

# Integration of solar energy systems for increased societal support

***Citation for published version (APA):***

Reinders, A. H. M. E., Lavrijssen, S., Folkerts, W., van Mierlo, B., Franco Garcia, L., Loonen, R. C. G. M., Cornelissen, H., Stremke, S., Alarcon Llado, E., Polman, A., & Weeber, A. W. (2020). Integration of solar energy systems for increased societal support. In *Proceedings of 37th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC)* (pp. 1911-1914)

***Document status and date:***

Published: 01/01/2020

***Document Version:***

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

***Please check the document version of this publication:***

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

***General rights***

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

[www.tue.nl/taverne](http://www.tue.nl/taverne)

***Take down policy***

If you believe that this document breaches copyright please contact us at:

[openaccess@tue.nl](mailto:openaccess@tue.nl)

providing details and we will investigate your claim.

## INTEGRATION OF SOLAR ENERGY SYSTEMS FOR INCREASED SOCIETAL SUPPORT

Angèle Reinders<sup>1,2</sup>, Saskia Lavrijssen<sup>3</sup>, Wiep Folkerts<sup>4</sup>, Barbara van Mierlo<sup>5</sup>, Laura Franco-Garcia<sup>2</sup>, Roel Loonen<sup>1</sup>, Hans Cornelissen<sup>6</sup>, Sven Stremke<sup>5</sup>, Wilfried van Sark<sup>7</sup>, Esther Alarcon-Llado<sup>8</sup>, Albert Polman<sup>8</sup> and Arthur Weeber<sup>9</sup>

1) Eindhoven University of Technology, Eindhoven, The Netherlands, 2) University of Twente, Enschede, The Netherlands, 3) University of Tilburg, Tilburg, The Netherlands, 4) TNO Energie Transitie, Eindhoven, The Netherlands, 5) Wageningen University of Research, Wageningen, The Netherlands, 6) Vrije Universiteit, Amsterdam, The Netherlands, 7) Utrecht University, Utrecht, The Netherlands, 8) AMOLF, Amsterdam, The Netherlands, 9) Delft University of Technology, Delft, The Netherlands

**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

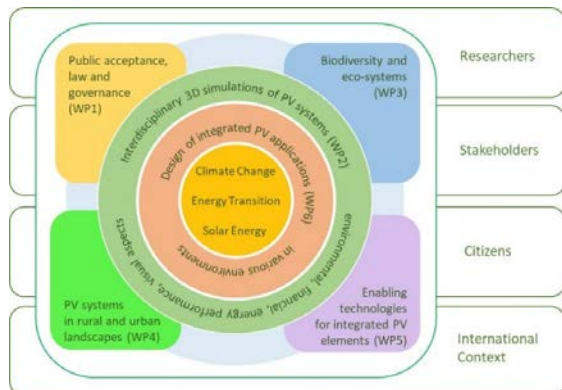
potential. For instance, the Dutch National Roadmap for PV Systems and Applications (Folkerts et al., 2017) states that a potential installation capacity of 200-250 GWp of PV systems will be required in order to reach the 2050 goals for CO<sub>2</sub> emission reductions in the Netherlands which would yield about twice the present total Dutch electricity demand at present. This amount of PV capacity would need a large installation area of approximately  $37 \times 37$  km<sup>2</sup>. 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 CO<sub>2</sub> equivalents per kWh produced (Thenakis and Raugéi, 2017). As such, the average CO<sub>2</sub> 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 ***
<b>2050 potential for PV****</b>			
<b>Nominal power (GWp)</b>	79	80	33
<b>Area (km<sup>2</sup>)</b>	456	518	184
<b>Type of PV application</b>	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).

## REFERENCES

- Diaz, S., Demissew, S., Joly, C., Lonsdale, W.M. and Larigauderie, A. (2015). Rosetta Stone for Nature's benefits to people. *PloS Biology*, 13, e1002040.
- Folkerts, W., Sark, W. van, Keizer, C. de, Hooff, W. van, and Donker, M. van den (2017), Roadmap PV Systems and Applications, Retrieved <https://www.topsectorenergie.nl/sites/default/files/uploads/Urban%20energy/kennisdossier/PV%20Systemen%20en%20Toepassingen.pdf>
- Fthenakis, V. and Raugei, M. (2017). Environmental life-cycle assessment of photovoltaic. The Performance of Photovoltaic (PV) Systems: Modelling, Measurement and Assessment, 209-232.
- Holland Solar, NLVOW, Energie Samen, Greenpeace, Milieudefensie, Natuur & Milieu, Natuur en Milieufederaties, Natuurmonumenten and Vogelbescherming (2019, November 13). Gedragscode Zon op Land. Retrieved from: <https://hollandsolar.nl/gedragscodezonopland>
- Hallmann, C.A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D., Kroon, H. de (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLOS ONE*, 12, e0185809.
- Hooimeijer, P., Kroon, H., and Luttik, J. (2001). Kwaliteit in meervoud. Gouda, Habiforum, Expertisenetwerk Meervoudig Ruimtegebruik.
- Klimaataakkoord (2019, August 20). Klimaataakkoord, Retrieved from <https://www.klimaataakkoord.nl/>
- Leccisi, E., Raugei, M. and Fthenakis, V. (2016). The energy and environmental performance of ground-mounted photovoltaic systems—A timely update. *Energies*, 9(8), 622, 1-13.
- NRC (2019, September 12). Opeens stond die windmolen in de tuin, Retrieved from <https://www.nrc.nl/nieuws/2019/09/12/opeens-stond-die-windmolen-in-de-tuin-a3973115>
- Sanchez-Pantoja, N., Vidal, R., and Pastor, M.C. (2018). Aesthetic impacts for solar energy systems. *Renewable and Sustainable Energy Reviews*, 98, 227-238.
- Vartiainen, E., Masson, G., Breyer, C., Moser, D. and Román Medina, E. (2019). Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelised cost of electricity. *Progress in Photovoltaics*, 1-15.