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Solar Energy

Que faire? A Bioeconomy and Solar Energy Institute at Italy's Research Council in the Context of the Global Transition to the Solar Economy

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Abstract: Driven by insight for which new research and education requires new institutional organisation, and drawing on two decades of research and educational efforts, we devise the profile and activities of a new bioeconomy and solar energy institute at Italy's Research Council. We further articulate the institute's activities suggesting avenues on how to deploy sound and giving more useful research, education and policy advice in these crucial fields for making tomorrow's common development sustainable. The outcomes of the study are of general interest, because the transition to a solar economy is of intrinsic global nature and the challenges involved are similar in many countries.

Introduction

Since about a decade, the world is witnessing an unexpected boom in renewable energy.[1] In 2016, the cumulative installed photovoltaic (PV) and wind power reached 303 GW (1 GW = 1 billion W)[2] and 486 GW, respectively.[3] Growing along this trend, with the price of PV modules continuing to fall by 10% a year up to 2030, PV energy will cover 20% of the global energy consumption by 2027.[4] Huge countries such as China can build a 1547 MW photovoltaic park in less than a year (the Tengger Desert Solar Park), while India is cancelling orders for huge (13.7 GW) coal-fired power stations,[5] and instead continues to install several GW per year of solar parks across the country through transparent auctions with ready provision of land and connection to the grid (targeting 100 GW by 2022, including 40 GW of solar capacity from rooftop solar).[6] By May 2017, the lowest cost of the kWh (kilowatt-hour) of PV energy purchased by the Government-owned Solar Energy Corporation of India for the subsequent 25 years reached INR (Indian Rupee) 2.44 per kWh (about US $ 0.038 per kWh), namely 31% lower than the wholesale price charged by a major coal-power utility.[5]

In brief, given the low and rapidly decreasing cost of renewable energy technologies to produce electricity from sun, wind and water, the transition of entire country economies to 100% renewable energy has become a topic of serious research and new policy efforts.[7] Comprehensive studies indicate a common basic feature of different energy systems evolution through the deployment of increasing levels of renewable energy source penetration (up to 10%, to 50% and over 50%),[8] even if only a short time is available to achieve the transition before the rapidly shrinking EROI (energy return per energy invested) of oil and the booming population dynamics will cross causing serious economic and social threats.[9] In brief, the world is en route to the solar economy envisaged by Hermann Scheer[10] in which energy, but also goods,[11] will originate from renewable and no longer from fossil resources.

The role of chemistry in this evolution cannot be underestimated. New production technologies and new bio-sourced materials developed in over 25 years of research in green chemistry, for example, are finally being transferred from the laboratory to production plants. Gone are the days in which the practice of green chemistry in the chemical industry was stagnant.[12]

Drawing on two decades of successful research and educational efforts, including 12 international conferences held in Sicily since 2009, in the following we discuss the outcomes of an analysis aimed at evaluating the opportunity for Italy's Research Council to establish a new bioeconomy and solar energy institute. Conceived from a broadened perspective in which social, economic, governance and innovation issues are dealt with scientific and technology aspects, the study has a general interest, which goes beyond Italy and Europe, as the urgency of a transition which is global in nature, and the challenges involved in different countries in such transformative process, are similar.

National and Global Context

Covering 7.7% of the overall electricity demand in the first five months of 2017,[13] photovoltaic energy in Italy has the largest share in the energy mix amongst world's highly industrialised

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countries. The benefits of PV generation are not only environmental (drastically abating the negative environmental impact of conventional electricity production, such as polluting gas emissions, freshwater ecotoxicity, eutrophication and particulate-matter exposure),[14] but also economic with a substantial fall in the price of electricity in the Italian wholesale electricity market (IPEX).[15] This replicates in Italy what is being observed in Germany, where a huge 40 GW installed solar park (twice the PV solar capacity in Italy) often leads to negative electricity prices, which compensates for the large renewable energy surcharge (€ 0.0688 per kWh in 2017).[16]

The bioeconomy, too, is flourishing, with the first highly innovative new companies producing high-value-added products and materials from bioresources, such as the first bioplastic companies manufacturing polyhydroxyalkanoates from biodiesel glycerol[17] or other bioplastics from starch.[18]

Driven by hyper-competition and full globalisation of markets in Italy, similar to most world's countries, the societal demand of innovation has dramatically increased.[19] Companies need both product and process innovation to stay ahead in a global market in which hyper-competition has become the rule rather than the exception. At the same time, organisations of all size and scope are called by the concomitant and related environmental crisis and energy-population conundrum[9] to adopt sustainability as a driving force reshaping much of their activities. In brief, organisations across the world are called to increase their energy and material efficiency, thus eliminating waste, and close the material and energy cycles, that is, shifting to renewable raw materials and renewable energy. Critics of renewable energy argue that, even though the cost of the photovoltaic kilowatt-hour is now the cheapest among all energy sources, it cannot be compared to the kilowatt-hour obtained from burning fossil fuels, or from nuclear fission, because said energy cannot be economically stored and made available when needed, for example in Li-ion batteries. These batteries would be too expensive, or there would not be enough lithium to meet the immense storage requirements of the global economy. These arguments echo those of fifteen years ago when a "physical barrier" to the cost of silicon solar cells was invoked due to the cost of ultrapure, solar-grade crystalline silicon needed to produce the PV cells. For example, in early 2008 one could read that:

"Although 90 percent of installed solar capacity uses silicon-wafer-based photovoltaic technology, it faces two challenges that could create openings for competing approaches. For one thing, though it is well suited to space-constrained rooftop applications (because it is roughly twice as efficient as current thin-film photovoltaic technologies), the solar panels and their installation are costly: larger quantities of photovoltaic material (in this case, silicon) are required to make the panels than are to make thin-film photovoltaic solar cells…"[20]

Yet, when in mid 2016 California's Government urgently asked utilities to install 70 MW of electrochemical storage to partly address the consequences of a prolonged leak from a natural-gas storage facility, three Li-ion battery companies installed such capacity in just six months after the emergency storage tender, with one company delivering 20 MW of storage capacity in just 88 days.[21]

The examples above are not of anecdotal value. Scholars across the world have long identified significant knowledge gaps in renewable energy and energy efficiency even within the science, technology and engineering communities. As put by Sovacool, energy problems facing society cut across academic disciplines,[22] and there is a clear need for more useful research and education giving proper attention to the social, human and economic dimensions of energy technology, so as to ease and streamline the adoption of renewable energy and energy efficiency technologies.

For example, in Italy the rooftops of only 500 000 (out of 11 million) single and double family homes and 8% (out of 1 million) industrial sheds are currently covered with PV modules. By integrating the missing rooftops with PV modules, Italy would generate from the sun radiation over 130 TWh of its 305 TWh electricity demand,[23] generating each day a large amount of clean electricity exactly where it is needed, cutting the load on the grid and freeing substantial capacity.

One of the main reasons that continues the delay of such a massive adoption of building integrated photovoltaics (BIPV) in Italy is the lack of suitable BIPV guidelines in light of the poor aesthetics of conventional PV modules. However, next to St. Peter Cathedral, an elegant 220 kW BIPV plant, built in 2008 conforming to the International Restoration Chart on the rooftop of Paul VI Hall (Figure 1), generates over 300 000 kWh each year (6% more than planned), while diminishing the heat load

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Figure 1. Section of the 225 kW PV plant on the roof of Paul VI Hall, next to St. Peter's Dome: 2394 tailor-made solar modules perfectly follow the sweeping, wave-shaped roof in concrete.

to be dissipated during summer. When, on May 2011 the authors held a presentation about this plant to the audience of the Seminar "Marcello Carapezza" held at Italy's Parliament, amongst the listeners was a director of the Ministry of Cultural Heritage of Italy, whose office in Rome is just a few hundred meters away from the above-mentioned building. Claiming his pronounced interest, he wondered why his community was entirely unaware of such achievements.

A similar surprise was claimed by Italy's Labor Minister visiting a state of the art olive mill in Sicily on November 2016, when he discovered a new olive biophenol extraction plant (Figure 2) built thanks to public–private cooperative efforts for which the research group of the authors provided scientific advice.[24]

Figure 2. Italy's Labor Minister (centre) visiting a new olive biophenol extraction plant in Sicily's Chiaramonte Gulfi, November 21, 2016.

Indeed, a study commissioned by the European Commission (which published the first European bioeconomy strategy as early as of 2012),[25] aimed at assessing the socio-economic and environmental benefits of the bioeconomy in Europe, recently concluded that the involvement of local communities in the development of strategies promoting a bio-based economy is crucial to reap the large local socio-economic potential impact of the bioeconomy. It is at regional level at which biorefinery activities "materialise in concrete processing plants through the adoption of standards and best practices to ensure the reproducible production of quality bioproducts".[26]

Growth-Driven Research and Education

Recent thorough assessments of global educational efforts in the field of solar energy[27] and energy management[28] revealed either a continued lack of well-structured curricula as well as of competent teachers or an insufficient educational offer, though empirical evidence shows how education is essential to bridge the energy efficiency gap of professionals and energy managers. Similar findings already emerge in the bioeconomy, where numerous scholars find that the pathway currently being pursued is too reliant on technology, with a narrow understanding of the bioeconomy concept, and underrepresentation of certain research topics.[29]

These outcomes suggest the opportunity to establish, across the world, new multidisciplinary educational and research centres able to effectively support and promote solar energy, energy management and the bioeconomy approach to production in different regions and countries. Drawing on two decades of successful research and educational efforts, we have identified a suitable set of activities (Table 1) that may function as reference for the forthcoming new centres invoked in this study.

Table 1. Activities fulfilling the mission of the new bioeconomy and solar energy institute.

I.	Shaping bioeconomy and solar energy researchers and professionals
II.	Growth-driven research aimed at practical application of breakthrough solutions
III.	Developing guidelines and best practices via international cooperation
IV.	Providing insight to policymakers and investors to inform policy design and investment

I. Shaping new bioeconomy and energy professionals

The potential of distributed energy generation through photovoltaic and photothermal solar collectors in promoting economic growth along with social and environmental progress is a well-established outcome of over three decades of solar energy applications. For example, the large-scale deployment of low-cost PV technology throughout the whole urban fabric by utilising the vast rooftop real estate available in all cities for infrastructure-scale photovoltaic development has made the solar city concept a feasible reality in small, medium and large municipalities.[30]

Likewise to our cooperation with the civil servants of Castronovo di Sicilia, a small centre in the hearth of Sicily, which now elegantly hosts 892 solar modules perfectly integrated on the roofs of five public buildings (Figure 3) with significant economic, social and environmental benefits, the new institute will act as an interdisciplinary centre for the education of

Figure 3. Building integration of PV modules on a public building rooftop in Castronovo di Sicilia, Sicily, as of late 2010.

young graduates and managers from both public and private sectors.

II. Growth-driven research aimed at practical application of breakthrough solutions

A common belief is that the practice of sustainable development will translate into economic *décroissance* (decline).[31] As evidenced by Krueger, however, sustainable development historically has evolved as an elastic concept the meanings and practical implications of which reflect varied views on the global environmental problems (and opportunities) facing mankind.[32] In the view of the authors, as well as of several other scholars, true sustainability aims to promote economic growth along with social and environmental care. Research, therefore, will be aimed at promoting local development by means of new green chemistry and new energy technologies. Modern research in solar energy is cutting-edge science that has a strong interdisciplinary character, being in the focus of organic chemistry, materials science, inorganic chemistry, physics, and engineering efforts aimed at progressing towards applications, such as photovoltaics,[33] solar photocatalysis for synthetic purpose[34] and solar fuels.[35]

Eighty years after 1939 Flexner's essay on the usefulness of useless knowledge,[36] curiosity-driven, fundamental research, best carried out in universities, is of even higher value today, truly providing the groundwork for all applied research and technology.[37] For a non-university institute dealing with solar energy and the bioeconomy today, we believe that the research carried out at its premises should be of applied nature, with an objective to locally promote the actual uptake of clean energy technologies and bio-based productions.

It is relevant to note herein that three factors were identified in the early 1990s as a key to explain the emergence in Europe of a regional innovation system: 1) dynamic networks between firms, 2) a rich institutional system providing vocational training and 3) a robust science and technology infrastructure.[38] Besides offering new training, the solar energy and bioeconomy centre would therefore act to support the progress of the technology infrastructure based on new technologies and new science. Three examples help to illustrate such researches.

The first deals with the necessity to transfer cleaner production methods for the conversion of bio-sourced waste into high value bioproducts in agriculture and food processing industries. This is the case, for instance, of waste citrus peel that is abundantly produced in Sicily and which can now be directly converted into pectin[39] and essential oil[40] using microwave-assisted hydrodiffusion and gravity.

Another technology with major sustainability implications is wastewater remediation based on controlled hydrodynamic cavitation. The dramatic values of temperature and pressure created by the collapsing bubbles formed in the process of cavitation allow for degradation processes that are more effective and less costly than conventional chemical and biological treatments. Along with significant energy savings, clean oxidants, such as aqueous H_2O_2, are used to remediate urban, agriculture and industrial wastewater,[41] affording cleaner water and producing a sludge as by-product that can be used to fertilise soil, closing thereby the material cycle.

Finally, another solar technology suitable to promote environmental remediation and economic growth is the nanostructured antifouling paint AquaSun developed with scholars at the Masdar Institute of Science and Technology (now Khalifa University of Science and Technology).[42] Encompassing the excellent fouling-release properties of economically and environmentally friendly xerogel coatings as well as their ability to cure at room temperature and easily bind to all type of surfaces,[43] the new solar coating immersed in water once hit by visible light produces significant amounts of native H_2O_2, which prevents the adhesion of foulants (Figure 4).

Biocide-containing antifouling coatings are a serious environmental issue, for which intense chemical research has recently resulted in the development of the first environmentally friendly technologies, though generally costlier when compared to conventional copper-based biocidal coatings.[44]

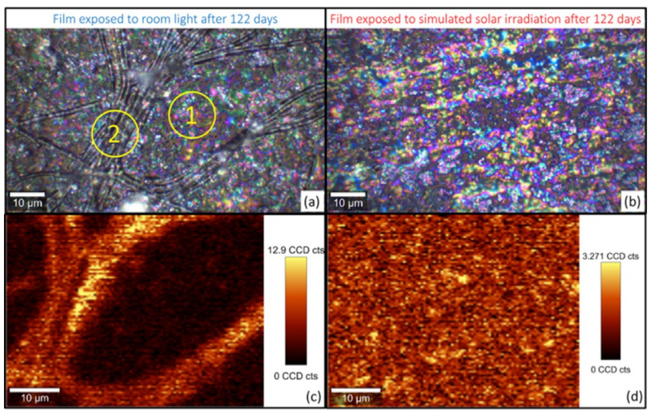

Figure 4. Optical images of a glass substrated coated with the AquaSun coating after 122 days in seawater in the absence (a) or in the presence of simulated solar light (b). 799 cm^{-1} peak Raman mapping (c, d) corresponding to the images above. [Photograph of G. Scandura, Khalifa University of Science and Technology].

III. Developing guidelines and best practices through international cooperation

The need for international cooperation for the development of best practices and guidelines is well rendered by two examples in the field of solar energy. One is solar ventilation,[45] namely the direct use of solar energy for naturally ventilating and heating buildings of any size and scope greatly enhancing air quality, thermal and hygrometric comfort and reducing energy costs; or for drying crops with truly significant energy savings exceeding 50%. Though widely used in northern countries such as Canada, the UK, Denmark and Germany, the technology is almost ignored in southern countries or in islands where, due the higher insolation levels, it could drastically cut the need for conventional burning of fuels for winter heating.

Another are photovoltaic tiles, a straightforward concept originally developed in Italy, subsequently finding application in several countries including the US and Britain. The technology combines the functionality of terracotta bent tiles with modern solar cells, maintaining the architectural appearance of the elegant rooftop practically unaltered (Figure 5).

The tiles are a truly advanced energy technology, each supplied with a certified 4 W solar module comprised of solar cells in monocrystalline Si covered with solar glass. The PV tile retains the thermal flywheel properties of the terracotta, and those of the waterproofing system. No fixing rods are required for laying the tiles, thus preventing problems caused by infiltration and thermal bridges. In addition the installed by-pass diode prevents problems caused by unexpected shade. Finally the bent tile makes the system less sensitive to summer high temperatures. Yet, despite so many advantages and although the technology was commercialised about a decade ago, only a few hundred homes in Italy have a rooftop covered with PV tiles. Clearly there is the need to inform policy makers as well as potential users about these new technologies, for example developing guidelines for the architectural integration of photovoltaic and phototermal solar collectors to make solar energy accessibile to all citizens.[46]

Figure 5. Home in Italy rooftop with solar bent tiles. The elegance and all functional properties of the earthenware rooftop are retained, but the roof now generates clean electricity every day. [Photo courtesy of Industrie Cotto Possagno].

IV. Providing advice to policy makers and investors

Both bio-sourced production and distribution of solar energy take place at local level where the economic, social, architectural, agricultural, educational and social needs greatly vary according to the geographic location. This is why, new insitutes such as the one described briefly in this study should be established at regional level in numerous countries. From the widely successful examples of CasaClima in northern Italy's Alto Adige province to the Ecodesign Centre at Cardiff Business Technology Centre, the idea is to facilitate sustainable innovation through collaboration at a local level taking an international perspective.[47] Policy makers and investors across the world are regularly advised by leading solar energy institutes, such as the Fraunhofer Institute of Solar Energy (Germany) or the Centre for Renewable Energy Sources and Saving (Greece). Again, what is further needed is advice for regional and municipal governments as well as for local entrepreneurs and investors.

Attracting Talents and Creating Development Opportunities

In January 2008, the authors gave a presentation in a city near Palermo on the forthcoming activities of "Sicily's Photovoltaics Research Pole", a lively educational and research centre resulting from new collaboration between the renowned photocatalysis research group at Palermo's University, and the group of the authors at the Research Council. It was inspired by successful efforts of University of Rome's Tor Vergata Centre for Hybrid and Organic Solar Energy (CHOSE).[48] The presentation was met by significant social interest, as shown by the presence of Italy's public television network; however, the claim that solar PV energy was going to become a significant part of Italy's and Sicily's energy mix within a few years was generally met with skepticism.

A few months later the first of the nine editions of the "Solar Master", an innovative intensive course on solar energy merging economic and technology aspects,[49] was inaugurated. Trainees originated from different regions of Italy, including someone from Alto-Adige, who lamented the absence of such courses in his region. Recognising that the scientific and technical literature in solar energy had become obsolete, we published several new books on solar energy and energy management,[50] including a volume on BIPV, and one of the first (in Italian) on the Energy manager profession. After ending the course, some of the trainees founded new solar energy companies, which are still active in 2017, despite the 2013 termination of incentives for the use of solar energy in Italy.

In 2011, the team established the "SuNEC—Sun New Energy Conference" (Figure 6) held yearly in Sicily ever since, which in six consecutive conferences saw the lectures of internationally renowned scientists such as Aldo Steinfeld, Bernard Kippelen, Vincenzo Balzani, Percival Zhang, Keith Barnham, Kisuk Kang

Figure 6. Logo of the SuNEC conference, held in Sicily since 2011.

and Bao Lian-Su. In 2012, it was the turn of the “FineCat—Symposium on Heterogeneous Catalysis for Fine Chemicals”, which similarly hosted the likes of Graham Hutchings, Manfred Reetz, Irina Beletskaya, Stephen Hashmi, Valentine Ananikov, Bert Sels, Gideon Grader, David Cole-Hamilton, Paolo Fornasiero, Serge Kaliaguine, Claudio Banchini, Tyler McQuade and Gadi Rothenberg. Delegates from over 50 different countries, along with trainees from every part of Italy demonstrate the potential of green chemistry and solar energy science and technology to turn Sicily into an attraction platform for scholars and students from across the world.

Outlook and Conclusions

In summary, starting from Ben-David’s vision that institutional roles in organisations are the fundamental foundation of scientific activity, and that whatever changes in such roles affect the nature and amount of science that will be done,[51] we have devised the profile of a new institute acting in the fields of solar energy and the bioeconomy. In other words, if we wish to change the “kind and the amount” of science developed at an institution, we need to change its organisation and individual roles. We have further explained that research and education oriented to economic growth would be particularly appropriate for such an institute. As proven by the huge success with solar energy of Germany, where the solar potential is below 1000 $kWh\,m^{-2}$ per year, solar energy and bioeconomy are of direct relevance to all countries, and not limited to sunny countries or to countries where significant agricultural, forestry or fishing activities exist. Two other factors are common to different countries and would complement the new institute’s tasks, namely developing guidelines and easing the adoption of best practices taken from a broad and international perspective in which collaboration for sustainable development plays a crucial role.

Commenting on the possible evolution of global scientific institution system, Herbst has recently argued that “its ′centre′ may not shift to another location in the 21st century, to China, for instance. Rather, we may have an opportunity of a distributed centre, diffused over the entire globe, with institutions where kindred minds could meet”.[52] Headquartered in Sicily, thirty five years after the pioneering efforts of Carapezza and Monroy,[53] the new institute of bioeconomy and solar energy of Italy’s Research Council would be such an institution.

In general, CNR’s institutes are created or suppressed by the board on a continuous basis. For instance, there were 108 in 2013 and only 103 in 2015, mostly resulting from the merger of the 310 smaller institutes scattered across Italy’s regions, with significant diseconomies of scale due to increased costs of coordination of decentralised units,[54] which in turn created the conditions for bureaucratisation and negative effects on research productivity.[55] With two units only, one in Sicily and another Tuscany, such conditions would be eliminated, while providing the country with an innovative centre where the above “kindred minds” from across the world could meet, continuously creating concrete opportunities for diffuse economic growth, as well as contributing to environmental and social progress, based on innovation and clean technology.

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