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Integrating Solar Energy in Rome's Built Environment: A Perspective for Distributed Generation on Global Scale

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Dedicated to Professor Livio de Santoli for all he has done to promote solar energy and energy efficiency in Italy's historic built environment

Large-scale integration of solar energy technologies in Rome's built environment epitomizes the needed general adoption of distributed generation via functionalization of buildings of all size and end use across the world, to become active energy generators and no longer energy users only. This essay identifies selected technology solutions and critical policy and educational initiatives to effectively achieve within the next decade (2018–2027) the widespread uptake of decentralized solar energy systems in the built environment on a global scale.

1. Introduction

A new model combining the competing dynamics of oil price, economic growth, and extraction costs,[1] suggests that investments in new renewable energy power need to be urgently increased to cope with the global consequences of the resulting energy and economic scenario.

With the global population growing along the current trajectory, in the 2016–2025 decade about 800 million people will add to the world's population. Correspondingly, in order to feed the "natural" growth of the gross domestic product (GDP) identified by the above model, by 2025 the total energy consumption should increase by about 1700 million tons of oil equivalent (MTOE) per year. Even to keep the oil fraction in the energy mix at the 2015 level (around 33%), this means that more than 11 additional million barrels per day will have to be added to current production levels.[1]

Consuming energy for space and water heating and electricity for cooling, lighting, and powering domestic appliances, buildings are responsible for a significant share of global energy consumption: more than 40% in European Union (EU) countries,[2] and a similar percentage in China, where building energy consumption has increased at 7% annual rate since 2001.[3]

Countries in Europe generally have limited or even no fossil fuel resources, with oil production from the oil and gas reserves in the North Sea having decreased at fast pace since 1999 (for instance, the United Kingdom's offshore oil production went from 398 million barrels in 1999 to 220 million barrels in 2007).[4]

In this context, aiming at saving oil and natural gas considered strategic for industry and transport sectors, it is perhaps not surprising that starting in the early 2000s the EU drafted increasingly tight legislation to promote energy efficiency in buildings along with the use of renewable energy. Since 2002 first, and even more strictly since 2010, an Energy Performance of Buildings Directive (EPBD) defines minimum criteria for the energy performance of new and refurbished buildings. The 2010 EPBD, for instance, requires all new buildings to be nearly zero energy by the end of 2020; and all new public buildings by 2018.[5]

The new legislation resulted in a decrease in the consumption of energy by the residential sector in the EU from about 318 MTOE in 2000 to 287 in 2014;[6] though half of the efficiency gains achieved through technological innovation in the household sector have been offset by an increasing number of electrical appliances and larger homes.[2]

Furthermore, action must be taken to improve the situation of the existing building stock, since about 75% of buildings are truly energy inefficient and, depending on the country, only 0.4–1.2% of the stock is renovated each year.[7]

Alone, the conflict between increasing specific dwelling consumption and increasing energy efficiency of buildings observed in the EU countries shows that energy efficiency alone is not enough. The generation and use of renewable energy is of similar paramount importance.

The solar city concept, namely, the use of surfaces in the entire urban built environment to generate electricity via solar photovoltaic (PV) modules,[8] is being actively explored in the context of the energy transition to renewable energy. Solar city possibilities, for example, were lately considered for cities as large and as important as Amsterdam, London, Munich, New York, Seoul, and Tokyo.[9]

When dealing with historic cities, large-scale adoption of solar energy requires systematic architectural integration of the solar energy technology to combine historic preservation with efficient generation of renewable energy.

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Preserving the architectural integrity and historic value of old buildings, indeed, is as important as the generation of clean energy. Referring to Rome as the city with the world's largest historic heritage, this paper identifies selected technology solutions and critical policy and educational initiatives to effectively achieve within the next decade (2018–2027) the needed widespread uptake of decentralized solar energy systems in the built environment on a truly global scale.

2. The Case of Italy

Hosting the largest historic heritage of the world,[10] and with good to excellent solar irradiance levels,[11] Italy has pioneered the development of building integrated photovoltaics (BIPV), a multifunctional technology that unifies the photovoltaic module with the overall building outer surface providing the building with several other functions.[12] For example, an Italian-German research and demonstration project (*PVAccept*) funded by the European Commission between 2001 and 2004 developed different marketable PV solar modules of innovative design for their integration into old buildings, historical sites, the urban space, and landscapes.[13]

Awarded the 2008 European Solar Prize for the category "solar architecture,"[14] Rome hosts on the rooftop of the "Paul VI" Audience Hall in the Vatican City an elegant PV array comprised of 2394 ad hoc modules in crystalline silicon of 220 kilowatt peak (kWp) nominal power (**Figure 1**).

Shortly afterward, de Santoli, who designed the system, has explored the integration of new energy technologies for sustainability in Rome, from the analysis of energy savings achievable through PV systems on school roofs,[15] through energy savings achievable via the retrofitting of public housing dwellings from the 1940s in an historic neighborhood.[16]

Yet, still today neither the city of Rome nor Italy's central or regional governments have published guidelines with the criteria for incorporating solar PV and solar thermal (ST) technologies in the built environment. As a result, the use of solar modules and thermal collectors in the historic center of cities like Rome, Florence, Venice, Catania, and Naples is vanishingly low. For comparison, in order "to find a proper balance between technical and aesthetic requirements," several Swiss Cantons adopted guidelines for the integration of solar technologies in the building environment.[18]

Figure 1. The photovoltaic array on the rooftop of "Paul VI" Audience Hall in the Vatican City. Image reproduced under the terms of the Creative Commons Attribution 3.0 Unported license.[17] Copyright 2008, Carsten Möller.

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Mario Pagliaro is a chemistry and energy scholar whose research team in Sicily at Italy's Research Council has contributed to advance various areas of catalysis, solar chemistry, sol-gel materials, solar energy and the bioeconomy. Co-chair of the 10th edition of the FIGIPAS Meeting in Inorganic Chemistry, the SuNEC-Sun New Energy Conference and the FineCat Symposium on catalysis for fine chemicals, he has a keen interest in education and regularly gives courses on the topics of his broad researches.

On the other hand, Italy's new energy strategy for the period 2020–2030 (Strategia Energetica Nazionale – SEN) has identified PV as one of the best options for increasing the share of renewable energy in the country,[19] and to eliminate coal power production by 2025 by increasing the share of renewable energy sources to 27% in 2030. In detail, power production from PV is expected to increase from 24.8 TWh in 2017 (7.8% of electricity demand in Italy, the highest stake in a highly industrialized country) to 72 TWh by 2030: an energy production target which requires new solar installations to exceed 3 GW year^{-1}.

In sharp contrast, since the end of the Feed-in-Tariff (FiT) incentives in mid-2012 through 2017 Italy has installed only 2.7 GW. Australia, over the same five years, installed around 6 GW of rooftop PV, despite a population about 35% that of Italy.[20]

3. Solar Building Integration

Integrating the PV modules in the urban context enables the distributed generation condition and its many economic and environmental advantages.[21] Now, a significant fraction of the electricity consumed within the built environment is produced there where it is needed, cutting through the cost of electricity transport and diminishing the load on the grid, especially when distributed generation is supported by smart grids and completed by more energy-efficient buildings.[22]

Integrating the photovoltaic functionality in Rome's building is a remarkable energy option. **Figure 2** shows an accurate estimation of the PV output electricity obtained with state-of-the-art software (*pvPlanner*, Solargis) relying on one of the world's most accurate solar database.[23] In Rome (lat/lon: 41.9028°/12.4964°) a 1 kWp PV system with modules in crystalline silicon has optimal orientation (azimuth) to South with an inclination of 34°. Under this condition, taking into account seven different energy losses yielding an average 78.3% performance ratio, the PV array will generate 1456 kWh.[24]

Table 1 shows that the same PV array in December produces an amount of energy which is 49.1% of the amount generated in the most productive month of the year (July). This means that in Rome photovoltaic generation can yield a significant contribution to the energy needs also during the winter months, even if extra electricity from the grid will be required to cover the high electricity demand from buildings during winter.

It is relevant that in Rome, where existing roofs in the historic center generally share a common tilt of 14°,[25] even a flat (horizontal) PV array will receive a global irradiance that is 86.3% of the ideal amount of sun radiation with optimal (34°) tilt.[24]

Assuming to integrate the PV functionality on the surface of all Rome's residential building rooftops (22 million m^2),[26] even previous generation PV modules affording 1 kW for each 10 m^2 would generate about 3.2 TWh of clean electricity annually there where this energy is mostly needed.

3.1. BIPV in Italy's Historic Buildings

In most cases in which Italy's (and Sicily's) Superintendences of Cultural Heritage denied homeowners permission to install solar panels, justification was mostly based on the exigence "to keep unaltered the chromatic, morphologic, and material features of rooftops."

In Italy, rooftops of the typical dwellings of historic cities and sites are realized with tiles in *terracotta* (earthenware), a material of exceptional properties whose use in Italy dates back to the early days of ancient Rome.

Progress in the development of solar energy systems, however, has solved the dilemma between clean energy and historic preservation, without having to compromise. Solar tiles in *terracotta* address exactly the objections raised by the Superintendences of Cultural Heritage mentioned above: they retain the morphological, chromatic, and material characteristics of conventional earthenware roofs, along with all other services provided by earthenware tiles including thermal flywheel and waterproofing properties, prolonged resistance to extreme weather conditions, and microbial attack.

In this sense, solar tiles in *terracotta* are truly multifunctional BIPV systems using solar irradiance to provide energy while also providing the building with many other functions. Even if seen from above, the result of the replacement of conventional tiles with the PV tiles in terracotta is an eye-catching roof in which the solar cells are barely visible (**Figure 3**).

In the 2017 Swiss guide to BIPV one can read that "solar tiles traditionally have a small market share due to the high cost

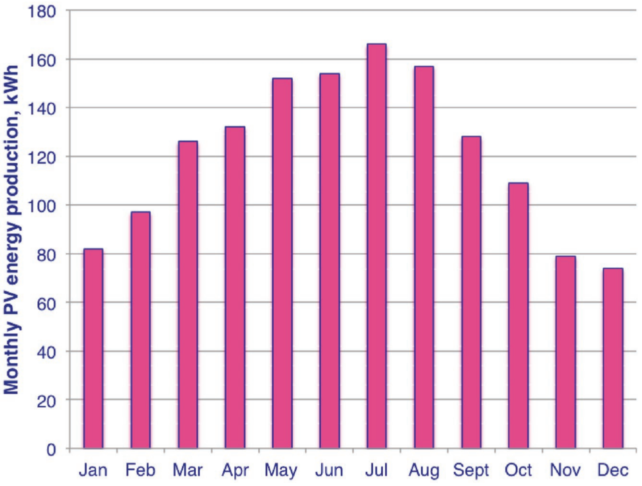

Figure 2. Monthly PV energy production of a 1 kWp array with optimal South orientation and 34° tilt angle (Source: pvPlanner, Solargis).

Table 1. Monthly energy output and performance ratio from a 1 kWp PV array in Rome with optimal tilt (Source: pvPlanner, Solargis).

Month	$E_m$$^{a)}$ [kWh]	$E_d$$^{b)}$ [kWh]	$E_{share}$$^{c)}$ [%]	PR$^{d)}$
Jan	82	2.63	5.6	83.4
Feb	97	3.46	6.7	82.5
Mar	126	4.08	8.7	81
Apr	132	4.40	9.1	79.6
May	152	4.89	10.4	77.4
Jun	154	5.14	10.6	75.8
Jul	166	5.37	11.4	74.6
Aug	157	5.07	10.8	74.8
Sept	128	4.26	8.8	77
Oct	109	3.52	7.5	79.4
Nov	79	2.63	5.4	81.4
Dec	74	2.38	5.1	83.1
Total	1456	3.99	100	78.3

$^{a)}E_m$ = kWh produced per month; $^{b)}E_d$ = kWh produced per day; $^{c)}E_{share}$ = % of the yearly energy production; $^{d)}$PR = performance ratio.

Figure 3. The 2 kWp rooftop in solar PV bent tiles at the center of this picture taken in Melito Porto Salvo, Calabria, Italy, is barely visible (Photo reproduced with permission, courtesy of Industrie Cotto Possagno).

levels, but recently gained significant marketing exposure due to their ability to replace the traditional tiling in a roof."[27]

Such "significant marketing exposure"[27] has been due to the dramatic fall in price of the solar cells integrated on each tile. The price decrease has gone along with accelerated technology progress which has concerned each component of solar PV systems.

The old solar cells in polycrystalline silicon iridescent and colored in blue due to the thickness of the antireflective coating with the silver contacts visible on the front of each cell, are replaced by more efficient cells in monocrystalline silicon colored in black with new generation antireflective coating. Progress also encompasses the use of a single bypass diode per tile, with the result of dramatically improving the shading tolerance when compared to conventional PV modules. In general, in fact, PV modules are sensitive to the current mismatches introduced by shadows (trees, chimneys, aerials, leaves, etc.) because of their series architecture of electrical interconnections.[28]

Today's state-of-the-art 60-cell modules use two or three diodes in the junction box to stabilize energy yield against shading. State-of-the-art PV tiles in *terracotta* (**Figure 4**) are each equipped with a single bypass diode (**Table 2**). Electricity generation is also enhanced by the natural ventilation ensured by an empty layer left between the solar cells and the bent tile which lowers the temperature on the back of the solar cells, improving the electricity output during the hot summer days.

Finally, contributing to lower installation costs, the electrical connection among the tiles is quick and easy relying on a simple "snap-on" multicontact fixture system, whereas the absence of a mounting system and fixing rods for laying conventional solar modules prevents potential rainwater infiltration and the formation of thermal bridges.

Generally developed by existing tile and brick manufacturers, often in collaboration with solar energy technologists and designers, different PV tiles are already available on the marketplace. One such tile, for instance, embodies 12 solar cells in polycrystalline silicon offering a 13.5 kW nominal power which, taking into account the tile size (478 × 428 × 90 mm), translates into a nominal power density of ≈91 W m^{-2} requiring only 74 solar tiles to achieve 1 kW of nominal power.[29]

Figure 4. A 6 kWp solar array in PV bent tiles comprising the rooftop of an early 1900s villa in Valdobbiadene, Italy (Photos reproduced with permission, courtesy of Industrie Cotto Possagno).

In general, the geometry and conformation of the tiles is studied in order to avoid shading and obstruction (maximum ventilation of the highly exposed photovoltaic surface). Again, the outcome of the solar tile integration is as elegant (**Figure 5**) as energy effective.

The replacement of conventional tiles with solar PV tiles is even more important when considering that new generation Marseille and Portuguese roof tiles, which cover more than 60% of pitched roofs in Europe and are ubiquitous in Mediterranean countries and islands, will prevent overheating of the building indoor environment even to a larger extent.[30]

Table 2. Typical characteristics of a current solar bent tile produced in Italy.

Technology[a]	Power [W]	Size [mm]	Power density	Price [CHF m^{-2}]
mc-Si	4	335 × 88 × 4 ($L \times w \times t$)	60 [W m^{-2}]	215 (excl. VAT)

[a] SUPSI/SEAC, Building Integrated Photovoltaics: Product overview for solar building skins, Status Report 2017.

Figure 5. A 3.024 kWp solar array in PV tiles comprising the rooftop of Cappella dell'Incoronata, Cassano Irpino, Italy (Photo reproduced with permission, courtesy of FotoSun).

In further detail, a significant reduction of energy consumption for cooling in Mediterranean climates is expected when compared to conventional rooftops in *terracotta* thanks to the slightly modified shape ensuring higher air permeability through the overlap of the tiles and improved under-tile ventilation independent of wind direction (newly designed inlet and outlet channels let the air flow horizontally as well as vertically).

The first results of the tests with real roofs in two buildings located in Israel close to the Negev desert, one equipped with conventional Portuguese tiles and the other with its evolution, show an air velocity achieved by the new roof which is two times higher than that of the standard roof.[31]

3.2. BIPV in Conventional Buildings

From flexible through semitransparent and bifacial modules, numerous BIPV solutions are commercially available to functionalize with solar technology conventional buildings of all size and end use.[32]

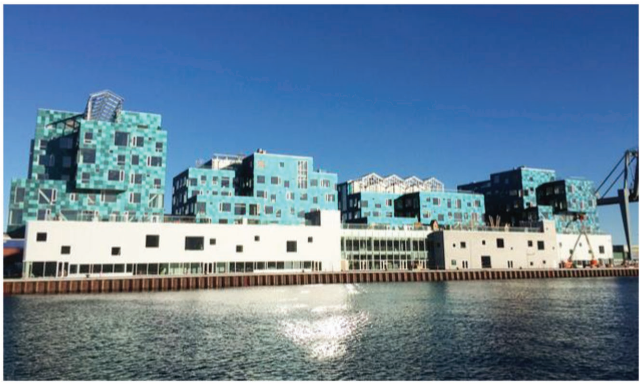

Figure 6. The facade of Copenhagen International School comprised of solar modules colored in sea green (Photograph reproduced with permission, Philippe Vollichard, EFPL).

Figure 7. A biosolar roof in London (Photograph of Livingroofs.org, UK).

A major advance toward the full integration of solar PV and solar ST technologies in the built environment has been the development of the *Kromatix* nanoscale coating technology eventually providing solar collectors with colors in a wide range (including blue, brown, green, and *terracotta*) due to light interference on the thin film.

The loss of collector's energy performance is <10% (for instance, by replacing the glass of a 300 Wp PV module with satinated glass with a thin film interference filter, the nominal power becomes about 280 Wp for the blue color and about 285 Wp for the orange).[33]

Further enhancing the overall aesthetics, the colored glass has an opaque finish making invisible the inner parts of the solar collectors, thereby overcoming all aesthetic challenges of conventional solar technology opening the route to full exploitation of all building surfaces (**Figure 6**).

Another major advance that will find widespread utilization in the world's cities is the concomitant functionalization of existing rooftops with PV modules and vegetation (**Figure 7**).

Provided that adequate vegetation such as hairy plants is first selected and properly managed to avoid shading and proliferation of invasive species, the resulting green solar roof generates clean electricity while reducing urban heat-island effects, rainwater run-off, and improving the quality of the city's air.

In comparison to a conventional rooftop in gravel or bitumen, electricity generation is enhanced thanks to the soil evapotranspiration which cools the PV cells and improves energy production in summer months.[34] Finally, the PV modules on the green roof successfully support biodiversity providing on their back an excellent microhabitat for pollinators, including honeybees, numerous insects, and birds.

Lately reporting that use of the biosolar roof across the world is still scarce,[35] Baumann et al. ascribed it to the lack of proper education with several cases in which the selected biosolar roof vegetation was not optimal, and positioning and orientation of the PV modules was not correct.

A similar trend toward building integration is concomitantly taking place for the solar thermal technology. For decades, for example, natural circulation solar thermal systems with their

Figure 8. Custom-size solar air thermal collector integrated in the balcony of a residential building in Palermo, Sicily.

cumbersome storage tanks and flat glass collectors, though highly effective in providing domestic hot water, have been the icons of solar energy technology poor aesthetics.

Today's ever more cost-effective and efficient solar thermal systems are elegant and building-integrated, leaving the roof available for integration of PV, with façade-integrated collectors providing numerous added benefits to the building.[36]

Figure 8, for example, shows the outcome of integrating a solar air collector in a building in Palermo, Sicily. The collector is barely visible, but the household has halved the natural gas consumption while accessing the unique health benefits of the solar ventilation technology, including enhanced indoor air quality, and thermal and hygrometric comfort.[37]

4. Perspective and Recommendations

In the context of the energy transition to renewable energy, the grand energy objective for the built environment is clear: we need to convert buildings from energy-inefficient consumers of fossil-derived energy to energy-efficient users and generators of renewable energy.

About half of the first 300 GW of globally installed PV power until 2016 was comprised of distributed rooftop PV;[45] and yet less than 5% of buildings globally are functionalized with PV modules.[38] It is therefore necessary to undertake a global effort using economically affordable solar technology to functionalize the existing building stock.

This process, for decades impeded by the high cost and by the poor aesthetics of the two main solar energy technologies (solar photovoltaics and solar photothermal), is now technically feasible and economically viable thanks to remarkable technical and industrial progress which resulted in dramatically improved economics and aesthetics of solar energy technology.

4.1. Renewable Energy, Competitive Advantage

The "economically sound but politically difficult renewable energy,"[39] to use Sovacool's language, has won its battle in terms of technical and economic feasibility.

Even without internalizing the costly environmental externalities of conventional electricity generation (i.e., taxing pollutant emissions), it has been enough to concomitantly deploy FiT policies and grant priority access to the grid to renewable electricity to literally revolutionize the electricity market in all those countries with a significant renewable electricity production, including Italy.[40]

Meanwhile, China's massive investments in solar cell production plants and solar energy R&D have been largely successful in bringing the price of PV cells and modules to historic lows (<€0.4 W^{-1}),[41] with production capacity capable to meet without problems the unexpected ≈100 GW demand of solar modules recorded for the first time ever in 2017.

In Germany, the world's fourth largest economy, electricity in 2017 traded at wholesale price of €33.14 MWh^{-1} with renewable energy production overcoming the 200 TWh for the first time, and 104 h of negative prices in the year.[42]

In three years only, from 2015 to 2017, the share of renewable energies in Germany's power generation mix increased from 33.5 to 38.2%; exceeding for the first time the 40% threshold in the first quarter of 2018 regardless of prolonged cold winter.[43]

Due to temporary surcharges financing the FiT incentives German electricity consumers are paying high electricity bills (≈€0.22 kWh^{-1} in 2017), and yet the wholesale price of electricity in 2017 was €0.033 kWh^{-1}, in a steep decrease parallel to the dramatic increase of renewable energy generation.

One might therefore ask what would happen to the economy of competing countries when, in about ten years from now, electricity bills in Germany will no longer comprise FiT surcharge and German companies and consumers will access electricity at unprecedented low cost.

The key concept is therefore as simple as challenging: countries need to seriously act now to vastly increase the amount of renewable energy in their energy generation mix, which obviously includes distributed generation in buildings.

The process is eventually taking place, though it needs to accelerate. In 2017, for example, the amount of installed PV power in the world increased by 29.3% approaching the 100 GW threshold (98.9 GW worth of new capacity, ≈52 GW of which in China only).[44]

A concomitant 60 GW increase in the amount of wind power installed in 2017 brought the total to cross the 530 GW threshold. Wind energy generation already covered 3.7% of the world's electricity demand in 2015, when the global power installed was

432 GW.[45] For comparison, the world's 440 nuclear reactors in 2015 covered 11% of the world's electricity yearly demand, with an energy output of slightly less than 2500 TWh.[46]

4.2. New Legislation Supporting Distributed Generation

One of today's main difficulties with promoting renewable energy decentralized generation arises from the need to effectively involve communities,[47] and therefore to focus on the vastly neglected social and cultural dimensions of this effort, for example, one in which "we are now moving from an era of constructing large-scale technologies to one of reconstructing complex, socio-technological systems that link energy to a wide range of other systems such as water, transportation, food production, and housing."[48]

This means, for example, that rather than focusing only on the technical and economic dimension of the transition to renewable energy, policy makers should creatively develop new policies that also take into account the social and cultural nature of the energy transition.

Based on successful outcomes in other countries, national governments are required to deploy legislation supporting distributed generation via preferential access to the grid and the development of microgrids powered by renewable energy.

Regional governments are called to draft new legislation aimed at promoting uptake of decentralized energy generation, publishing updated guidelines for the integration of solar technologies in both conventional and historic buildings.

Cities, on their turn, are required to update building codes inserting measures aimed at supporting adoption of building-integrated solar technology, from green solar rooftops[34] to rooftops using solar tiles.

New involvement efforts will therefore also be aimed at experts in other fields who are not acquainted with solar energy and energy efficiency technologies, for example, to foster collaboration among professionals in both historic preservation and solar energy to receive appropriate support and guidance.[49]

4.3. Community Involvement and Communication

Renewable energy companies, environmental activists, educational centers, regional governments, and cities must unite forces and deploy effective communication strategies to reach out citizens and make them aware of how advantageous for them and for the community is the adoption of decentralized solar energy.

For example, local cooperation is needed to optimize the contribution of distributed generation and distributed storage of different households to insert the renewable energy in a jointly owned microgrid with mutual delivery.[50]

Besides deploying highly usable and interactive websites concerning solar technology integration in buildings as well as energy efficiency solutions as done by Australian Renewable Energy Agency which proactively shares knowledge learned through its projects with the aim to accelerate Australia's shift to an affordable and reliable renewable energy future,[51] we recommend the creation of efficient contact points and information centers.

Selected successful examples include the Swiss BIPV Competence Centre,[27] or the New York City Solar Partnership aimed to expand access to solar energy for all the city's inhabitants by reducing the nonhardware costs of installing solar by streamlining the permitting, interconnection, and inspection processes.[52]

4.4. Renewed Education

Driven by the urgency of the oil, population, and wealth dynamics,[1] a serious and committed policy effort can, and should, be deployed with solar energy to accelerate the energy transition.

In the age of nearly-zero energy buildings and low-cost solar energy, alas, knowledge of solar energy science, technology, and architecture is still limited. For example, scholars in a top literacy country such as Hungary were reporting that the "lack of knowledge of building-integrated solar technology among architects" still in 2012 was "the main problem requiring new education...to show them how they can...create attractive solar architecture."[53]

Similarly, education in highly successful contemporary rainwater harvesting remains scattered and limited to pioneering countries such as China or South Korea, with the opportunity to use the built environment for either generating energy and harvesting water so far largely missed, at least from a global viewpoint.[54]

Countries are therefore called to establish new solar energy research and educational institutes, where to shape the professionals needed to guide and facilitate the energy transition. Vastly renewed in both content and teaching methodology, the forthcoming education in solar energy will encompass science and technology with management, energy, and economic topics.[55]

In the path toward a fully renewable energy future, we can borrow concepts and ideas from domains apparently far away, for example, from medicine. With a community of 13 000 well-trained physicians scattered throughout the island responsible for between 1000 and 1500 patients, Cuba, an island with 11.2 million inhabitants only and a modest gross domestic product, has brought life expectancy from 70.04 in 1970 to 78.7 years in 2016; and infant mortality rate from 37.3 in 1959 to 4.3 per 1000 live births in 2016, a rate equivalent to that of Australia, and lower than that of the United States (5.8).[56]

The whole system is based on 13 medical schools where all the country's physicians are trained. Actually, these schools have trained a surplus of physicians so that the country sends 25 000 physicians abroad annually to provide care in developing countries.[57]

With the transition to the solar economy now unfolding across the world, we argue in conclusion, within a few years all world's countries will operate similarly successful solar energy and bioeconomy institutes, capable to deploy useful research, education, and policy advice in both crucial domains of the emerging solar economy.[58]

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Conflict of Interest

The authors declare no conflict of interest.

Keywords

BIPV, energy efficiency, energy transition, photovoltaics, solar energy

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