Solar Energy 155 (2017) 304–313

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Environmental impact comparison of a ventilated and a non-ventilated building-integrated photovoltaic rooftop design in the Netherlands: Electricity output, energy payback time, and land claim

M.J. Ritzen [a,b,*], Z.A.E.P. Vroon [a,c], R. Rovers [d], A. Lupíšek [e], C.P.W. Geurts [c]

[a] Zuyd University of Applied Sciences, Nieuw Eyckholt 300, 6419 DJ Heerlen, The Netherlands
[b] Department of the Built Environment, Eindhoven University of Technology, De Wielen, 5600 MA Eindhoven, The Netherlands
[c] TNO, Stieltjesweg 1, 2628 CK Delft, The Netherlands
[d] SBS, Wollenbergstraat 37, 5581 HH Waalre, The Netherlands
[e] University Centre of Energy Efficient Buildings, Prague, the Czech Republic/Technical University Prague, Czech Republic

ARTICLE INFO

Article history:
Received 2 December 2016
Received in revised form 20 March 2017
Accepted 15 June 2017

Keywords:
Building integrated photovoltaics
BIPV
Environmental assessment
Photovoltaic systems

ABSTRACT

Building Integrated PV (BIPV) is considered as a key development for successful deployment of PV in the built environment. However, the effect of PV integration on environmental impact is not fully understood. In this study a single indicator for environmental impact assessment of BIPV is investigated in the Netherlands. A BIPV rooftop with 24 multi-crystalline 60-cell modules has been designed with and without backside ventilation, and the environmental impact of these configurations has been assessed in the current situation and three future scenarios. The results are expressed in terms of electricity output difference (Δ_{Eout}), Energy PayBack Time (EPBT), and the single indicator Land Claim (LC); the calculated claim in land-time on the carrying capacity to realize the BIPV rooftop. The EPBT calculations are based on two different datasets, SimaPro and the Inventory of Carbon and Energy (ICE), and the LC calculations are based on two different models, SimaPro and MAXergy. Calculations indicate that the ventilated BIPV rooftop design generates 2.6% more electricity than the non-ventilated BIPV rooftop design on a yearly basis. Calculations indicate that the EPBT of the ventilated BIPV rooftop design (3.56 and 4.59 years, based on SimaPro and ICE, respectively) is 9 and 6% longer than the EPBT of the non-ventilated BIPV rooftop design (3.25 and 4.32 years, based on SimaPro and ICE, respectively). Calculations indicate that the LC of a m^2 ventilated BIPV rooftop design (24.4 and 19.4 m^2 a, based on SimaPro and MAXergy, respectively) is 18 and 10% higher than the LC of a m^2 non-ventilated BIPV rooftop design (20.0 and 17.4 m^2 a, based on SimaPro and MAXergy, respectively). In the optimal future scenario EPBT might decrease to 2.06 years and LC might decrease to 10.6 m^2 a. This study indicates that the non-ventilated BIPV design shows a lower environmental impact in spite of a lower electric performance and that environmental impact can significantly be reduced in future scenarios.

1. Introduction

To reach lower fossil fuel dependency and to decrease CO_2 emissions in the European Union (EU), it has been agreed to increase the share of renewable energy sources in the Final Energy Consumption (FEC) to 20% by the end of 2020 (European Commission, 2010). Photovoltaics (PV) can be a major contributor to this target. In 2011, electricity consumption was 3500 TWh in the EU of which 117 TWh in the Netherlands (European Commission, 2013). The amount of PV surface needed to cover this electricity consumption would result in a total of 7100 km^2 PV modules for the EU and 1300 km^2 for the Netherlands, placed in the optimum orientation and inclination (Šúri, 2007). This area calculation is not taking into account improved efficiency of PV systems, degradation of PV systems, grid/storage interaction and increasing electricity demand. The potential roof and façade surface for building integrated PV is a total of 4979 km^2 in the EU and 210 km^2 in the Netherlands (Defaix, 2012). Theoretically, 70% of the electricity demand in the EU and 16% of the electricity demand in the Netherlands could be fulfilled by BIPV, not taking into account lower efficiencies due to less optimal inclination and orientation, degradation over time, PV efficiency improvement, grid/storage aspects, and other installation and operational aspects.

---

[*] Corresponding author at: Zuyd University of Applied Sciences, Nieuw Eyckholt 300, 6419 DJ Heerlen, The Netherlands.

E-mail address: michiel.ritzen@zuyd.nl (M.J. Ritzen).

http://dx.doi.org/10.1016/j.solener.2017.06.041
0038-092X/© 2017 Published by Elsevier Ltd.

Nomenclature

BAPV	building added photovoltaics
BAU	business as usual scenario
BIPV	building integrated photovoltaics
CO_2	carbon dioxide
Δ_{Eout}	difference in electricity output (%)
E_{agen}	annual electricity generation of the PV installation (MJ)
E_{aoper}	annual energy demand for operation and maintenance of the PV installation (MJ)
EE	embodied energy (MJ)
E_{emb}	primary energy demand necessary for the realization of the PV installation (MJ)
E_{EOL}	primary energy demand for end-of-life management of the PV installation (MJ)
E_{gen}	energy generated over lifespan of the installation (MJ)
E_{inst}	primary energy demand to install the PV installation (MJ)
EL	embodied land (m^2 a)
EL_{EE}	embodied land necessary for embodied energy generation (m^2 a)
EL_{fact}	embodied land factory (m^2 a)
EL_{mat}	embodied land materials ($m^2 \cdot a$)
EL_{pv}	embodied land photovoltaic device (m^2 a)
E_{manuf}	primary energy demand to manufacture the PV installation (MJ)
E_{mat}	primary energy demand to produce materials for the PV installation (MJ)
$E_{non\text{-}vent}$	energy output of non-ventilated BIPV (MJ)
EPBT	Energy PayBack Time (years)
E_{raw}	primary energy demand to extract raw materials for the PV installation (MJ)
EROI	energy return on investment
E_{trans}	primary energy demand for transportation during and in between the different process steps (MJ)
EU	European Union
E_{vent}	energy output of ventilated BIPV (MJ)
f	conversion factor (based on the amount of m^2 necessary to generate the embodied energy with the given installation)
FEC	final energy consumption (MJ)
ICE	inventory of carbon and energy
IEA	International Energy Agency
LC	land claim ($m^2 \cdot a$)
LCA	life cycle analysis
LCI	life cycle inventory
MWT	metal wrap through
η_G	grid efficiency, the average primary energy to electricity conversion efficiency at the demand side (44.3% in the Netherlands) (World Energy Council, 2015) (%)
NL	the Netherlands
NREL	National Renewable Energy Laboratory
OPT	optimistic scenario
PEC	primary energy consumption (MJ)
PV	photovoltaics
PVPS	Photovoltaic Power Systems International Research Collaborative
REAL	realistic scenario
SAM	system advisory model
STC	standard test conditions
TDoT	The District of Tomorrow, field test location in the Netherlands
Wp	Watt peak, nominal power at STC of PV modules (W)

PV can easily be applied to buildings because PV installations are easily connected to the electricity system of a building and are not based on either potentially dangerous processes or use potentially dangerous resources, as opposed to for example gas based heating systems. The 60-cell multi-crystalline PV modules under investigation in this study can be added to the building envelope (Building Added PV - BAPV) or can be integrated in the building envelope (Building Integrated PV – BIPV), as illustrated in Fig. 1A and B.

In the case of BAPV, a construction is added to the building envelope to carry the PV modules, with in general an air gap between rooftop and PV. In the case of BIPV the modules are directly placed on the rooftop construction, possibly replacing roofing materials resulting in a smaller or no air gap.

The acronym BIPV is generally used when the PV installation is both technically and aesthetically contributing to the functionality of the building (Sinapsis and Donker, 2013). Four key factors are considered essential for the success of PV: cost reduction, efficiency increase, electricity storage, and its integration in the building, i.e. BIPV (Raugei and Frankl, 2009). One of the barriers on the track towards more BIPV is the possible negative side effect of physical integration on the performance and durability of the PV installation due to increased operating temperatures and increased relative humidity (Ritzen et al., 2014a,b,c; Mei, 2009; Norton, 2011; Ritzen et al., 2017), caused by a lack of backside ventilation. For this reason, the relation between PV output and backside ventilation is an important topic of ongoing research (Ritzen et al., 2014a,b,c). PV application has an environmental impact, in the form of energy necessary to produce the PV installation (embodied energy – EE) and in the form of resource extraction and processing, which might increase due to a shorter lifespan of PV installations. This creates a possible imbalance between energy generation on the one hand and embodied energy and material consumption on the other hand.

The availability of resources, in combination with the renewable energy potential, to deliver the necessary operational energy

Fig. 1. (A) Photograph of rooftop BAPV realized in Florianopolis, Brazil (Santos and Rüther, 2012) and (B) Photograph of rooftop BIPV realized in Badia, Italy (GSE, 2012).