Integration of solar energy systems for increased societal support

INTEGRATION OF SOLAR ENERGY SYSTEMS FOR INCREASED SOCIETAL SUPPORT

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ABSTRACT: How can we integrate photovoltaic (PV) solar energy systems in the built environment and rural landscapes while increasing societal support and making effective use of space? This important research question is inspired by several grand societal challenges, namely humankind's response to anthropogenic causes of climate change, the required sustainable energy transition and innovations in the design of systems, products, buildings and local infrastructures which enable an optimal use of solar energy. Consequently, new sustainable energy environments must be created which will meet the needs of users, will fit in a societal context, will have an excellent performance in energy production and which will be aesthetically appealing. For this purpose a new interdisciplinary Dutch research consortium has been established, which will evaluate so-called 'Solar Integration' from the perspectives of (1) public acceptance, law and governance, (2) biodiversity, ecosystems and spatial quality, (3) PV system configurations in rural and urban landscapes, (4) enabling technologies for integrated PV elements, and (5) design approaches. This research consortium will support Solar Integration by (a) design-driven research on innovations in PV solar energy, (b) the creation of a broad consortium of stakeholders with various backgrounds and interests, (c) execution of the project in both the Netherlands and internationally, and (d) involving adult and young citizens in knowledge utilization.

Keywords: Integration, Design, Landscapes, Built environment, Eco-systems, PV systems, Performance

1 SOLAR INTEGRATION

An added advantage of PV technologies is their attractive integration feature, see Figure 1. Their modular character is such that systems can be designed at any power up to gigawatt sized plants with their high efficiency, proven reliability, low maintenance requirements, absence of moving parts, lack of noise nuisance, and the fact that they can be potentially used as construction materials and can be easily integrated in grids and/or combined with other electrical technologies. Moreover, they can have various colours, eventually with graphical patterns, in a bendable form (both for thin-films and c-Si based) and/or with tuneable transparency. Due to their integration features, PV systems can significantly contribute to the sustainable energy transition (Klimaatakkoord, 2019). However, the current installed PV capacity is very much below its full potential. For instance, the Dutch National Roadmap for PV Systems and Applications (Folkerts et al., 2017) states that a potential installation capacity of 200-250 GWp of PV systems will be required in order to reach the 2050 goals for CO2 emission reductions in the Netherlands which would yield about twice the present total Dutch electricity demand at present . This amount of PV capacity would need a large installation area of approximately 37 × 37 km2. This will cause interesting challenges towards, among others, the use of space required for PV installations in various landscapes, regulatory frameworks, societal acceptance, biodiversity and ecosystems, see Figure 1. In the end this should result in a significant reduction of greenhouse gas emissions at feasible costs. These topics will be shortly discussed in the following sections.

Figure 1: Top left: Kuijpers building Helmond (Netherlands) realized by Kuijpers, Studio Solarix, Sorba and Kameleon Solar; top right: floating PV system realized in 2019 at Sekdoornse plas by GroenLeven and BayWa; bottom left: PV systems applied to slopes of dikes (source: Folkerts), bottom right: innovative colourful design of a PV system in an urban environment (TNO)

2 INTEGRATION OF PV APPLICATIONS IN VARIOUS LANDSCAPES

To illustrate the concept of integration of PV in various environments, Table 1 shows the options for integration of PV systems in various infrastructures and types of possible PV applications. Here, we will focus on three different types of environments: (1) urban environments, (2) rural landscapes with inland water bodies and (3) infrastructures which could be either located in urban or rural areas. In each environment either housing, economic activities and/or transport take place, leading to specific PV applications, see Figure 1 and 3, which suit the environment and the required function. For instance, in rural landscapes with agricultural activities, it is expected that solar parks with regular rack-mounted PV systems consisting of PV modules, inverters and other system components, so-called BOS, will be installed. However, innovations such as vertically bifacial PV systems, see Figure 1, and PV powered greenhouses may also fit in these rural landscapes, and create new opportunities for dual land use for agriculture and power generation. Note that in Table 1 the 2050 potential for PV applications in the Netherlands is based on existing PV system configurations, however other types of PV applications that do not exist commercially yet, will be further developed in the future. This applies for instance to the cases of bifacial agro-PV systems, PV systems on slopes of dikes and the design of coloured PV modules, shown in Figure 1.

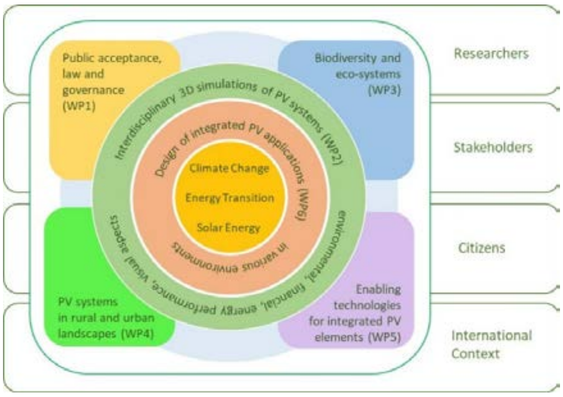

Figure 2: The interdisciplinary research framework towards Solar Integration and various parties which will be involved

3 LOW ENVIRONMENTAL IMPACTS AND COST

Solar integration is a good development because PV systems have very low emissions (Leccisi et al., 2016, p.1), which are currently within the range of 18 to 28 g of CO2 equivalents per kWh produced Fthenakis and Raugei, 2017). As such, the average CO2 emissions per kWh generated by PV systems in the field are less than 2.5% of those produced by a coal-fired plant. As of the year 2019, utility-scale PV systems are also the cheapest electricity source, with a levelized cost of electricity ranging from 24 €/MWh in Spain to 42 €/MWh in Finland (Vartiainen et al., 2019). This is remarkable as it means that PV electricity is already cheaper than the average spot market electricity cost across Europe. On the basis of these arguments we conclude that, given their low carbon footprint and low cost, PV systems are a serious alternative for wind turbines on land, which seem to invoke great societal opposition (NRC, 2019) for each new installation.

4 LEGAL FRAMEWORKS AND GOVERNANCE

Good governance by good regulations, good procedures and effective regional and local spatial policy may contribute to a smooth and just implementation and integration of PV applications in various landscapes. We will therefore examine how law and governance instruments interact within contextual conditions of integrated solar PV energy systems. One can think of spatial conditions of the built environment and rural landscapes, financial conditions and subsidies, interactions with electricity grids, energy justice aspects (referring to a just distribution of the costs and benefits of the energy transition and fair public participation procedures that involves current and future generations) and public acceptance. Because legal and policy aspects are at present subject to rapid changes, we aim to cover these modifications in the research and identify the impact of these changes on the public acceptance of integrated solar PV systems. At the beginning of 2020 one can think about developments related to the draft Omgevingswet (this is an environmental Dutch law which regulates regional and local participation procedures), legislation for the stimulation of renewables such as the SDE+ regulation, international, national and regional legislation on nature conservation, and national and regional laws on housing and spatial planning.

5 PUBLIC ACCEPTANCE

In general, societal support for solar energy has always been very high in the Netherlands. However, concerns appear with the current increase of planned and realised solar parks (see Figure 3). Recent articles in regional newspapers and television channels show that societal resistance against solar parks is among others based on concerns regarding distortion of the rural landscape and declining biodiversity, a loss of agricultural land or recreation opportunities, bad appearance, fear for unsafe situations and unevenly distributed costs and benefits of solar energy systems. In addition to producing electricity in a renewable way, many other values are attached to solar energy systems applied in rural and urban environments. Dutch society also witnesses citizens actively promoting solar energy projects among others via local energy initiatives. The arguments in favour of and against solar energy systems have to be taken seriously in the development of future systems in need of an acceleration of solar energy implementation for the renewable energy transition. We hence aim at improving the understanding of how solar energy can be integrated in ways that are acceptable for Dutch citizens: socially, in public decision-making processes, as well as physically, in urban and rural landscapes, providing multiple societal functions. Better integrated solar systems are expected to decrease public resistance and stimulate public acceptance and support (Sanchez-Pantoja et al., 2018).

Table 1: Options for integration of PV systems in various environments and specific types of possible PV applications.

Type of landscape	Urban environments* (both residential and commercial)	Rural landscapes** (incl. agricultural land and inland water bodies)	Infrastructures ***
2050 potential for PV******			
Nominal power (GWp)	79	80	33
Area (km^2)	456	518	184
Type of PV application	Building applied PV systems	PV systems / Solar parks	Sound barrier systems
	Building integrated PV: roofs	Vertical bifacial Agro-PV systems	Solar roads
	Building integrated PV: facades	Greenhouses	PV on dikes
	PV charging stations for EVs	Floating PV systems	PV along rail roads

*) Urban environments cover areas for housing (39 GWp) and commercial buildings (40 GWp)
**) Rural landscapes cover agricultural land (45 GWp), agricultural buildings (11 GWp) and inland water bodies (24 GWp)
***) Infrastructures cover roads, dikes, rail roads, waste lands, sound barriers and such
****) According to National Roadmap for PV Systems and Applications (Folkerts *et al.*, 2017)

6 ECOSYSTEM SERVICES, BIODIVERSITY AND SPATIAL QUALITY

Ecosystem services, i.e. the benefits people obtain from ecosystems, include provisioning services, e.g. food production; regulating services such as soil moisture retention during droughts; supporting services such as biodiversity; and cultural services such as recreational and aesthetic benefits (Diaz et al., 2015). Biodiversity itself also provides key services to people; for instance, a high local diversity of flower colours and shapes will support a richer insect population and insects have been in dramatic decline in Western Europe in recent decades (Hallmann et al., 2017). Spatial quality refers to values that are ascribed to a certain environment. Commonly, spatial quality has three constituents: functional, experience and future values (Hooimeijer et al., 2001). Spatial quality has been improved successfully in the past in Dutch climate adaptation projects. An increase of spatial quality, similar to biodiversity, is believed to promote societal support and public acceptance of solar landscapes (see e.g. Klimaatakkoord, 2019; Holland Solar et al., 2019). Presently, however, mono-functional PV installations often modify land use and landscape infrastructures. This can affect the supply of ecosystem services and, in turn, frequently results in low public acceptance of solar landscapes. Therefore, ecosystems, biodiversity and spatial quality of solar landscapes will be investigated to develop a better understanding of cultural, regulating and provisioning ecosystem services supplied by landscapes. Namely we aim to enable a more informed decision-making on PV installations that accommodates stakeholder values and preferences with regards to their living environment.

7 CONCLUSIONS

The following research results are expected

- Detailed insights in the interrelations between economic regulations and laws, spatial planning laws and regulations, (fair) public participation procedures, system innovation processes, biodiversity and public acceptance will form an essential breakthrough as compared to existing solar PV research which mainly has a strong mono-disciplinary technical scope.
- Revealing the relations between selected ecosystem services affected by PV systems and operationalizing spatial quality for the design of solar landscapes.
- Design guidelines for well-integrated solar energy systems, as well as products and buildings, with an excellent spatial quality covering smart solutions for shading and intermittency of electricity production.
- New materials for PV devices that can be integrated in PV modules with improved integration features, such as colouring, form giving and transparency, matched to the application environment, i.e. fitting to the built environment if integrated in buildings and mimicking nature if applied in rural areas.

Simultaneously this approach will evoke the following societal change

- Increased societal support of the integration of PV applications in various environments by both citizens, professional stakeholders and governmental bodies.
- A framework for good governance of a just, sustainable energy transition with a focus on solar energy.

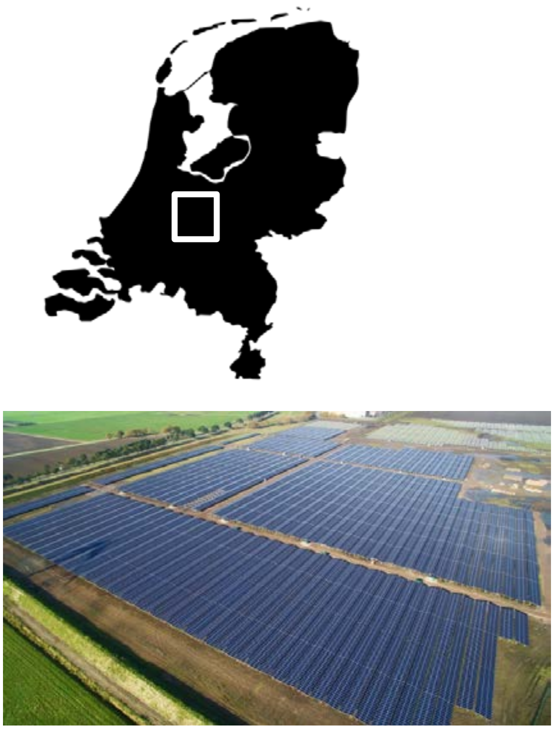

Figure 3: Above: required area to achieve the targets for PV power production in the Netherlands according to the National Roadmap for PV Systems and Applications (Folkerts et al., 2017). Below: a very large PV system of 30 MW, SunPort Delfzijl (Solarfuture, 2019).

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