Technical Evaluation of BIPV power generation potential in EU-28

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ABSTRACT: The present study evaluates the potential PV capacity that could be installed on roof and façade surfaces of buildings in the EU-28. The paper then evaluates the potential power generation and the theoretical PV penetration in key countries and in Europe as a whole. Drawing from methodological approaches previously developed in earlier papers, the paper presents a modular approach that provides a base study from where more focused research can be derived as needed. The paper assesses in detail each of the underlying assumptions and makes use of most recent information available on the EU building stocks. The power generation potential is calculated using the current state of the art in building applied and building integrated PV technologies (BAPV / BIPV). Finally, a sensitivity analysis is carried out on the major assumptions and the results are discussed and compared to those provided in earlier reference studies.

Keywords: economic analysis, photovoltaic production, BIPV, BAPV, distributed generation, roofs, façades.

1 INTRODUCTION

1.1 Context of the Research

The unprecedented decrease of PV technology costs has also driven down the price for PV generated kWh much faster than expected. Standard applications of PV are becoming increasingly competitive in Europe and it is expected that under the regulatory pressure on the energy performance of buildings, advanced integration of PV in the built environment will become an important focus in both the building and the PV industries.

This is especially the case in Europe, as a consequence of high population density and therefore, the increasing scarcity of affordable land surface for large-scale ground mounted PV plants. It is therefore of major interest to assess the technical potential of BIPV, i.e. the total net surface offered by roofs and facades in the built environment that is suitable for PV.

Although various studies have discussed the subject, the figures most often cited in the literature refer to the original study of S. Nowak & al. performed in the framework of IEA PVPS in 2002[1]. The present study attempts to provide an updated view on this estimation, also using the most recent information available on building stocks as well as more precise solar irradiation calculations.

1.2 Building Applied vs. Building Integrated PV

An important distinction exists between Building Applied PV (BAPV) and Building Integrated PV (BIPV).

BAPV typically refers to situations where a solar installation (PV modules) is applied on (and in addition to) the envelope of a building, be it on facades or more frequently on roofs. In such case, the PV functionality is simply added to an existing building, such as modules fixed onto the existing roof or façade. BAPV represent the vast majority of existing PV installations on buildings.

In contrast, BIPV describes a situation where the PV module makes an integral part of the building envelope and contributes to the envelope functionalities, such as (but not limited to) water tightness, mechanical stability, noise reflection, thermal insulation, heat reflection, shading, etc… BIPV should therefore rather be considered as a building material to which PV functionality was added. BIPV that typically, until recently, meant "additional costs", has been mostly limited up to now to more emblematic high-end architectural projects. However several major building materials producers have announced to work on highly standardized, innovative and affordable new BIPV products thus paving the way towards mass adoption.

1.3 Purpose of this study

The present study aims only at evaluating the roof and façade available surfaces that are suitable for PV generation and consequently, the power generation potential of buildings in Europe, notwithstanding the fact PV could either be effectively integrated (BIPV) or applied (BAPV) to it. There is no attempt in the present study to discuss the distribution of BIPV and BAPV, even if the former is expected to grow in the future, driven both by improved aesthetics and increasingly attractive economics.

For the sake of ease in this study, “BIPV” will be used indistinctively when referring to “BIPV” or “BAPV”.

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2 Methodology

2.1 Overview

Working on the complex manifold of building data obviously requires the use of statistical approaches and a number of assumptions on how to model the building’s population.

For instance, in Germany only, it is estimated that about 38 million buildings exist[2]. Considering only residential buildings in Germany, about 22 different generic building typologies[3] can be distinguished.

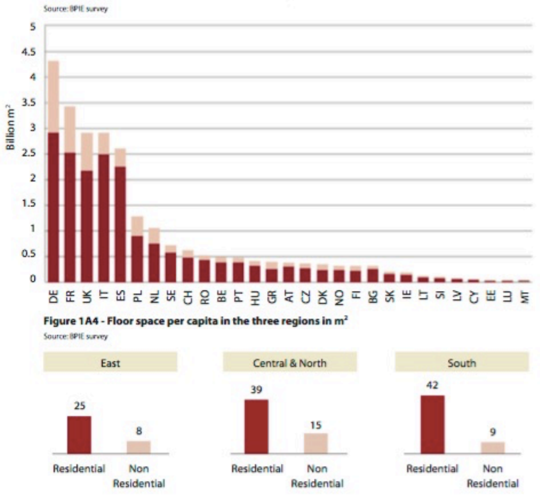


Figure 1: Residential / Non residential floor area per capita in EU

Figure 1 illustrates the vast diversity of situations encountered in Europe and therefore the need for using carefully chosen sets of assumption and statistical analysis.

In the wake of the EU Energy Performance of Buildings Directive[4], numerous studies exist now that describe the EU stock of buildings. Unfortunately, in most cases, building information has been collected in the view of socio-demographic and energy conservation analysis and always refer to gross or net floor surfaces. Only very few information exist on the height of buildings (e.g. their number of floors), a variable that is essential to e.g. obtain façade surfaces from floor surfaces.

Two main studies have been performed after the baseline of S. Nowak & al. (ref 1). The study of R. Defaix & al.[5] provides additional insights on the evaluation of the number of floors per building segment. The study of H. Lehmann & al.[6] uses an alternative approach based on the correlation found between population density and facades and roof areas per capita. However based on our extensive analysis of existing building data we’re considering this approach as less robust than the previous ones.

2.2 Methodological Approach

The methodological approach used in this paper is inspired from the original approach of S. Nowak & al. (ref 1) but has been developed independently and modified to integrate more precise building data and PV yield information that are now available.

Also, all base assumptions have been reconsidered and reassessed independently from the original study.

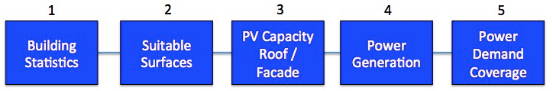


Figure 2: Methodological Overview

Figure 2 provides a synthetic overview of the methodological process used in the present paper for deriving potential BIPV penetration from raw building statistics.

2.2.1 – Building Statistics

The EU Climate and Energy Framework[7] and the EPBD Directive[8] have resulted in an increased focus on the EU building stocks, leading to a number of detailed EU funded research projects on the subject.

The paper draws essentially from these sources, which can be generally found on the website of the Building Performance Institute Europe[9]. In particular, the paper has used data from the Eurostat database[10], the Buildings Database[11] the Episcope Platform[12], the Entranze Data Mapping Tool[13] as well as the Tabula Web Tool[14].

Additional country specific studies and databases have been used when possible.

In this paper, we have analysed data for 10 EU representative countries, representing about 80% of EU-28 population and Switzerland: Austria, Belgium, France, Italy, Germany, Netherlands, Poland, Romania, Spain, Switzerland, and United Kingdom.

These countries therefore can be considered as highly representative of EU-28 as a whole, in particular for deriving average power demand coverage potential.

2.2.2 – Suitable Surfaces

Building statistics provide quite detailed information on gross and net floor areas, buildings segmentation as well as some information of generic building typologies for each country.

In order to derive roofs and façade surfaces from floor surfaces, assumptions have been made to obtain a generic number of floors per buildings segment. Our detailed analysis of buildings typologies and distribution across Europe resulted in a EU-28 average of 2,25 floors (ground floor = 1floor) per building in the residential segment and of 2 floors in the non-residential sector (a similar figure can be found in US EIA[15] regarding non-residential buildings on the densely populated areas of US East Coast). This parameter is essential as it conditions the translation of floor surface into ground surface, from where roof and façade surfaces can be derived. As such, these assumptions have been carefully considered based on building typologies available in the Tabula Web Tool[16] and on analysis provided in the paper from Defaix & al (ref 5). A sensitivity analysis was carried out considering a variation of +/- 10% of this parameter, in the residential and non residential segments.

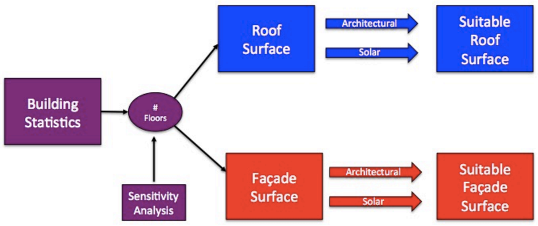


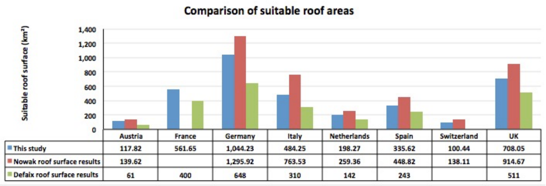
Figure 3: Determination of Suitable Surfaces

Roof surface can be derived from the ground surface, which is calculated from the total floor surface and number of floors. However, roofs can have various slopes, varying from flat (0°) to sharp slope (60°). Building statistics show however that in average about 1/4 of total roof surfaces are flat and 2/3 of tilted roofs surfaces have slopes lower or equal to 30°.
Considering this slopes distribution, and the fact tilted roofs present a relatively greater surface than flat roofs relative to the same ground area, the calculated average ratio is 1,2 m2 of roof surface for every 1m2 of ground surface.

The next step is to define what portion of that roof is suitable for PV use. Two factors will be analysed:

- The architectural suitability. It reflects the portion of roof surface that can be used for PV when removing all surfaces that are not available for urbanistic reasons, geometric constraints, presence of other roof constructions, such as HVAC or chimneys, and shadowing created by other roof superstructure.
- The solar suitability. We will arbitrarily consider only surfaces that are able to provide at least 80% of the maximum yield provided at the same location for a module with optimal orientation. Any surface leading to an inferior yield will be considered as unsuitable for PV.

Considering a selection of representative roof typologies, it has been assumed that 50% of the roof surface is architecturally suitable both in the residential and non-residential segments.
Regarding solar suitability, we must consider all combinations of tilt angle (slope of the roof) and azimuth angle (deviation from meridian direction) that will provide at least the pre-defined acceptable yield.
Considering an average EU latitude, computations have been done for a typical distribution of roof slopes in both the residential and non-residential segments, and assuming a random azimuth distribution. For both segments calculations show that on average, 63% of roof surfaces satisfy the conditions of solar suitability.

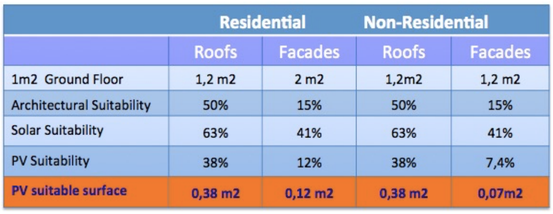


	Austria	France	Germany	Italy	Netherlands	Spain	Switzerland	UK
This study	117.82	561.65	1,044.23	484.25	198.27	335.62	100.44	708.05
Nowak roof surface results	139.62		1,295.92	763.53	259.36	448.82	138.11	914.67
Defaix roof surface results	61	400	648	310	142	243		511

Figure 4: Suitable Roof Surfaces

Figure 4 provides the calculated roof surface (blue bar) and is compared with results of the baseline study of Nowak & al. (ref 1) and with the results of the study of P.R. Defaix & al. (ref 5).
The current study, based on most recent data consistently provides results within the range defined by the 2 previous studies.

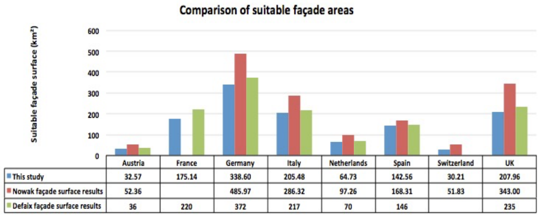
Façade surface will be derived again from estimated ground surfaces and number of floors.
As façade surfaces vary linearly with the ground perimeter and not ground surface, average ground surfaces have been calculated separately for the residential and non-residential segments, which typically feature very different ground surfaces. Calculations have yielded an average of 2 m2 and 1,2 m2 façade area per 1 m2 ground surface, respectively in the residential and non-residential segments.



	Residential		Non-Residential	
	Roofs	Facades	Roofs	Facades
1m2 Ground Floor	1,2 m2	2 m2	1,2m2	1,2 m2
Architectural Suitability	50%	15%	50%	15%
Solar Suitability	63%	41%	63%	41%
PV Suitability	38%	12%	38%	7,4%
PV suitable surface	0,38 m2	0,12 m2	0,38 m2	0,07m2

Figure 5: Key surface parameters

Facades can be very diverse considering the various typologies and orientations. They can range from plain facades with no opening to window facades, and include all intermediate situations.
Considering openings are usually found on well-exposed facades and the need to ensure a visually pleasing PV organisation, we have taken the conservative assumption that only 15% of façade surfaces will be architecturally suitable for PV.
Regarding solar suitability, it is assumed that all facades have a 90° tilt angle, and a random azimuth distribution.
Considering the same average EU latitude, we have calculated that only 41% of façade surfaces would be satisfying the solar suitability criteria.



	Austria	France	Germany	Italy	Netherlands	Spain	Switzerland	UK
This study	32.57	175.14	338.60	205.48	64.73	142.56	30.21	207.96
Nowak façade surface results	52.36		485.97	286.32	97.26	168.31	51.83	343.00
Defaix façade surface results	36	220	372	217	70	146		235

Figure 6: Suitable Facade Surfaces

Figure 6 provides the calculated facade surface (blue bar) and is compared with results of the baseline study of Nowak & al. (ref 1) and with the results of the study of P.R. Defaix & al. (ref 5).

The current study, again consistently provides results within the range defined by the two previous studies.

It is interesting to note, that suitable façade area is generally less than one third of roof suitable surface.

2.2.3 – PV capacity on roofs and facades

In this paper, we have considered mainstream commercial opaque BAPV or BIPV products, typically consisting of c-Si or CI(G)S technology.

It must be emphasized that novel BIPV products (e.g. based on new technologies such as dye or organic cells) are expected to come on-line in the short to medium term and have not been considered in our studies yet. These new technologies promise numerous benefits such as flexible form factors, semi-transparency, ease of integration and better performance under difficult light conditions (e.g. shadows and diffuse light). They ultimately should offer additional PV capabilities to buildings so that the estimation provided in this paper should be considered as a minimum PV penetration theoretically achievable.

We have considered an average solar efficiency of 15%, meaning every 1 m2 of PV would represent a capacity of 150Wp.

This capacity should obviously be calculated on a country-by-country basis, given the variance in solar irradiation, and separately for roofs and façades, considering both provide different yields at any given location.

2.2.4 – Power Generation

Power generation is calculated for each country separately for roof and façade surfaces.

The paper has used PVGIS[17] tool from the JRC. In the case of countries that span over a significant range of latitudes, a weighted average of solar yields has been calculated on different location points of the country.

The more recent SAF-Climate PVGIS irradiation database has been used, with the rather conservative assumption that all installations would be integrated (BIPV), thus with a lower yield due to higher assumed operating temperatures.

2 EU BIPV TECHNICAL POTENTIAL

Based on the preceding, the technical potential of 10 EU countries and Switzerland has been calculated.

A sensitivity analysis has been performed on the estimated average number of floors, for a +/- 10% variance of this parameter on both residential and non-residential segments.

The analysis shows that the estimated power generation exhibits a lower variance, which confirms the robustness of the methodological approach, and the reliability of the derived figures.

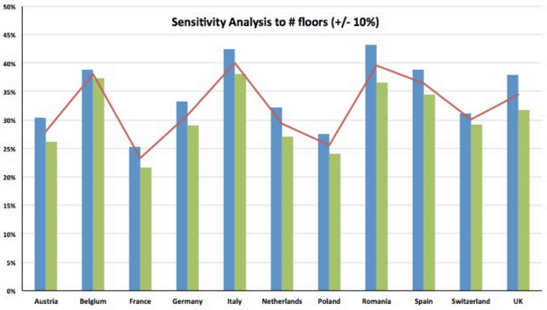
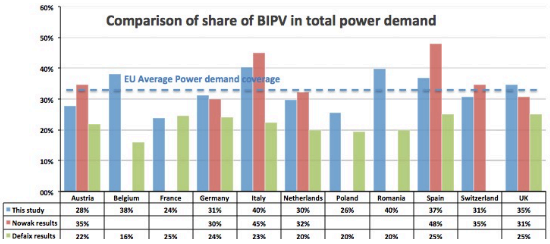


Figure 7: PV coverage of power demand by country

The BIPV coverage of the demand varies from country to country within a range of 24% to 40%.

As expected the coverage rate generally varies and depends on the irradiation level (latitude of the country), the general structure and typology of the built environment as well as on the very country specific overall power intensity. Not surprisingly, France, which has high power intensity due to e.g. widely spread electric domestic heating, has the lowest demand coverage, while Spain and Italy achieve much a higher coverage of about 40%.



	Austria	Belgium	France	Germany	Italy	Netherlands	Poland	Romania	Spain	Switzerland	UK
■ This study	28%	38%	24%	31%	40%	30%	26%	40%	37%	31%	35%
■ Nowak results	35%			30%	45%	32%			48%	35%	31%
■ Defaix results	22%	16%	25%	24%	23%	20%	20%	20%	25%		25%

Figure 8: Comparison between main studies

Figure 8 shows the comparison of results calculated in the present paper (blue bar) with the results provided by the baseline study of Nowak & al. (ref. 1) and the study of P.R. Defaix (ref. 5).

The comparison confirms once again the good alignment of this study, which generally provides demand coverage ratios comprised in the range of the 2 other studies and confirms the excellent estimation that was performed 15 years ago by Nowak & al. (ref.1).

The weighted average maximum demand coverage of BIPV only is about 32% at the EU level, confirming and the huge potential of buildings for distributed power generation

3 FURTHER ANALYSIS

The present study provides a refined estimation of the global technical generation potential of buildings in Europe, assuming all suitable surfaces of the envelope carry PV generating capabilities.

Buildings Segmentation

Although special care have been brought to ensure choices of parameters that satisfactorily represent the distribution of buildings, a finer segmentation of buildings would allow to better represent the huge diversity of buildings typologies (e.g. office buildings, sport facilities, hotels, restaurants, education, retail buildings, agricultural and industrial warehouses that all belong to the same non-residential segment) and of the attractiveness they represent in terms of power generation potential.

In addition, such a finer segmentation would allow further assumptions on self-consumptions ratios that are expected to increasingly affect the distributed generation economics.

In depth Country Analysis

As evoked earlier, EU countries present a significant level of diversity when it comes to the distribution and typology of the built environment. The present study was based on an extensive set of EU-wide studies and research projects, providing country specific information, collected through similar methodologies and presented under comparable formats. More specific country analysis could be performed by using, when available, country specific data and statistics on its building stock, that in some cases allow a much finer segmentation and analysis than that performed uniformly across all EU-countries as in the present study.

Novel PV technologies and applications

As mentioned in § 2.2.3, the present paper assumes only mainstream mass market commercial technologies are used. It is however anticipated that, more sophisticated front-end treatments on classical cells, or the use of novel technologies such as dye or organic cells will provide additional BIPV solutions in the future, notably due to more flexible module formats, mechanical flexibility, light weight, and useable transparency, potentially allowing other applications and/or additional areas of the envelope (e.g. windows) to be used.

5 CONCLUSION

The present study unequivocally confirms the huge theoretical potential that buildings represent in terms of distributed power generation, with roof surfaces being the main contributors to power generation, However, a significant number of technical, economic and non economic obstacles need to be overcome and streamlined before such potential could, even partially, be exploited through massive implementation of BAPV / BIPV applications.

While major building material manufacturers are working on the integration of the PV functionality into the building material, one can expect an increasing number of cost attractive PV enabled materials to come on-line.

The continuous downward pressure on PV costs, and the increasing focus of policymakers on implementing self-consumption schemes should further drive the interest for BAPV/BIPV.

Finally, deep renovation and new constructions constitute an ideal moment to consider an economically attractive implementation of PV-enabled envelope components. While there is a pressure to triple the annual renovation rate of the EU building stock from the current 1% to 3% by 2020, policy makers should carefully establish the proper framework conditions that will make the use of PV-enabled envelope components a standard practice across EU in all deep renovations or new construction.

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