business and professional communities, in the academy, with policy makers and citizens.

SoLL has been promoted by Consorzio ARCA, a public- private consortium specialized in business creation and incubation, technological and social innovation, technology transfer and business advisory. Thanks to this background, a 4-helix interaction has been introduced in all the processes, where researchers, companies, public bodies and citizens debate about the practical application of commercially available and innovative technologies that could improve the environmental resilience of the Mediterranean communities, with positive effects on employment and economic wealth, too (Montagnino 2016).

At SoLL infrastructure, in an area granted by the University of Palermo (Italy), two technologies have been already implemented: a polygenerative plant using Linear Fresnel Reflectors (LFR) and a hybrid photovoltaic/thermal high concentrating system (HCPV/T); integration and hybridization with other systems are under assessment.

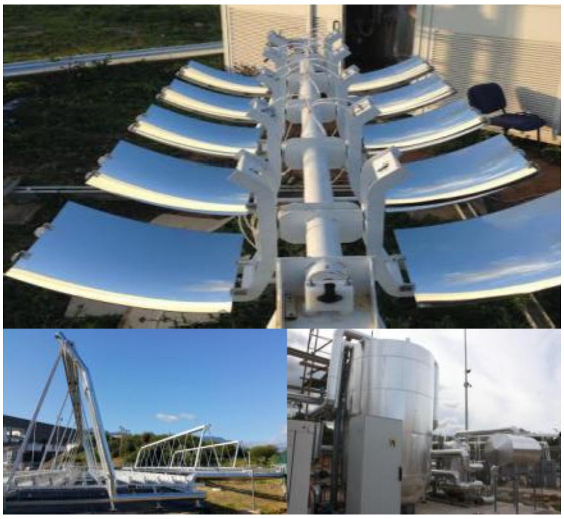

Figure 1. SoLL research infrastructure in Palermo, Italy

The demonstrative plant as a whole is an open and accessible infrastructure for practitioners, researchers, students, companies, and welcomes contributions to its further technical, economic and social development, thanks to its favourable location in front of the University business incubator.

SoLL has been the first site that has been adopting a Living Lab approach inside a Mediterranean network of similar demonstrative infrastructures, which are hosted in Aglantzia, Cyprus (at Cyprus Institute), Markaz Belbes, Egypt (at Sekem Hospital), Irbid, Jordan, (at Al Balqa Applied University college).

Figure 2. SoLL twinned research infrastructure in Jordan

Figure 3. SoLL twinned research infrastructure in Egypt

Figure 4. SoLL twinned research infrastructure in Cyprus

All these plants have been installed within the STS- Med project, financed by the ENPI CBC MED programme, to demonstrate that a smart integration and optimization of both commercially available and innovative solar technologies, at a settlement level, can open a way towards the goal of “zero energy” communities in the Mediterranean region (Rashad et al. 2015, Kiwan et al. 2016), with a significant reduction of CO2 emissions and consumption especially in seasonal peak.

The four twinned plants have been conceived as Living Labs introducing the technology mix into different real-life environments acting as showcases for the respective local communities. Thus, the design of each demo site has been adapted accordingly with the result of specific energy audits and the availability of either ground or roof space for the collectors. Local communities have been involved in awareness activities and local SMEs have been invited to take part into educational activities during the preparatory and installation phases. The participation of users, in the validation of the proposed solutions, and of local SMEs, in the construction and in the supply chain of components in these first demonstrative plants, can be considered the fundamental step in the set-up of a capacity building process.

Comparative studies of design options and subsystems are in progress to identify the best strategies for the overall optimization of both efficiency and cost; at the same time, the local academic and technical communities will have a joint and open access to the demo facilities as platforms for future collaborations and developments. The full adoption of the Living Lab approach by the Cypriot, Jordanian and Egyptian site has been agreed and planned.

4 Methodology

Design thinking

The process leading to the set-up of SoLL started in 2011 by gathering a thematic network of competence (from universities and research centres, municipalities, SMEs and large companies from the energy supply chain, science communication associations, local development agencies, software and automation developers, engineering and construction companies) around design thinking for a new energy transition arena. Territorial challenges have been tackled benchmarking with global experiences, referring to three scales: building, settlement and community. The co-design process for the implementation of the Living Lab has been developed on four main pillars:

i) vision at the political and administrative level and participation to maximise local value creation and community empowerment;
ii) knowledge management and design thinking, through analysis of data and promotion of idea- generation initiatives;
iii) demonstration of appropriate technologies in relevant, open environments;
iv) business models attracting investors and partners, project financing and crowdfunding,

cross-sector engagement and energy co-ownership.

Open innovation

In the Open Innovation paradigm, ongoing innovation flows, within a collaborative environment, stimulate challenges for all systems concerned (research, business, social and institutional), promoting the development of new devices, methodologies, architectures, the acceleration of the evolution of the competitive scenario as well as the integration of new actors in the value chain (EC, 2015). The compatibility of the Open Innovation paradigm with the User Innovation stream, centred on distributed innovation processes from the perspective of the user, has been increasingly encouraged, not only in academic theory, but also in business practice (Schuurman, 2015).

Through a legacy open innovation platform (http://wave.consorzioarca.it/) managed by ARCA, SoLL may support scouting and collecting innovative solutions for sustainable ecosystems to match the energy demand of local communities for improving their quality of life without a depletion of resources.

Entrepreneurship through experimentation is a key step of the process. “Experimentation is like yeast that raises the propensity for entrepreneurship and in this way helps to strengthen the inducement to invest in new venture” (Curley 2013); an open innovation setting, in our case, has also fostered casual interactions between people with different backgrounds and expertise.

Responsible research and innovation

SoLL is matching the Living Lab approach with the Responsible Research and Innovation principles (RRI) to commit researchers, social players and innovators to interact in order to generate ethically acceptable and socially and environmentally sustainable innovation products, services and processes in the energy sector and to boost technological applications which really fit crucial societal challenges.

RRI fosters transdisciplinary to help the research and innovation community to deal with the prescriptive limitations of scientific knowledge and technological know-how. It is a combined future and goal-oriented responsibility for sustainable development with a clear societal demand-driven strategy, re-empowering citizens and researchers, including them in democratic R&I process (Deblonde 2015).

One of SoLL strength points is the availability of technology services at the demonstration sites, where it is now possible to see in operation a number of devices and solutions that can be discussed, transferred or criticized and upgraded through the interaction between the R&D and the business community, till the integration of downstream technologies from the solar source (cooling, water treatment, power blocks, etc.) and a further characterization of the process.

It is hosted – not by chance – in a site where educational and research activities are running. The intention is to foster an ongoing dialogue among researchers, trainers, professionals, companies on the advancement of these technologies and keep on communicating to the citizens (particularly, to schools) any improvement to get them aware of the impact and raise the level of acceptability. Undergraduate students and PhD students of local University from different disciplines (physics, engineering, energy, electronics, environmental sciences) carry out some field training on site to gather information, study innovative solar collectors and do experimental work on the construction, operation and monitoring of advanced solar systems. SoLL has also hosted some simulation activities within the research work of PhD holders of other countries participating in H2020 international mobility schemes.

Multi-actor and public engagement have been pursued as a key factor for positioning the Lab both in academic, business and civil communities, enabling the access to scientific results and advanced knowledge, establishing formal and informal training processes, enhancing the pilot plant as a key attractor for future development. The design of SoLL has been driven by the consciousness that research and innovation systems, in order to address the great challenges of our time, have to face a transition phase where comprehensive collaborative practices should be introduced.

Thus, one sensible effect of SoLL upon the academic institutions engaged in the field of renewable energy is the advance in understanding and applying open and user innovation principles and processes. Namely, the R&I institutions have been partnering with local municipalities, business actors, NGOs, associations and other representative networks and citizens have been engaged in energy awareness-raising public events.

Hence, SoLL intends to prove that developing alternative technologies to harness renewable energies can help make life better and contribute to reach the ambitious UN target of universal access to modern forms of energy by 2030. In particular, it has the ambition to act as a place where not only energy transition, but also social transition is facilitated allowing different actors (representing politics, academia, business and civil society) to discuss and map innovations for transition and collaborate to the development of creative solutions (Snick 2016).

Citizens' ownership as energy prosumers is at the centre of RRI strategies which are being implemented by the research performers and technology providers connected with SoLL environment and is the core of democracy in energy vision that is being mainstreamed into local action plans and territorial development strategies.

Citizens' engagement

Within SoLL community, attention is paid to make technologies fully accessible by a wide unskilled audience.

Figure 5. Solar Hackaton

SoLL invests in communication targeted to different groups, such as:

i) schools, getting the chance of guided visits to the demonstrative site and to practice about the new technologies thanks to educational labs and scientific exhibits;

Figure 6. Students' guided visit to SoLL plant

ii) energy professionals, participating in workshops, training sessions, seminars;
iii) companies, involved in joint projects and initiatives with the research community;
iv) citizens, invited to join big informal events for science communication, getting familiar about innovative energy solutions and the impact on their daily lives;

Figure 7. SoLL educational labs

Value co-creation and business networks

In SoLL, business actors operating in the field of renewable energy are informed, trained and involved in field activities related to the emerging opportunities in solar innovation. They are, in most cases, mature companies that are already delivering solar or downstream components. Also, other industrial partners have been joining the supply chain from less specialized businesses such as the production of metal parts and glass plates, plumbing and cabling, civil works.

Engineering companies are experiencing the design process at a pilot scale, preparing themselves to exploit their potential at a broader and larger scale.

Figure 8. Local company staff at work in the demo plant

A successful innovation often demands an innovative business model (Chesbrough, 2003). As for new ventures, successful business models in this sector should consider: a good availability of the energy source, the attention from national/regional policies, proper market conditions, interest in secure and low-impact energy systems and off-grid energy solutions, incentives to support small and medium scale innovative systems at a community level, local supply chains to be developed.

SoLL has become a benchmark for the technological development of some specific components, for instance for the producers of mirrors, which have shown interest in implementing new industrial processes to keep their production competitive.

It has been proved that, if they have access to the right knowledge, small size companies operating in the field of manufacturing of mechanical parts, industrial automation, civil work and plumbing, civil and ancillary works, air conditioning, can be effectively clustered around the supply chain of multigenerative solar plants (Montagnino 2016) (Montenon et al.2016).. Furthermore, it is of utmost importance that local companies adopt an open attitude to research and collaborative development, being available to test open innovation practices, to implement highly specialized shared services on technologies ensuring high performances, to expand a development model based on networks involving both small, medium-sized and big companies together with other stakeholders in an international perspective (Marsh et al. 2011).

Figure 9. Installation works in the twinned plant in Egypt

5 Results

SoLL has registered significant achievements so far:

- 6 local communities involved in Italy
- about 5.000 individuals reached by SoLL services
- 30 public authorities for energy and industrial development taking part in the policy improvement process
- more than 1.000 trained professionals, researchers, energy experts, technicians
- about 30 companies sensitized and qualified to invest in this technology or to operate within the supply chain
- 12 technical awareness events organized with more than 500 participants
- almost 300 participants in an energy festival open to the public
- about 700 registered visitors to the site.

Pilot installations of SoLL technologies will be soon implemented in France and Cyprus, in

the framework of the H2020 project ZERO-PLUS (Achieving near Zero and Positive Energy Settlement in Europe using Advanced Energy Technology), as a result of an iterative design process.
Industry-academia collaborations have been developed with some among the most active universities in Europe in the field of solar thermal research, institutions and companies. These institutions, after visiting the SoLL site, have considered the showcased technologies for new research and innovation projects.

A valuable replication effect has been produced also at the regional scale in another community located in an inner area of Sicily, which led to set up the Madonie Living Lab, which is promoting the larger perspective of energy sovereignty within the green & resilient community strategy adopted by this rural area (Mazaj et al.2018).

At the same time, the challenge related to its sustainability in terms of human resources and funds allocated has to be faced on a daily basis, trying to take advantage from SoLL roots in the community as well as its links with global networks to reinforce its role and the value of its mission.

6 Conclusions

A wide range of solar energy technologies exists, but only some of them are market mature or nearly mature, while others are still too expensive or uneasy to install. In the Mediterranean basin, solar technologies can give a determinant contribution towards the goal of 100% RE communities, improving their environmental and economic resilience.

SoLL has paved the way to foster an ongoing debate on these issues, raising the interest of the general public as well as of the scientific and business community, while interacting with the policy makers concerned. It has registered so far significant targets at the different levels above mentioned (civil society engagement, policy makers consultation, industrial research and innovation progress, business development) and it is acting as a model for a broad network of similar platforms in the Mediterranean area. It has designed and set up demonstrative plants conceived as Living Labs in order to support the further development of the technologies in a real-life environment, supporting the local smart specialization strategies in collaboration with SMEs, local stakeholders and citizens.

Furthermore, it is experimenting the integration of the Living Lab approach and participatory strategic planning as valuable tools of regional and national development policies.

Coherently with SDG 7, co-design, experimentation and public engagement activities have been launched to increase the renewable share in the energy mix, to downsize systems at building, settlement or community scale for an enhanced effectiveness and a reduced environmental impact, to put citizens at the centre of energy research and innovation, to foster sustainable and inclusive business in the energy domain and improve the provision of modern and sustainable energy services in developing areas.

7 Acknowledgements

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