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Rethinking solar energy education on the dawn of the solar economy

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ABSTRACT

Combining different approaches, this article describes a multidisciplinary graduate course (*Solar Master*) on solar energy for science, engineering, economics and management students aimed to shape professionals capable to understand, develop and disseminate solar energy seen as a strategic and critical resource. Eventually, students ending the *Solar Master* will become professionals whose companies will not only use or install high quality solar energy systems, but will be able to increase public perception of solar energy as an intrinsically reliable and cost competitive energy source to produce electricity on utility scale as well as electricity, heat and light for all sort of buildings across the world.

Contents

1. Background

Accompanying the world's solar boom, [1] the cost of generating electricity from solar power using the photovoltaic (PV) technology has decreased by >80 percent over the past 10 years. Clean, safe and low-cost renewable solar and wind energy, are poised to meet the world's energy needs in the near future, ending threats to public health, energy security and the environment due to combustion of fossil fuels, and nuclear fission of uranium [2].

The feasibility of 100% renewable electricity supply in top industrialized countries such as Germany is no longer a futile exercise, but rather a realistic perspective for which thorough recent studies indicate how the transition could be achieved; [3] including the roadmaps of Jacobson and co-workers to convert 139 countries of the world to wind, water, and sunlight using technologies selected to provide electricity which include wind, concentrated solar power (CSP), geothermal, solar PV, tidal, wave, and hydropower. for all energy purposes by 2050 [4].

The transition to large-scale use of renewable energy, namely to a true solar economy with its economic, environmental and social benefits due to non polluting electric power and low temperature heat generation, [5] requires a better education of scientists, engineers, and managers one for which true understanding of renewable energy becomes a significant part of their

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scientific literacy [6]. Education in solar energy science and technology, indeed, is not as developed as it should, and this despite the pioneering efforts of Broman and other scientists who first argued in the mid 1980s that education had to become a central part of worldwide solar energy activities [7].

Prior to the global solar boom started in the early 2000s, research in solar energy science was largely restricted to a few specialists based on the wrong assumption that the cost of both photovoltaic and solar thermal energy technologies would inevitably remain high, being limited by "physical" thresholds.

All has changed during the ongoing global solar boom started from the "Feed-In-Tariff" (FiT) in Europe, and to the massive market entrance of new solar cells manufacturers based in China, which has rapidly led to widespread diffusion of the PV technology to produce electricity from sun's radiation in both developing and developed countries at unprecedented low cost [1].

On the verge of said solar boom, about a decade ago, the authors started educational activities on solar energy in Italy, today the country with the largest fraction (8.7% in 2014) [8] of electricity production provided by PV modules. We readily realized that available books on the topic of solar energy were either outdated or simply absent.

This led us to write some of the first new books [9] on solar energy in order to fill this educational gap and provide students with updated educational resources.

We outlined the concept of a new course dubbed *Solar Master* and, alongside with Giovanni Palmisano (now a professor of chemical engineering at a prestigious institution abroad), [10] in less than four years gave ten consecutive editions of a course whose practical outcomes, including the foundation of four new solar companies and high customer satisfaction recorded in student's evaluation of the course, prompted us to further expand our educational efforts with the aim to offer a similar new course to an international audience.

Was obsolescence in solar energy education a feature of Europe only? At least not apparently. For example, at the 2014 meeting of the American Society of Mechanical Engineers, the outcomes of a review of engineering curricula in the US included the following findings [11]:

> "Engineers and scientists have failed on large extent to fully address the sustainability issues… Engineering graduates do not possess necessary skills to tackle sustainability related problems. Current engineering curricula are not equipping them to properly deal with these challenges due to little integration of sustainable and green design strategies and practice… These concepts and methods are still relatively new to engineering curriculum and are not an established practice for most of such programs."

In 2014, Broman and Kandpal, a scientist at Indian Institute of Technology, published an ample review with over 370 references to the international published literature on renewable energy education and training at university, school and professional training level [12]. Twenty five years after the foundation of the International Association for Solar Energy Education (see below), its co-founder reported that during the previous three decades several countries had started academic programs on renewable energy technologies. Yet, a lack of availabile well structured curricula as well as of competent teachers were clearly identified as the main causes creating a lack of human resources with required knowledge and skills needed for accelerated dissemination of renewable energy technologies.

Similarly, a 2010 study reporting first attempts to "nourish green minds" in United Arab Emirates and related oil-rich countries, found that most universities in the region had not yet introduced or integrated solar energy in their curricula [13].

Prolonged past experience across the world has shown that modern solar energy education requires the integrated and multidisciplinary study of technology, resources, systems design, economics, industry structure and policies. Said another way, attempts to add one or two units of study on renewable energies into traditional science and engineering degrees will *not* produce graduates with sufficient knowledge to use solar energy effectively [6]. Accordingly, new graduate courses on solar energy are being organized at several universities worldwide, with the aim to integrate sustainable energy into the basic university education in physical and chemical sciences [14].

In this rapidly evolving context, after describing the main features of the emerging solar economy, we identify the requirements of an innovative course for undergraduate and graduate students of science, engineering, economics and management aimed to shape professionals capable to understand, develop and disseminate the use of solar energy as a strategic and critical resource to make sustainable our common development.

2. The solar economy

Energy is a critical resource which plays a vital role in the socio-economic development and human welfare of a country [15]. Electricity, in particular, is a strategic commodity whose availability at affordable cost is directly linked to economic development [16].

From a purely economic viewpoint, thus, a solar economy is one in which making power from sunlight costs less than making it from burning the cheapest fossil fuel, namely coal. In early 2015 a solar PV module manufacturer signed a power purchase agreement for a 200 MW project in Dubai that will profitably sell electricity for $0.0584 per kilowatt-hour (kWh) [18]. A few months later, in the US a local utility agreed to buy electricity generated by a 100 MW solar farm comprised of CdTe thin film solar modules at a price of 3.87 $ cents per kWh [19]. These figures alone may explain the origin of the global solar boom (Fig. 1), analyzed in detail elsewhere [1].

Seen from the distributed generation viewpoint, on the other hand, the consequences of PV modules being profitably sold at $<0.5$$/W imply that families and businesses can efficiently self-generate electricity at lower cost than the price of electricity sold by utilities through the grid.

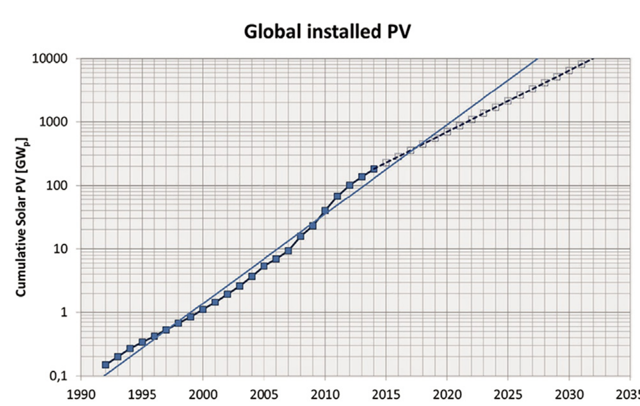

Fig. 1. Cumulative global PV installations has grown exponentially between at constant growth rate of about 25% per year (the dotted line). Blue dots show the installed PV in the world. [Image courtesy of Dr E. Heindl; reproduced from Ref. [17], with kind permission]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Coupled to quicker than forecasted cost reduction of lithium-ion batteries, [20] furthermore, this is making the transition to off-the-grid systems, or to renewable power stations supplying electricity to private grids serving local communities, a practical reality [21].

The significant reduction in wholesale energy costs of massive production of solar electricity in industrialized countries such as Germany [22] or Italy [23] have been thoroughly investigated, modeled and understood. Perhaps less understood are the environmental and social benefits of the emerging solar economy. When producing energy (at least for 25 consecutive years but in reality for much longer time), photovoltaic systems do not emit any polluting substance. PV systems have an energy payback time between 1 and 4.1 years (in the following order: cadmium telluride, copper indium gallium diselenide, amorphous silicon, poly-crystalline silicon, and mono-crystalline silicon) with mean harmonized EROI (energy return on energy invested) varying from 8.7 to 34.2, with ranking of different PV technology depending primarily on their embedded energy and not on their efficiency [24].

Only considering the surface of solar collectors installed at the end of 2008, researchers at the International Energy Agency were reporting an annual avoidance of 39.4 million tons of CO_2 emissions, adding that [25]:

> “Until now, solar thermal technology has not been a high priority, therefore only very limited financial resources have been allocated for R&D in this sector. The primary reason for this is that in many circles, solar thermal systems are regarded as a well established, low-tech technology with little potential for development. However, the enormous potential for energy production, particularly in the heating and cooling sector, and the enormous potential for technical development of solar thermal technology demonstrate that solar thermal technologies are dramatically underestimated”.

Finally, the social benefits of solar energy widespread adoption in terms of jobs creation as well as improved first clearly delineated by Scheer since the early 1990s, [26] have been verified by actual developments in advanced economies first, and then wherever a significant amount of PV power has been deployed. Amongst the least known benefits, Scheer identified also the drastic cut in administrative costs to control and monitor damage due to conventional energy generation plants. In Germany only, the renewable energy industry doubled its employment between 2004 and 2009 when 340.000 people worked in an industry, and gross employment conservatively forecasted to increase to around 500–600 thousand people by 2020 [27].

3. Professional competencies

Aimed to build professional competences in university science, engineering and management students alike, the course addresses the theoretical and practical aspects of solar energy conversion and utilization via the most affordable and widespread solar energy technologies. As such the *Solar Master* does not aim to educate science and technology experts capable to conduct R&D activities in the PV industry, [28] but it rather aims to build updated, general competencies in solar energy seen from strategic and entrepreneurial standpoints.

Willing to identify the requirements of said course, it is highly useful to look at previous educational efforts.

A first outcome emerging from reviewing the first twenty years of experience, is that education in solar energy can only be successful when providing “sufficient connection with the real world to facilitate the real use of the new knowledge” [29]. In other words, hands-on experience is just as important as principles and theory. This immediately leads to the necessity of having each day in the classroom two professors, one of whom will focus her/his activity onto the demonstration, practically oriented work.

4. Curriculum, educational materials and course evaluation

Building the useful competencies mentioned above requires a well developed curriculum, good quality teaching-learning materials, and effective teaching. For the course to be effective, the number of students should be limited to a maximum of fifteen. Students originating from across the world should have a basic knowledge of science (energy, chemistry, physics) economics and management.

The course is held in English. Lectures and tutorials are as important as hands-on activity and field trips to working facilities. The overall length of the course is one trimester, for an overall total of 120 h of direct interation in the classroom and hands-on experience during 10 consecutive weeks Each week comprises 3 days of lectures (3 h per day).

The subjects (Table 1) involve elements of science and energy engineering, as well as elements of economy, social, environmental and management science. In the last of twelve recent recommendations for strengthening solar energy education in the above mentioned study, [12] Kandpal and Broman argue that educational programs in this area require continued assessment based on feedback from the renewable energy users. Millions of businesses and families worldwide, today self-generate electricity and low temperature heat via their own solar plants [30]. Similarly, energy companies around the world produce and profitably sell huge amounts of solar electricity at $5–6c/kWh according to typical 20 years purchase power agreement contracts [1].

The selection of the solar energy technologies, therefore, is guided by the global market acceptance of today's low cost technologies, which so far are photovoltaics, [31] and solar thermal, namely the simple and reliable technology based on solar collectors analogous to PV modules that has reached the installation cost and efficiency that make it in many world's areas largely preferable to burning fossil fuels to produce hot water and hot air for homes, hospitals, hotels, swimpools, farms, food processing industry, and so on [32].

Said solar energy technologies, however, are dealt with along with economic, marketing and management aspects. For instance, referring to a system dependent upon diesel and solar PV generation for its electricity, students are taught how using today's storage technologies (batteries) at low degrees of penetration (0% to 30%) simple substitution of fossil electricity with renewable solar energy yields immediate energy cost reductions, while

Table 1
Topics and lecture length – Solar Master.

Module number	Topic	Length (h)
1	Photovoltaics: Principles and main technologies	18
2	Solar Thermal: Principles and main technologies	18
3	Solar energy: Economic, environmental and social aspects	18
4	Communicating renewable energy	12
5	Building integrated solar systems	12
6	Cost-effective solar electricity storage	6
7	Lean management of renewable energy enterprise	12
8	Field trips to working facilities	12
9	Hands-on experience	12
		Total 120

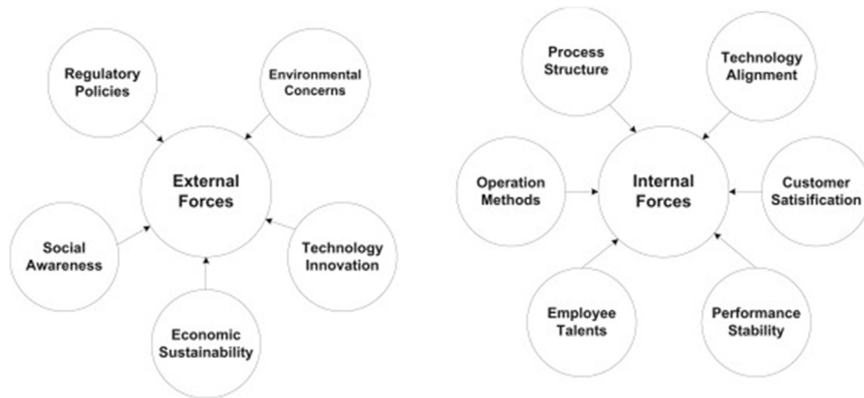

Fig. 2. Factors taken into consideration as impacting renewable energy growth. [Reproduced from Ref. 34, with kind permission].

remaining economically viable up to around 80% [33]. Only at renewable penetration exceeding about 80% the cost of energy becomes not affordable without some form of easily storable (*i.e.* liquid or solid) energy-dense fuel.

Getting to management topics, as another example, students somehow surprisingly learn that renewable energy companies across the world are not doing well in terms of handling internal forces (unstructured business process, business technology strategies unaligned, talent shortage and performance instability, Fig. 2) which obviously affects the business condition making them more volatile, complex and uncertain; whereas the external forces (environmental concerns, lack of societal awareness and technological innovation deficiencies) indicators are consistently higher [34].

Carefully produced and made available to students ahead of each lecture, high quality teaching-learning materials is produced by the teachers (including invited speakers) and made available to students as digital slides. Said slides encompass hyperlinks to updated online references including press articles and interviews.

Selected quality multimedia resources including videos and webinars, in particular, are identified and made available to students as the course progresses. Again, relying on the findings that not all pictures and videos can improve learning, [35] instructors will take care to design effective multimedia presentations by drawing on advances in the science of learning, and in the principles of multimedia instructional design grounded in cognitive theory and practice [36].

Alongside with a selection of thoroughly selected scientific articles and updated technical reports, students receive digital excerpts from five books, namely *Handbook of Photovoltaic Science and Engineering,* [37] *Planning and Installing Solar Thermal Systems*, [38] *Integration of Distributed Generation in the Power System*, [39] *Flexible Solar Cells*, [40] and *Power Density: A Key to Understanding Energy Sources and Uses* [41].

Amongst the hands-on activities are the tutorials on several solar energy and energy software packages including the HOMER (Hybrid Optimization of Multiple Energy Resources), [42] and cloud-based software HelioScope energy modeling tool that integrates the AutoCAD tool so that the designer can, for example, rapidly lay out a rooftop and get the energy modeling [43].

The final exam is based on a presentation offered by each student on a research project focusing onto a solar energy system selected locally on the basis of its significance in terms of energy generation and quality (reliable high performance, elegance of the building integration, etc.).

The success of this new course concept is demonstrated by the subsequent sustained adoption of solar energy technologies in the region where the course graduates will operate. In other words, course evaluation will start from assessing the student's satisfaction, but will culminate with recording the subsequent practical involvement of the course graduates in promoting the adoption of the solar energy technologies among businesses, families, communities and public bodies on the dawn of the solar economy, the helionomics.

5. Effective teaching

The course is conceived for an international audience. Hence, it follows guidelines conceived to maximize the educational impact of training providers and presenters [44]. As a result, students are trained by educators in their turn trained to encourage participation, and having strategies and techniques to address problems faced within the training room, including managing and incorporating feedback effectively. The outcome is an intensive course of excellent quality both in its contents design and delivery.

Educational effectiveness derives from the choice of a good curriculum (*what* to teach), and from the teaching method employed (*how* to teach). No matter how good the curriculum and the teaching materials may be, education will not be successful without effective teaching offered by motivated educators. Said motivation, in its turn, originates from: (i) teaching a frontier topic whose actual utilization contributes to end pollution both locally and on a global scale; and, (ii) a good salary rewarding years of studies and teaching experience.

Solar energy has a fascinating history that must be told, [45] and a significant personal impact on the life of individuals, families and entire communities. In this sense, effective teaching of solar energy demands to avoid teaching abstract theory and principles, but rather needs to be continuously reconnected to real people's life, from the first life-saving solar pumps used by Father Verspieren in Mali in the late 1970s during the country's worst drought of the twentieth century, [46] through the negative solar energy prices recorded in Germany as of Spring 2015 due to the record 27 GW of solar power connected to the grid [47].

This brings to the need to renew the education of scientists by integrating scientific and management education within a unified culture context [48]. Inclusion in the present course on solar energy of relevant elements of economy, sociology and marketing is essential because these are nowadays indispensable resources of the scientific profession. In practice, to quote Lévy-Leblond, scientists and science educators “recognizing their cultural gap before willing to correct the deficiencies of profanes must add to their studies those elements needed for a better understanding of the public” [49].

It is reassuring, in this respect, to find out that a similar exigence was remarked by Jennings, a leading renewable energy education practitioner, noting that “it is essential that training

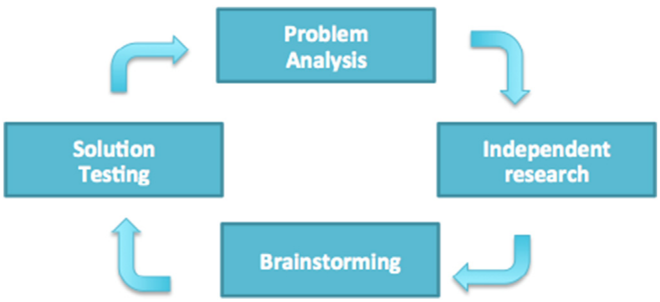

Fig. 3. Problem solving cycle. [Adapted from Ref. 50, with kind permission].

should address economic, social and environmental issues arising from the technology as well" [6].

Similarly, rather than being confronted with traditional instruction in which they attend lectures, solve homework problems, and engage in structured type laboratory activities, students are taught solar energy via problem-based learning, namely being presented each time with an open-ended problem with little content preparation, in an open-ended and contextualized process in which learning is driven by the problem itself [50].

Working in small teams, students learn "how to learn" by engaging in a circular process (Fig. 3) that includes problem analysis (to identify and frame the problem), independent research and brainstorming (to identify and for acquiring the knowledge and skills necessary to solve the problem), and solution testing (factual check and then optimize the solution) [51].

Almost invariably, indeed, hands-on teaching methods are effective in introducing principles of various types of renewable energy to engineering technology students; [52] for working on real projects, and supervised by faculty with expertize, students not only get a better understanding of the basic concepts of various renewable energy sources, but become able to gain practical skills for fabricating and testing key materials, components, devices, and systems of different solar energy technologies.

6. Networking and continuous improvement

In an innovation-driven global society where change is constant, continuous effective learning is essential for any individual's career development. The Internet and the World Wide Web, of course, offer unprecedented ease of co-operation and access to a myriad of educational resources, including updated information made available from suppliers of solar systems. Purposeful utilization of said online resources is a key competence of the future solar energy educators trained within the present course.

Attending scientific meetings of international standing is of course highly recommendable, especially of those conferences where leading scientists and technology experts focus onto solar energy practical applications such as, for example, the yearly SuNEC conference [53].

Finally, fruitful interaction amongst the *Solar Master* organizers and former students is another unique feature that has shown to be instrumental in guiding improvement efforts. Former students turned into entrepreneurs, managers or technologists will lecture at subsequent courses focusing on the difficulties encountered, and the solutions applied, to become successful players in the solar energy community.

From the course organizers' viewpoint, the need to continuously improve and innovate the course requires effective networking with other scholars and stakeholders in the solar energy industry, including manufacturers, designers, engineers, installing companies, publishers and journalists. Their input will be vital to review the curriculum every year in order to ensure that it continuously corresponds to the market, technology and cultural state of the art.

7. Outlook and conclusions

Education in solar energy has been clearly identified as a viable route to sustainable development [54]. Very often, however, the adjective "sustainable" is associated to the positive environmental impact of a technology, a choice or a technical solution. The present course, on the other hand, emphasizes the dramatic positive economic impact of low cost solar energy and energy storage technologies in reshaping the conventional energy paradigm.

As the world's solar boom continues, [1] the need of energy professionals and entrepreneurs with a broad knowledge of solar energy science and technology as well as of management and economics of renewable energy becomes self-evident in an increasing number of countries. On the other hand, extensive review of renewable energy educational practices shows that its present status is not satisfactory, [12] likewise to the ongoing separation between management and science education [48].

This requires refinement and improvement of both the content and the teaching methodology of renewable energy courses, including the educational materials.

Combining different approaches, this study describes a multidisciplinary graduate course on solar energy (*Solar Master*) aimed to physical science, engineering, economics and management students with the objective to shape scholars capable to understand, develop and disseminate economically viable solar energy technologies.

Drawing on more than ten years of direct experience, and at least three decades of educational experiences across the world, the course includes "hands-on" activities and field-trips.

Eventually, students ending the *Solar Master* will become renewable energy professionals, managers and entrepreneurs whose companies will not only use or design and install high quality solar energy systems, but will be able to increase public perception of solar energy as an intrinsically reliable and cost-competitive energy source to produce electricity, heat and light meeting the energy needs of businesses, families and communities.

The choice of the course technology subjects is guided by the market acceptance and global dissemination of the selected solar energy technologies. A teaching methodology based on problem based learning as well as on the historical development and the broad societal impact of low cost solar energy technologies is presented, which emphasizes the need to present the direct connection of solar energy to the real life of individuals, communities and economic systems. Students, furthermore, are trained on aspects of management, marketing and economics which are directly relevant to their forthcoming activity of clean energy professionals.

Renewable energy, in conclusion, is a technology topic and management field of action which is strategic to make sustainable the development of both developed and developing countries. As such, education in the field requires the merging of updated technology with management, energy and economic education. This is the aim of the *Solar Master* and related emerging courses for an international audience.

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