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PV potential and potential PV rent in European regions

by
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Abstract

The paper provides a GIS based model for assessing the potentials of photovoltaic electricity in Europe by NUTS 2 regions. The location specific energy potential per PV-panel area is estimated based on observations of solar irradiation, conversion efficiency, levelised costs and the social value of PV-electricity. Combined with the potential density of PV-panel area based on land cover and environental restrictions, the PV energy potential and the potential PV resource rent is calculated. These calculations enbable the model to estimate the regional patterns at NUTS 2 level of the potential economic importance of PV electricity.

Acknowledgements

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Scientific disciplines involved

Geography, technology, economics.

Keywords

Photovoltaics, energy potential, spatial energy resource assessment, resource rent.

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The EU member states plan to expand the PV electricity generation capacity to supply 8.1% of the gross final energy consumption in 2020 increasing from a level of 1.8% in 2010 (ECN, 2013). The total capacity of PV panels installed in EU27 in 2011 was reported as approximately 52 TWp (EurObserv'ER, 2013) and the total amount of electricity produced by PV in the EU27 was reported at approximately 45 TWh in 2011 (EC, 2013a; EurObserv'ER, 2013).

Assessment of the PV energy potential is important for regional planning as well as national level energy planning. The model developed below can be used to give a rough estimate of the regional potential taking into account physical, technological and economic conditions. Comparing the actual generation of PV electricity and the aggregate installed effect of PV panels would be helpful in analysing progress in the transition to a green economy, but the potential intensity of solar power (installed effect per km^2) must be expected to differ by region. That is, the default values used in this study would have to be adapted to local priorities for land use and use of built environment surface.

The assessment of PV energy potentials rests strongly on spatial conditions. Thus, the overall objective of the study is to develop the GIS based approach to PV energy potential assessment. The present assessment study takes departure in a methodology for assessment of the technical potential for PV energy in Europe that has been applied by (Šúri et al., 2007). The study estimated the installed capacity and the area required to satisfy 1% of the electricity consumption in the EU countries. The objective of the present study is to take this approach further towards an assessment of the economic potential of the PV energy resources in Europe. We proceed by expanding the technical assessment with estimates of the cost of PV-electricity, the profit margin per kWh PV electricity and the potential rent per m^2 solar panel. Finally, the maximum aggregate rent that can be obtained from a given area depends on the area suitable for PV energy plant installation.

The assessment of the PV potential is conducted through a multi-layer GIS raster based analysis. The process involves combining the global irradiation potential with land use planning and environmental restrictions as well as economic considerations. A specific raster layer represents each aspect, where the individual raster cells in the layer have a specific value as being either promoting or restrictive to PV generation. These layers are combined to provide an assessment of the PV potential. The advantage of using a multi-layer based analysis is that it provides a simple, quick and flexible spatial analysis of PV potential. The model can then be used to re-assess the potential, where the individual layers can be updated as changes or improvements in the physical data occur, with technological improvements (including cost reductions) or as social, political or economic conditions change.

The model's analysis process is illustrated in figure 1. The analysis begins with the measured global irradiation values over Europe, represented by Layer 1. These values are then combined with the state-of-the-art PV-solutions expected for the period 2015-20 represented in Layer 2. Total costs for power generation for each solution are shown in Layer 3. These costs can be compared geographically with the socially acceptable price cost of PV generated electricity to determine whether or not it is economically viable for PV production. The next step in analysing the PV potential is to identify the land and building surface areas where PV panels realistically may be installed. This involves land cover data (Layer 4) and environmentally protected areas (Layer 5). Layer 4 also includes a suitability factor indicating the percentage of the total land area it is possible or even acceptable to install the PV solar panels on. These restrictive layers can then be combined with Layer 1 to provide a PV density for Europe. The density can then be summed up geographically to get a total of the PV potential for each region or country. This total can then be compared with the actual installed capacity to evaluate the current utilization versus the proven PV reserves.

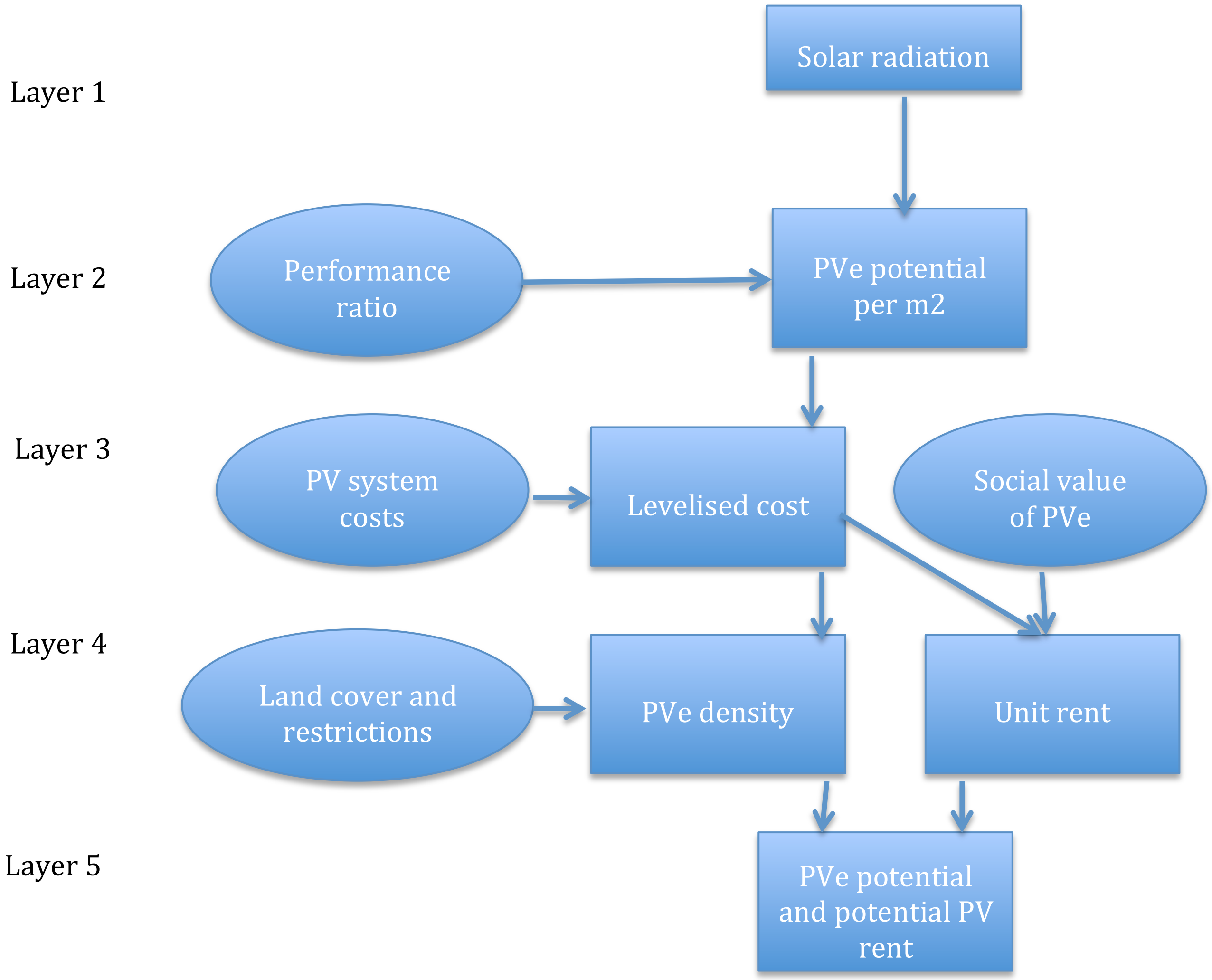


Figure 1. GIS-based progression for the assessment of the potential for photovoltaic electricity generation in Europe

The study considers the potential for building integrated photovoltaic potential (BIPV) as well as for large utility-scale plants (USPV). BIPV includes wall-mounted systems as well as roof-top mounted systems and genuinely integrated PV layers (e.g., in tiles or window glass). USPV are power plants with a large rated effect. In this study, we do not distinguish between stand-alone and grid-connected PV installations, but it is expected that stand-alone PV-installations make up a very modest fraction of the PV capacity installed in Europe in the 2010s.

Input layer definitions

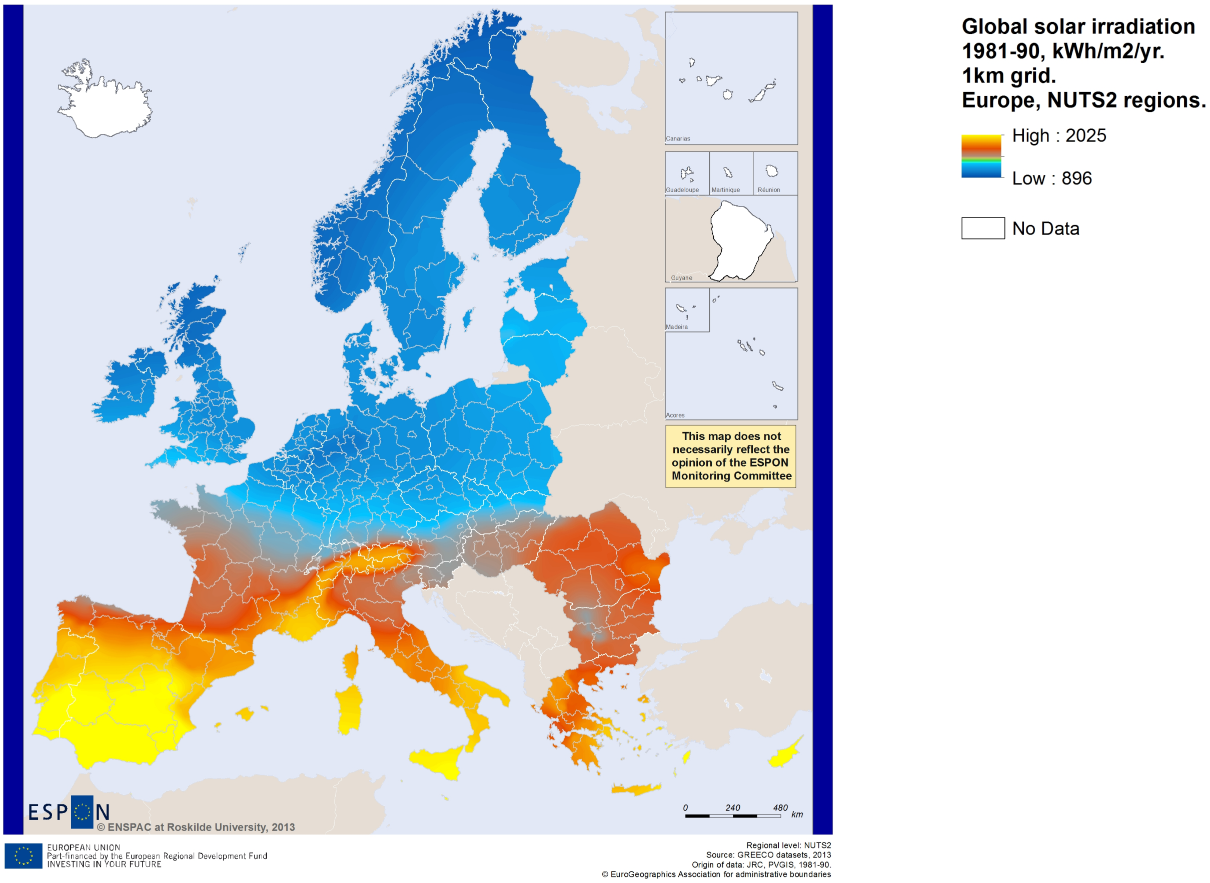
This section provides a specific description of the methodology used in the creation of each individual layer. This includes a specific description of the data involved as well as the uncertainty associated within the calculations of each layer.

Spatial patterns of global irradiation in Europe (Layer 1)

The evaluation of PV potential combines the published global (direct + diffuse solar irradiation) irradiation values for Europe with other parameters, which will affect how much PV energy can be taken advantage of. These additional parameters include the costs of production, land use and planning restrictions, and nature reservations. The spatial pattern of each variable is captured in GIS layers.

The European Commission Joint Research Centre (JRC) Institute for Energy and Transport (IET) is the leading centre of research in PV electricity potential. It has developed a "PVGIS" database drawing on ground station observations 1981-90 and satellite measurement 1998-2011 of irradiation. This database has been coupled to a variety of models on transformation of the irradiation to electricity (Šúri et al., 2007). The irradiation data used in the present assessment is the *yearly sum* of global irradiation incident on *optimally-inclined south-oriented* PV modules. The data are collected at monitoring stations across Europe in the period 1981-90 and interpolated to 1000m resolution. More recent observations based on satellite data are available as well, but at lower levels of resolution.

The peak output is defined as the output in kWh/m^2 at global irradiation of 1000W/m^2. Map 1 shows the values for the sum of global irradiation over Europe on a 1kmx1km raster grid. The values range from as low as 900 kWh/m^2 per year in northern Norway and northern Finland, to over 2000 kWh/m^2 on the Mediterranean islands of Malta and Cypress. The high mountain region in Switzerland, Austria and Italy is also seen to have a higher PV potential with respect to its latitude.



Map 1. Global irradiation in Europe (kWh/m²).

Source: (JRC-IET, 2013; Šúri et al., 2007).

PV technology and performance (Layer 2)

The yearly sum of irradiation per m² may be interpreted as the expected full load hours of system operation. In the process of converting this irradiation energy to useful electricity delivered to grid or to domestic uses, there are losses due to temperature, inclination, cable and inverter loss and other factors. Rather than modelling the expected incidence of each of these losses, Šúri et al. (2007) assume an overall *performance ratio* covering all of the losses of 0.75 kWh/kWp, that is, delivered energy per rated effect. The 0.75 parameter is based on an approximate assessment of the average performance of small-scale rooftop mounted PV-plants in Europe. This means that the performance ratio would be higher if it only included optimally inclined panels.

In the present study all three PV-solutions considered here – rooftop and wall mounted and -scale – are assumed to have a performance ratio of 0.75. A priori, it may be expected that the degrees of freedom for optimally inclining the panels are larger for utility-scale and smaller for wall-mounted systems, but due to the lack of data, we assume a uniform 0.75 performance ratio for all three solutions. Defaix et al. (2012) assume a performance ratio of 80% based on the progress in performance observed by other studies and assumed to continue in the future. We choose to use the more conservative assumption.

A small fraction of the PV potential will be realised as stand-alone systems that are not connected to the grid. This study, however, does not distinguish between stand-alone and grid connected systems.

Against this backdrop, the expected electricity from solar panels with a rated effect of 1 kWp varies linearly with the global irradiation that can be expected at the location.

The technology assumptions are thus reduced to a performance ratio

(1) $E = 0.75$

and a technical PV potential

(2) $B = A/E$,

where A is the solar irradiation.

Levelised cost (Layer 3)

Photovoltaic technology makes solar irradiation a primary source of electricity, an energy resource. Similar to other energy resources, the amount extractable depends on the cost of generating useful energy and the price that society is willing to pay for that energy. The latter also depends on the energy available from other sources. Thus, the costs and socially acceptable remuneration for PV generated electricity are key parameters in the assessment of any potential in the sense of a resurce to the economy.

There are many assessments of the cost of PV electricity in different countries. For instance, estimates such as those by Energy Saving Trust (2012) ranging from about 3.70 to 4.00 €/Wp, including installation and balance of system (BOS) components. Operation and maintenance (O&M) costs are also included in the cost calculation. PV solar panels have shown to be very robust, with generally only panel washing and inverter rebuilding/replacement needed over the life-span of the unit, which keeps the O&M costs fairly low (Salasovich and Mosey, 2012); (Moore and Post, 2008). The O&M costs estimated to be at less than €0.01/kWh ((Salasovich and Mosey, 2012); (Moore and Post, 2008)). However, it is noted that for individual residential units O&M costs can be much higher, up to €0.05/kWh (Moore and Post, 2008).

Such cost estimates rapidly become out-dated, as photovoltaic electricity (PV) technology is a newer technology on a relatively steep learning curve. Prices have been cut in half in the last 5-10 years. Through a combination of reduction in production costs and increased cell efficiency, it is predicted that this trend will continue with costs being reduced a further 50% within less than a decade (International Energy Agency (IEA), 2012; Raugei and Frankl, 2009).Thus, the cost assumption should not be of a stationary, but rather of a dynamic nature. It should be the expected cost *trajectory* according to which the cost for a certain period or point of time is consistent with learning effects.

The PV system costs assumed by the IEA in its World Energy Outlook 2012 (International Energy Agency (IEA), 2012) are of this nature. The agency assumes PV system costs to follow a learning rate of 18%. A learning rate of 18% corresponds to a progress rate of 82%. That is, the costs per kW installed PV declines by 82% per doubling of the cumulative production of PV installations measured in kW.

The USPV plant is assumed to have a higher performance ratio than the typical rooftop installations. Furthermore, the installation costs per rated effect are expected to be slightly lower.

The cost assumptions used here and valid for 2015-20 include expected an life-time of 25 years, a real discount rate of 6%, investment cost of €1530/kWp (USPV) and €1770/kWp (BIPV) and annual operation and maintenance costs of 19 and 24 €/kWp/yr, respectively (all in 2010-€).

Based on these assumptions the annual costs per kWp are defined as

(3) $K = F*I+O$,

where F is the capital recovery factor, I the investments costs and O the operation and maintenance costs. K amounts to €139 per kWp for USPV and €162 per kWp for BIPV. Dividing by the expected annual electricity generation per kWp yields the levelised costs of PV electricity.

These costs presented here assume direct connection to the electricity grid, and that the connection is easily accessible. It does not include the costs associated with the establishment of off-grid systems. Off-grid systems would be applied for individual houses/buildings with their own battery storage capacity. According to the prices available from multiple producers, the costs associated with battery storage for off-grid PV networks is €0.08 – 0.10 per kWh. In this case, when assessing off-grid systems, this amount will need to be added to the costs shown in map **2**.

Cost benchmark: The social value of PV electricity

Despite the continuously declining costs, the costs of PV electricity is not expected to be fully competitive with conventional methods of energy generation – even in the sunniest regions - before the end of the 2020s. The country average of electricity price (exclusive of taxes and grid costs) reflects the market costs of conventional electricity generation. It varied from 3 to 13 c/kWh across the various industrial electricity consumer segments and countries of Europe[1] in the 2009-12 period (EC, 2013b). Taken as an estimate of the wholesale market price that the marginal electricity consumer is willing to pay for electricity, it is far from what is needed to cover the projected costs of PV-generated electricity in 2015-20.

PV-electricity does, however, represent a higher value to society than is reflected in the wholesale market price of electricity itself: It doesn't involve fossil fuel combustion and the related air pollution and global warming. It is produced domestically wich excludes risk of suppliers combining supply eith political demands and reduces the import requirement of production and consumption. It can be distributed at rooftops with no competing use of the space and it generates energy during the daytime when electricity consumption is highest, offering a potential for "peak-shaving". Moreover, due to the learning effects, installing PV at a time when it is not fully competitive is a necessary condition for being able to install PV plants at lower costs in the future. Thus, the social value of PV electricity is higher than the price of conventional electricity and it is to varying degrees reflected in feed-in prices and other financial arrangements supporting PV installation.

The levels of financial support to photovoltaics across Europe varied in 2011 from 8 c/kWh in Romania to 54 c/kWh in Luxembourg (Council of European Energy Regulators (CEER), 2013). These figures are, however, not necessarily to be interpreted as additional to the whole sale price at which the PV electricity otherwise could have been sold and they do not necessarily include the tax expenditure of due to the non-taxing of producer's own consumption.

The ongoing reforms of renewable energy support schemes across Europe points towards a lower level of financial support in many EU member states. This is more an indication of a decline in the financial support needed to finance PV systems as the costs decline than an indication of a desire to constrain the expansion of PV electricity generation. The present assessment includes estimates based on social value of PV electricity of 8, 10 and 12 c/kWh as benchmarks for the economic potential.

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[1] With the important exceptions of islands such as Cyprus and Malte where conventional energy is considerably more costly.

Land cover specific potential PV-density (Layer 4)

Not all land surface areas are suitable for the installation of PV solar panels. For example, it is not possible or practical to install panels in forested areas, whereas on rooftops or open agricultural areas, it would be possible. Therefore, this layer aims to take the different land surface areas into account in order to provide an estimate of the potential or maximum PV-density that can be achieved in each raster cell.

We base the estimates of areas suitable for installation of PV panels on the CORINE Land Cover classes (CLC) 2006 (Bossard et al., 2000; European Environmental Agency (EEA), 2012). The CORINE database classifies land cover in Europe into 44 classes at its level 3 classification. In this study, these classes are represented in a raster form with a 1km x 1km grid. Each grid cell is given a weight or an expected maximum PV-area (in km^2) based upon its land cover class (table 1).

The *area suitable and avilable for PV* results as the sum of a multiplicative expression of the BIPV potential and the land area suitable and available for USPV:

$$(4) \qquad M = g * h + j,$$

where g is the building ground floor density (km^2/km^2) assumed for the CLC class of the cell, h is the assumed proportion of suitable PV area per square meter of building ground floor area and j is the fraction of the land cover class of the cell assumed to be suitable for USPV plant installation.

The PV-suitable area includes rooftop as well as wall mounted panels. Whereas sunlit rooftops and facades have the virtue of being available without many competing uses until now, this is likely to change in the future. Solar heating systems, green roofs, roof terraces and roof gardening may in the future also claim some of the area available for PV panel installation. In addition to this, of course, standard aesthetical considerations may also exclude the installation of PV panels. The quantity of these competing uses will, however, depend on design properties, surroundings history and other features unique to the individual building or the urban space in which it is situated. Thus, expectations on the fraction of the PV-suitable area where PV-panels can actually be installed must be based on experience, ideally statistically solid data, rather than deterministic models.

The ground floor area and the roof top area differ mainly by elements mounted on the roof and the inclination of the roof. Thus, they are used interchangeably in the assumptions below.

Buildings, roads and artificial surfaces cover 80% of the area of cells classified as “continuous urban facric” and 50-80% of cells classified as “discontinuous urban fabric”.

Sørensen (2001) followed a similar strategy for calculating global PV potentials applying the parameter value of 1% corresponding to g*h in urban areas and 0.01% in cropland areas (farm houses, barns etc). Parameter values corresponding to j were set as 1% of rangeland areas and 5% of marginal land (scrub land and desert).

IEA (2002) provided rules of thumb for calculating BIPV potentials. The rule of thumb for the h-type parameter was 0.55 composed of rooftop area 0.4 and façade area 0.15.

Izquierdo et al. (2008) studied the potential for energy generated by rooftop PV-installations in urban areas in Spain. The method included an innovative use of available municipality level statistics on population density and building density (buildings per km^2). The municipalities were classified in 16 classes differing by these two densities. The parameter corresponding to g for residential urban areas varied between 0.21 and 0.45 within these 16 classes (built-up surface reduced by void fraction). The parameter corresponding to h (further reducing for shadow and competing uses) varied between 0.22 and 0.42. The total suitable PV area per km^2 (gh+j) varied between 0.05 and 0.14 km^2.

A study of the PV potential of the Piedmont region in Italy applied parameters corresponding to h of 0.06 for residential and 0.3 for industrial buildings taking orientation, features and shadows as well as competing uses into account (Bergamasco and Asinari, 2011). In this study the horizontal building area was adjusted by a factor assuming a 20° roof inclination for residential and 30° for industrial buildings to calculate the roof area.

A study on the ratio of PV-suitable roof and façade area to ground floor area of typical urban buildings in Germany led to a series of h-type parameters for the various building types. The h-type ratios of industrial and office buildings, shopping centres etc was 0.25-0.56, whereas the ratio for single-family houses was only 0.05-0.07. Multi-store residential buildings could have ratios between 0.12 and 0.29. Due to the differences in the design characteristics of the building stocks of the new *länder* and the rest of Germany these parameters tend to differ between east and west (Everding, 2004).

Defaix et al. (2012) estimated BIPV for European countries, but did not explore the matter at the regional level. The method of estimation, however, was similar to the method used in the present study and the h-type parameter applied is 0.64 for residential and 0.54 for non-residential buildings.

Against this backdrop, the parameters j, g and h are chosen within a wide range for discretion and the absolute values of the PV potential should be interpreted against this background. The present assessment is based on parameter choices in the low end.

All fractions are restrictive as it is assumed that the entire area of a particular land cover type in no case could be fully covered with panels. The land cover is divided into two general categories: totally restrictive and partially restrictive. The totally restrictive category represents the areas that are not suitable for PV energy, that is, j = g*h = 0. It includes forests, wetlands, water bodies, construction sites, mines and urban green areas. Moreover, many other areas are designated as nature areas or otherwise protected in a way that exclude installation of PV systems. Environmental restrictions preventing the installation of solar panels include, for example, Natura 2000 protection areas, where ecosystem habitat is being protected. These areas are simply given a raster weighting value of 0 and thus filtered out of the calculation of the PV potential.The non-suitable areas are shown in map **3**.

The partially restrictive land surfaces are given a weight or suitability ratio based on non-negative values of j, g and h. If a land use type is available for the installation of solar panels, a weighting of 0.01 (1%) is given. The only exceptions are for continuous urban fabric, discontinuous urban fabric and industrial and commercial units, which have been given a higher value. The higher value is because in these areas, rooftop solar panels can be installed.

The values used for g, h and j appear from table 1. They are intended to be conservative, i.e., in the low end of the intervals of comparable parameter assumptions in the literature cited above.

Table 1. Factors in determining PV-suitable area by land cover class.

	Level 1	**Level 2**	**Level 3**	**Building area density (h)**	**BIPV area ratio (g)**	**USPV area ratio (j)**	**PV-suitable and available area density (hg+j)**
1	Artificial surfaces	Urban fabric	Continuous urban fabric	0.3	0.2	0	0.06
2	Artificial surfaces	Urban fabric	Discontinuous urban fabric	0.15	0.2	0	0.03
3	Artificial surfaces	Industrial, commercial and transport units	Industrial or commercial units	0.3	0.2	0	0.06
4	Artificial surfaces	Industrial, commercial and transport units	Road and rail networks and associated land	0	0	0.01	0.01
5	Artificial surfaces	Industrial, commercial and transport units	Port areas	0.1	0.1	0	0.01
6	Artificial surfaces	Industrial, commercial and transport units	Airports	0.1	0.1	0	0.01
7	Artificial surfaces	Mine, dump and construction sites	Mineral extraction sites	0	0	0	0
8	Artificial surfaces	Mine, dump and construction sites	Dump sites	0	0	0	0
9	Artificial surfaces	Mine, dump and construction sites	Construction sites	0	0	0	0
10	Artificial surfaces	Artificial, non-agricultural vegetated areas	Green urban areas	0	0	0	0
11	Artificial surfaces	Artificial, non-agricultural vegetated areas	Sport and leisure facilities	0.1	0.1	0	0.01
12	Agricultural areas	Arable land	Non-irrigated arable land	0	0	0.01	0.01
13	Agricultural areas	Arable land	Permanently irrigated land	0	0	0.01	0.01
14	Agricultural areas	Arable land	Rice fields	0	0	0.01	0.01
15	Agricultural areas	Permanent crops	Vineyards	0	0	0.01	0.01
16	Agricultural areas	Permanent crops	Fruit trees and berry plantations	0	0	0.01	0.01
17	Agricultural areas	Permanent crops	Olive groves	0	0	0.01	0.01
18	Agricultural areas	Pastures	Pastures	0	0	0.01	0.01

19	Agricultural areas	Heterogeneous agricultural areas	Annual crops associated with permanent crops	0	0	0.01	0.01
20	Agricultural areas	Heterogeneous agricultural areas	Complex cultivation patterns	0	0	0.01	0.01
21	Agricultural areas	Heterogeneous agricultural areas	Land principally occupied by agriculture, with significant areas of natural vegetation	0	0	0.01	0.01
22	Agricultural areas	Heterogeneous agricultural areas	Agro-forestry areas	0	0	0.01	0.01
23	Forest and semi natural areas	Forests	Broad-leaved forest	0	0	0	0
24	Forest and semi natural areas	Forests	Coniferous forest	0	0	0	0
25	Forest and semi natural areas	Forests	Mixed forest	0	0	0	0
26	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Natural grasslands	0	0	0.01	0.01
27	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Moors and heathland	0	0	0.01	0.01
28	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Sclerophyllous vegetation	0	0	0	0
29	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Transitional woodland-shrub	0	0	0	0
30	Forest and semi natural areas	Open spaces with little or no vegetation	Beaches, dunes, sands	0	0	0	0
31	Forest and semi natural areas	Open spaces with little or no vegetation	Bare rocks	0	0	0.01	0.01
32	Forest and semi natural areas	Open spaces with little or no vegetation	Sparsely vegetated areas	0	0	0.01	0.01
33	Forest and semi natural areas	Open spaces with little or no vegetation	Burnt areas	0	0	0.01	0.01
34	Forest and semi natural areas	Open spaces with little or no vegetation	Glaciers and perpetual snow	0	0	0	0
35	Wetlands	Inland wetlands	Inland marshes	0	0	0	0
36	Wetlands	Inland wetlands	Peat bogs	0	0	0	0

37	Wetlands	Maritime wetlands	Salt marshes	0	0	0	0
38	Wetlands	Maritime wetlands	Salines	0	0	0	0
39	Wetlands	Maritime wetlands	Intertidal flats	0	0	0	0
40	Water bodies	Inland waters	Water courses	0	0	0	0
41	Water bodies	Inland waters	Water bodies	0	0	0	0
42	Water bodies	Marine waters	Coastal lagoons	0	0	0	0
43	Water bodies	Marine waters	Estuaries	0	0	0	0
44	Water bodies	Marine waters	Sea and ocean	0	0	0	0

Source: CORINE 2006 land cover database (Bossard et al., 2000; European Environmental Agency (EEA), 2012) and own assumptions.

Slope gradient and aspect are two factors, which could also be taken into account, but are ignored in this study. Particularly steeper slopes with aspects towards the north would not be ideal locations for the establishment of solar panels, and should be given a weighting of 0. However, for a European-wide analysis, using a 1 km^2 grid scale, incorporating slope gradient and aspect in the GIS-based model becomes impractical. At a regional scale, where a finer grid can be used, it would be possible to accurately include gradient and aspect in the model calculations.

Model overview

Table 2. PV energy potential, levelised cost and resource rent by 1kmx1km raster cells.

	(€-figures are in 2012 purchasing power)	Unit	Calculation	Examples	
				USPV	BIPV
A	Sum of global irradiation	kWh/m^2/yr		1752	1402
E	Performance ratio	kWh/kWp		0.75	0.75
B	Technical PV potential	kWh/m^2/yr	A*E	1314	1051
T	Service years	years		25	25
r	Discount rate	%		6	6
F	Capital recovery factor	%	$r/(1-(1+r)^{-T})$	7.8	7.8
I	Investment cost	€/kWp		1480	1480
O	Operation and maintenance	€/kWp/yr		19	24
K	Annualised costs per kWp	€/kWp/yr	F*I+O	135	140
c	Levelised cost*)	€/kWh	K/B	0.10	0.13
P	Social value of PV energy	€/kWh	(1,2,..12)	0.12	0.12
Q_P	Economic PV potential at P	kWh/m^2/yr	B if c≤P 0 if c>P	1314	0
g	Building ground floor area	km^2	See table 1	0	0.3
h	Ratio of PV suitable area to ground floor area	km^2	See table 1	0	0.2
j	USPV suitable area	km^2	See table 1	0.01	0
M	PV suitable area per km^2	km^2/km^2	gh+j	0.01	0.06
N_P	Economic PV potential at P	TWh	Q_P * M	13.14	0

*) The numbers refer to the IEA 450 scenario assuming a high growth in the globally installed effect of PV plants.

The resource rent for each cell is calculated as the margin between the social value of PV and the levelised costs times the PV potential off the cell at that social value. The regional aggregate PV resource rent sums all of these cell-level resource rents.

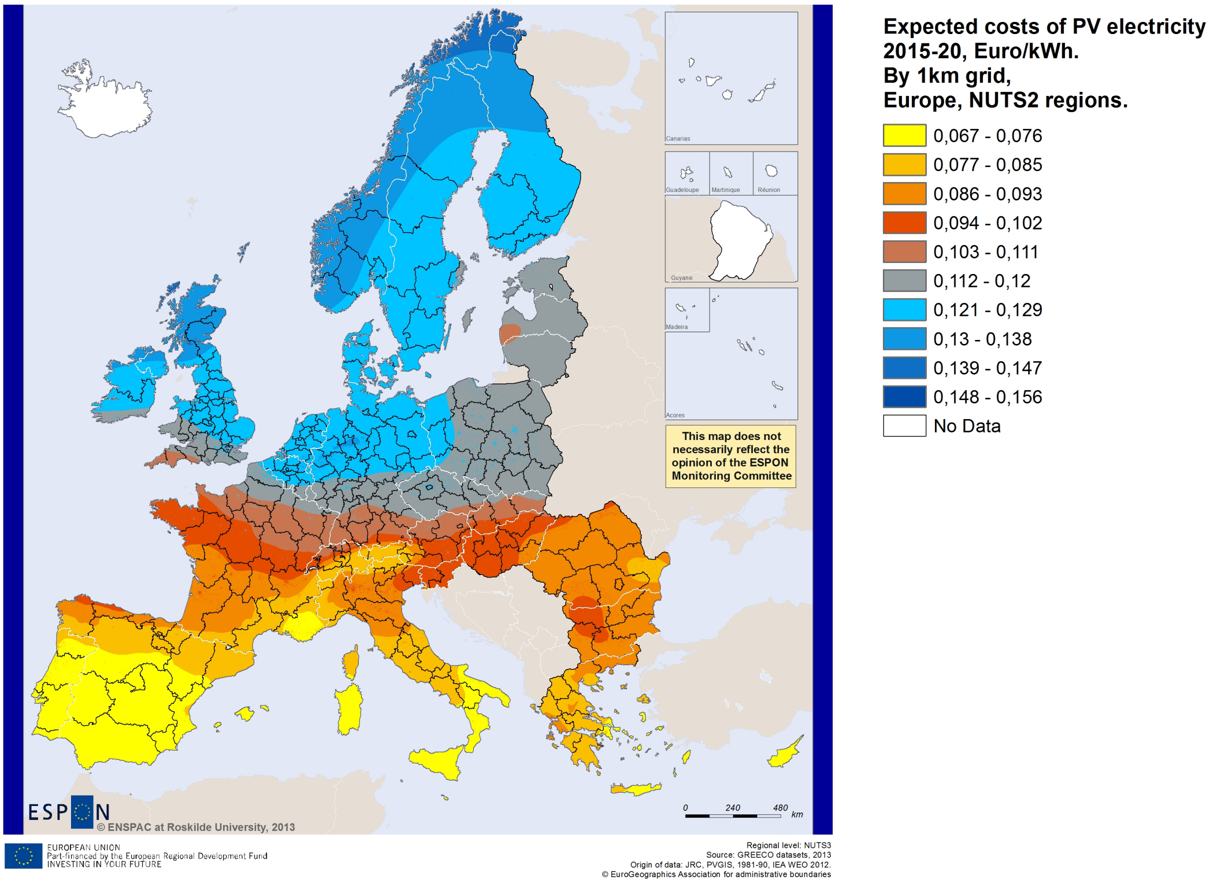
$$(5) \qquad V = (12-11)(N_{12} - N_{10}) + (12-9)(N_{10} - N_8) + (12-7)N_8,$$

Note that the unit rent is a net figure in the national accounts sense, that is, net of fixed capital consumption (depreciation).

Results

PV energy generation costs

The levelised costs of PV energy – installed according to the standard conditions described above – vary by the solar irradiation and thus by local conditions such as latitude, patterns of cloud cover and absorption by the atmosphere. This also means that the spatial patterns of levelised costs displayed in map **2** shows high cost pockets at latitudes otherwise dominated by low costs and *vice versa*.



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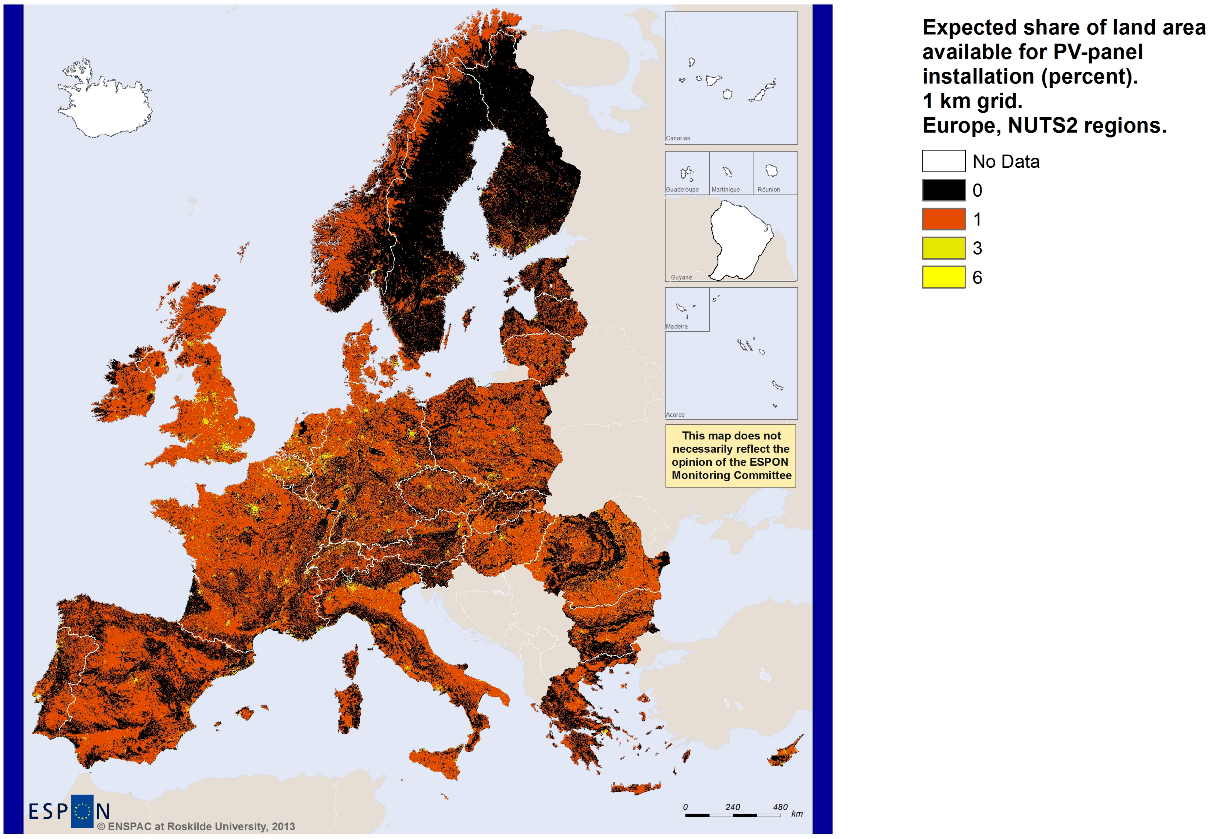
Regional level: NUTS3
Source: GREECO datasets, 2013
Origin of data: JRC, PVGIS, 1981-90, IEA WEO 2012.
© EuroGeographics Association for administrative boundaries

Map 2. Costs for photovoltaic electrical power generation, given in €/kWh produced.

The spatial patterns of levelised costs displayed in map **2** shows – not surprisingly – that the lowest levelised cost of PV electricity is expected to be found in the Meditarainean region. The PV *potential*, however, depends on the available area suitable for PV panel installation and this area is restricted by competing uses and environmental and aestethic resttrictions.

In the present study, Layer 4 and 5 is combined to represent the PV-suitable and available area weighting for determining the PV potential. This is based upon the land use restrictions and panel area density (as given in table 1) combined with the environmental restrictions (Layer 5). Map **3** shows the amount of PV suitable area available for each 1 x 1 km grid cell under the above conditions.



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Regional level: NUTS2
Source: GREECO datasets, 2013
Origin of data: EEA, CORINE 2006..
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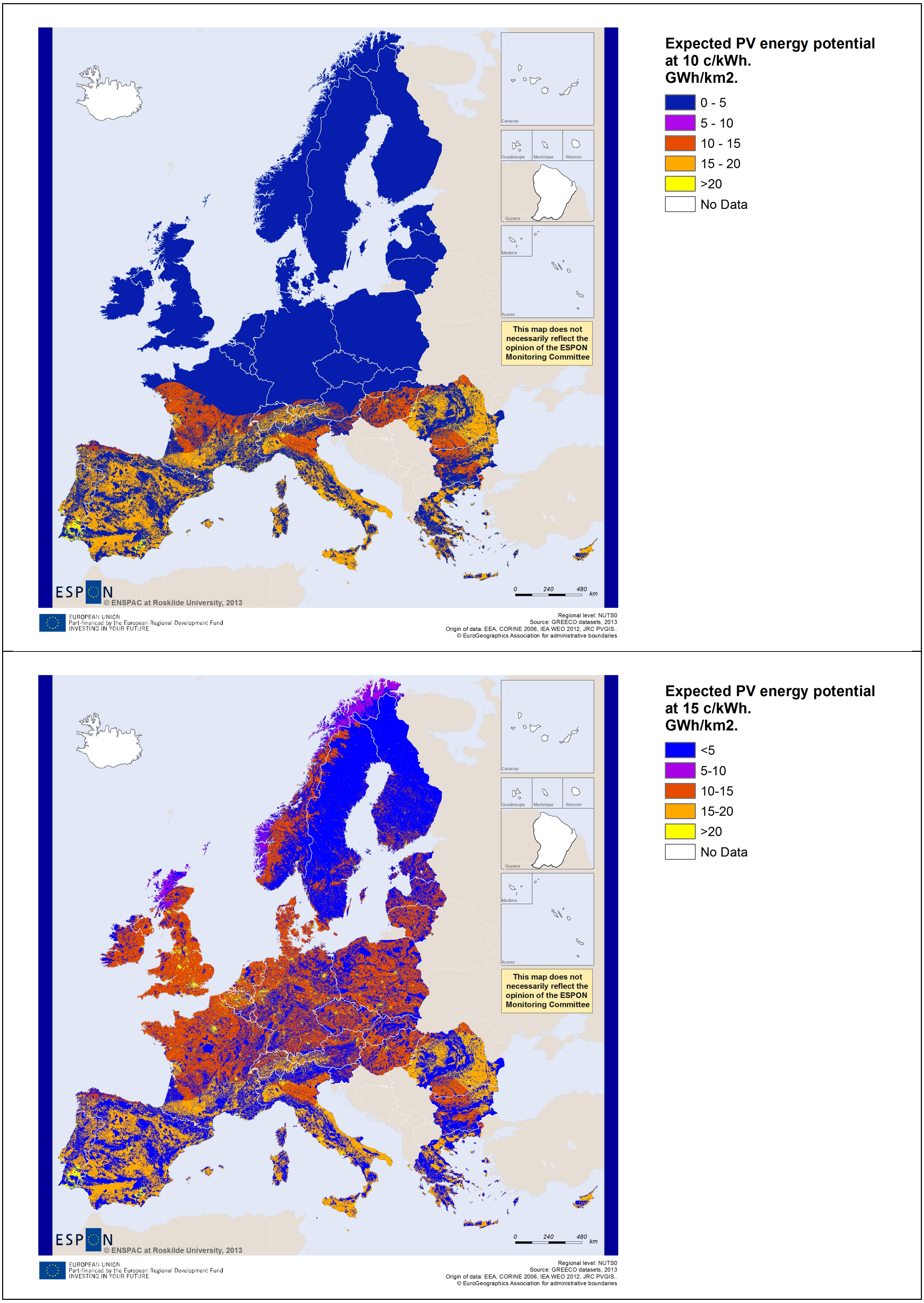
Map 3. Expected maximum PV panel density. Suitable (>0%) and non-suitable (0%) areas for PV-panel installations.

Overall, for 30% of the total land area it is not possible to have PV production (black in map **3**). This is particularly apparent in Sweden and Finland, where the large forested areas prevent the possibility for PV production. According to the asumptions in table 1 65% of the total land area, predominately agricultural land and open area, can be utilized at a approximately a 1% rate (red areas in map **3**) . This adds particularly large potentials to the U.K., Denmark, The Netherlands and Belgium. 4% of the total land area consists of low density urban areas, where it is estimated that 3% of the land area can be utilized (particularly on roof-tops). 1% of the total area is high density urban areas and industrial areas, where it is estimated that up to 6% of the land area can be utilized, particularly on roof tops and open industrial areas. This is reflected in the high maximum PV-density areas (yellow) in map **3.**

Potential PV energy density and regional resource rents

By combining the global irradiation layer with the fraction that potentially could be used for PV energy generation (Layers 4 and 5) a total energy density (given in GWh/km^2) is calculated .



Map 4. Potential PV energy density (GWh/km^2) at 10 and 15 c/kWh.

The importance of the remuneration of PV electricity generation to the size of the PV energy potential emerges clearly from map 4. At 10 c/kWh only a modest potential can be realised north of the Alps. At 15 c/kWh large potentials become available, even in Norway. In both cases, however, the energy density is greatest in the Mediterranean countries, decreasing northwards.

The potential energy density in map 4 is measured in GWh/km^2 (equivalent to kWh/m^2) Around the larger urban areas, including London, Birmingham, Brussels, Berlin, and Hamburg amongst others, the potential PV energy densities reach high levels compared to other locations at the same latitude. This is due to the urban areas, where the assumptions listed in table 1 – a high roof area density - leads to a higher potential PV density.

The photovoltaic potential that meets the physical, technical and economic (cost and area allocation) criteria described above is not a projection or prediction of the actual PV potential realised in 2015-2020. It is rather a tool for comparison of the PV energy potentials of regions according to a set of uniform parameters. Potentials aggregagted to the national level appears from table 3.

Table 3 also shows the economic rent that would emerge from realising the full potentials under these conditions cf equation (5) above. Again, it is not a prediction of the rent earned by PV electricity generation in 2015-20. Related to the economic potentials of the region, such as Gross Value Added (GVA), it does indicate whether PV electricity generation potentially may be economically significant or insignificant in the region. It would be more adequate to relate the PV rent to Net Value Added rather than Gross Value Added since the PV rent is a net concept (net of fixed capital consumption). The regional data are, however, not sufficient for estimating fixed capital consumption at the regional level.

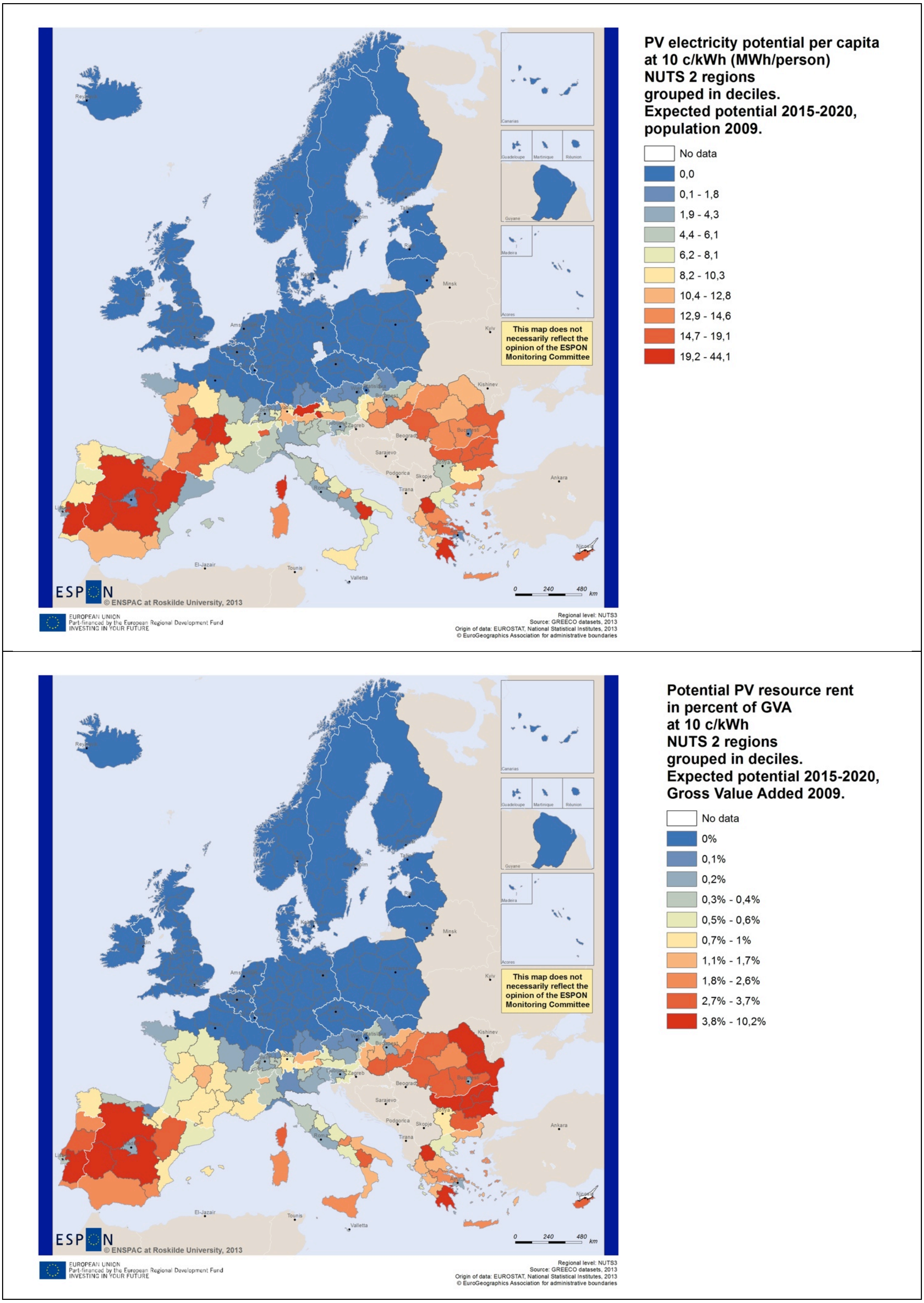
Table 3. Aggregate PV energy potential and potential PV resource rent by country.

		PV12	**PV10**	**PV8**	**PV12R**	**PV10R**	**PV8R**
			TWh			**€mio**	
AT	**Austria**	75960	37221	13628	1777	645	136
BE	**Belgium**	2231	0	0	22	0	0
BG	**Bulgaria**	93870	91869	0	2776	919	0
CH	**Switzerland**	48477	36459	17652	1567	718	177
CY	**Cyprus**	13925	13925	13925	696	418	139
CZ	**Czech Republic**	62077	0	0	621	0	0
DE	**Germany**	121868	4803	10	1315	48	0
DK	**Denmark**	0	0	0	0	0	0
EE	**Estonia**	17051	0	0	171	0	0
EL	**Greece**	98709	98709	45315	3868	1893	453
ES	**Spain**	511245	510935	435348	24038	13816	4353
FI	**Finland**	149	0	0	1	0	0
FR	**France**	563739	348958	53812	13693	4566	538
HU	**Hungary**	101490	88209	0	2779	882	0
IE	**Ireland**	8192	0	0	82	0	0
IS	**Iceland**	0	0	0	0	0	0
IT	**Italy**	350372	349936	159673	13696	6693	1597
LI	**Liechtenstein**	265	265	114	10	5	1
LT	**Lithuania**	53664	0	0	537	0	0
LU	**Luxembourg**	2165	0	0	22	0	0
LV	**Latvia**	35073	0	0	351	0	0
MT	**Malta**	705	705	705	35	21	7
NL	**Netherlands**	0	0	0	0	0	0
NO	**Norway**	0	0	0	0	0	0
PL	**Poland**	204198	0	0	2042	0	0
PT	**Portugal**	90698	90698	90562	4532	2718	906
RO	**Romania**	266042	265287	0	7966	2653	0
SE	**Sweden**	2095	0	0	21	0	0
SI	**Slovenia**	9915	8831	0	276	88	0
SK	**Slovakia**	37646	4169	0	460	42	0
UK	**United Kingdom**	63520	0	0	635	0	0

The economic rent of PV electricity generation is calculated as a function of the remuneration level and the levelised cost level. In this study, it assumed that the social value of PV electricity is equal to all countries. In reality, however, it differs. As noted above, the virtues of PV electricity generation differ from country to country and they are to varying degrees relfected in the level of public support to PV electricity generation.

The resource rents in table 3 are calculated under the assumption of social values that are uniform acroos Europe and fully reflected in uniform feed-in tariffs. This enables comparisons of the PV energy potentials.

From an economic point of view, however, the potential contribution of the PV potential to human needs are more interesting than the potential PV energy density per se. Consequently, we have calculated the ratio of potential PV energy generation to the population and the ratio of the potential PV resource rent for each NUTS2 region.



Map 5. PV electricity potential per capita and potential PV resource rent in % of GVA.

Map 5 shows that in Southern Europe, the PV energy potential per capita is considerable compared to a household consumption rate of 1-2 MWh/person. In Northern Europe, however the potential contribution at this level of costs and social value is more modest. The ratio of potential resource rent to the aggregate income generation (Gross Value Added) displays a slightly different pattern. This is because the per capita GVA varies by region. In regions with a high rate of employment and a high rate of productivity, the potential contribution of PV energy to the economy means less than in regions with low rates of employment or productivity, even if the per capita PV energy potentials are identical.

Discussion and concluding remarks

This paper provides a model for analysing regional PV potentials in a transparent and comparable manner. This is particularly important for calculating the impacts on the PV energy potential of changes in public support and land-use restrictions.

The key parameters used to determine the PV potential above was defined as

- the solar irradiation density (kWh/m^2)
- the performance ratio (kWh/kWp),
- the ratio of BIPV suitable and available area to building ground floor area (km^2/km^2),
- the ratio of ground floor areas to CLC class area (km^2/km^2),
- the ratio of areas suitable and available for USPV to CLC class area (km^2/km^2),
- the levelised cost of PV electricity (€/kWh) and
- the social value of PV electricity (€/kWh)

These parameters vary considerably across Europe, but as they are used in this study, they ensure a transparent basis for comparison of regional PV-potentials. The above list also serves as a list of research questions that require further empirical research for assessing the PV potential and the potential PV rent of region.

The interesting outcome of this study is the regional patterns of economic PV-potentials compared to the value of productive activities in general rather than a prediction of future PV generated electricity from each region.

The model used in this study can provide a flexible tool for a relatively quick assessment on how management decisions can impact PV electricity generation. Generally speaking, the PV potential of any specific area is constant, and will not change with rezpect to the model calculations (with the exception of small adjustments in PV potential as we get better data at a smaller scale). However, the economics and social decisions will. Thus planners can adjust the socio-economic parameters of this model to assess how planning decisions may impact or how subsidies will change the amount of PV electricity available. This will in turn aid in the assessemnt of the costs associated with achieving politically determined PV generation goals.

Sørensen (2001) subtracted 40% from the PV potential to take account of the need for storage and recovering PV energy thus converting it to an energy source available at any time and place where it is needed (e.g., two way fuel cells and hydrogen). This technology was however foreseen for the PV potential in 2050, whereas the present study has a shorter time horizon. The PV energy potential studied here is linked to the electricity grid and only available at the time at which it is generated or by the still limited capacity for electricity storage.

A higher weight to land cover classes such as 26, 27, 31, 32 and 33 with little competing agricultural use instead of agricultural land could change the pattern in a more economically optimal direction, but will not necessarily do so. The CLC classes of area covered by crops do not distinguis between cultivated areas with high yields and low costs and those that are cultivated due to the agricultural policies.

The social value of PV electricity is not a given figure independent of the planned expansion of the PV generation capacity. Rather it should be regarded as the remunation necessary to achieve the socially desirable rate of progress in PV generation capacity expansion. If the financial support schemes are designed along the same lines in the future, we can expect the declining costs of PV systems to be accompanied by declining remuneration levels. The recent anti-dumping action by the European Commission probably implies that the price of PV systems at the EU market will decline less than expected until recently. If the member states maintain their targets for PV electricity generation it must be expected that the levels of remuneration will be reduced in a lower pace than otherwise envisioned.

In such a regime of PV electricity finance, the economic rent of the PV generation depends less on cost developments than on the planned realisation of the potential.

Due to the regional differences in the parameter values determining the PV potential the economic impacts are particularly large in the regional dimension. Ambitious targets for PV energy expansion require a high level of remuneration reflecting that a high social value is assigned to PV electricity. Typically, the remuneration will be delivered by a feed-in tariff financed by a Public Service Obligation tariff on all electricity consumption. Then the PV financing schemes direct purchasing power from the electricity consumers to the PV producers. As the ratio of PV electricity production to electricity consumption differs by region, the interregional economic flows can be considerable. The present assessment shows that the rent of PV electricity generation can be important for the income generation in regions with high PV potentials compared to their population and general economic activity.

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