GREECO

Territorial Potentials for a Greener Economy

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1. Green economy indicators at NUTS levels 2 and 3

1.1. The green economy

The objective of the GREECO project is to study the potentials of the green economy, primarily at subnational territorial levels. The EU Commission, for instance, has demonstrated how the European economy can be transformed from an economy that is totally dependent on fossil fuels to an economy, where fossil energy still is consumed, but at a modest and sustainable scale (EC, 2011). In a range of other aspects, the European economies have potentials of becoming a economies that unlike the typical 20th century economies are very productive, but with sustainable use of resources and the environment.

The regional economy of every NUTS2 and NUTS3 region in the EU will go through such transformations as well. Thus, the GREECO project aims at finding datasets and key figures that can be useful in assessing the challenges of transformations. The outdated patterns of unsustainable resource use that the economy needs to leave and the new patterns of sustainable resource use that the economies need to take up.

We have looked for and developed datasets with some information value for the transformation of the economy to a "green economy" and a reasonable coverage across European NUTS regions defined at level 2 or 3, but what is a "green economy"?

The "green economy" is in the GREECO project defined as the operationalization of the principles of sustainable development laid down in the documents of the Rio-summit in 1992 and the subsequent Rio+10 and Rio+20 summits. There is no stringent scientific definition of the term "sustainable development", but in the consensus statements from these summits, it includes progress in the ecological and social as well as economic dimensions.

Briefly put, recognising that there are trade-offs between the three dimensions, progress in the economic dimension at the cost of a step backwards in the ecological or social dimension will be classified as "GDP growth", but not as "sustainable development".

In sum, the green economy allows society to *prosper* in an *economic* as well as an *ecological* sense *without excluding* any social group from this prosperity. This definition gives rise to four questions that should be addressed by an appropriate toolbox of indicators at the NUTS 2 and 3 levels. They include

1) how the *quantitative balances* of such an economy differ from those of an unsustainable, typical 20th century economy
2) how *distant* a given economy is from such a green economy: Challenges and progress,
3) what *actions* are taken, investments done to transform it towards the green economy and
4) the inclusion of all groups of society in economic and ecological prosperity

The present report is about developing a series of the datasets with a reasonable coverage at NUTS levels 2 or 3. This must necessarily be a *compromise between the desirable and the possible*. Much of the economic statistics on economy, ecology and social issues collected and processed in Europe is standardised allowing for crosscountry comparability, but very little of it is collected and processed with such a level of detail that regional statistics at NUTS levels 2 or 3 can be generated. Moreover, the national accounts statistics itself is designed to accommodate the analytical demands of the 20th century growth economy rather than the 21st century sustainable development economy. Thus, the statistical datasets are supplemented with some recommendations as to data that would be useful to collect and process at the regional level.

1.2. Accounting frameworks for linking ecology and the economy

The standard indicator framework for environmental statistics follows the DPSIR logic classifying indicators in six categories. They link environmental impacts and states to the economic activities and the societal responses to these links. The six categories are:

- Drivers
- Pressure
- State
- Impact
- Response

Under ideal circumstances, it would be possible to calculate indicators of challenges or potentials as well as on the performance of responses.

Indicators of drivers, pressures, states and impacts of unsustainable materials and energy flows and unsustainable land-use may describe the *challenges* for delinking econosphere growth from economic growth.

Drivers, pressure, state and impact follow the chain of physical changes from the material side of the economy through the sink and source pressures, the subsequent changes of resource stocks and environmental qualities and the final impacts on important living conditions.

Responses, however, reflect institutional changes materialised in delinking of pressures from economic activities as well as states and eventually human well-being against adverse impacts. Thus, responses are activated in any link along the chain. Changes in institutional frameworks such as those affecting the cost of applying green as opposed to conventional solutions predominantly take place on the national level. They materialise over time in a real capital stock designed to provide services to households and firms with a minimum of flow of materials and energy.

The GREECO dataset is contains two groups of indicators. One group is related to the production and consumption of energy (the “energy economy”) and the flows of related materials and energy through the economy. Another group is related to ecosystem services and the related patterns of land use.

The datasets generated by the GREECO project similarly follows the materials and energy chain approach in defining what a green economy is. It is, however, the *links* between the drivers and the pressures, the pressures and the states, the states and the impacts that are most important and the responses aimed at replacing the links with a different set of links designed to accommodate prosperity in the ecological as well as the economic dimension.

1.3. The design of biogeophysical links to economic well-being

The green economy definition above implies that the links between the level of services provided by the economy and the biogeophysical foundation must be designed differently than in a typical 20th century European economy. The close links between economic growth and the use of fossil fuel as well as reservation of land for economic activities must be replaced by a different *design* of the biogeophysical structures of the economy. The economic value created in an economy measured as GVA and GDP can be created with different links to materials and energy flows and different patterns of land use. It does, however, require that the fixed capital stock and associated organisatioons are designed to generate services from sustainable rather than unsustainable flows of materials and energy and land use.

This interface between the economy and its environment is in the following labelled the *econosphere*. It includes the direct use of abiotic resources as well as the indirect use through the biosphere, the ecosystem services themselves and the entailed waste emissions and other pressures to the environment.

Ecosystem services are the services provided directly or indirectly by ecosystems to society. They are based on ecological functions that transform elements and energy to from the biosphere as well as from the abiotic environment of the ecosystem to useful services to society. They also regulate hydrological flows and other natural cycles and they provide cultural services as well. Finally, they support other ecological processes that eventually are beneficial to society. The ecological functions are, however, also vulnerable to the resource use and waste functions of the economy.

Economic activities also benefit from energy and materials and regulating and cultural services from the abiotic environment directly. These direct links between the environment combined with the direct and indirect links via the ecosystem services form the econosphere. The econosphere necessary flow or flux of energy and materials and spatial demands required attaining the standard of living of the society. It is necessary and required because the fixed capital and generally the technical solutions are *designed* to provide their services from a certain throughput of materials and energy and use of land.

The 20th century type of technical solutions were designed to derive services from considerable flows of fossil fuels and other materials with unsustainable in unsustainable use rates. Similarly, the rate of use of land for economic purposes (represented by “artificial surface” land cover) to economic value creation exceeded what would be sustainable with the value creation expected in the 21st century. Thus, this growth model suffers from deficient capacity to create economic values without the loss of important resource and environmental values.

Delinking the ecological losses from economic activities is a fundamental process in the transition to the green economy. It involves

- substitution of unsustainable flows of material and energy by labour, capital and sustainable flows
- recycling of materials and heat recovery
- realocation of land from less valuable economic use to valuable nature

These processes lead to a resource efficient economy. The challenge facing all regions is to accomplish such process alongside with a more efficient use of the labour and capital resources.

It follows from these concepts that the fixed capital formation is a key variable in describing the transformation of the economy from the 20th century type of econosphere to a green economy with a resource efficient and materials recycling econosphere.

Formation of fixed capital is – at best – specified on infrastructures, buildings, machines, transport equipment etc., but not on whether they are designed to the use of fossil or renewable energy, flow through or recycling, resource waste or resource efficiency etc.

Instead the GREECO datasets use energy and materials flow indicators at entry and exit points of the economy to indicate the progress of transformation.

The fixed capitals and economic organisations are *designed* to derive useful services from either the 20th century type of material and energy flux or the green economy type of resource efficiency with low rates of waste and high rates of recycling. Statistical accounts by such design features of the regional capital stock and associated supply chains would be useful, but they are not systematically collected and processed at the national level and even less so at the regional level.

Consequently we have derived two groups of indicators of the transformation of the econosphere. The first group relates to the transformation from fossil energy based economies to non-fossil economies. This process is in the EU terminology referred to as "decarbonisation" or transforming the economy to resource efficiency. The second group relates to the ecosystem services that are provided by ecosystems "processing" the abiotic environment to matter, energy and protected niches on and in which human societies can thrive.

The structural links between economic and ecological progress can indicated by the factors of the so called IPAT equation: Impact * population * affluence * technology. In the case of the links of carbon emissions to population and economic growth it can be more explicitly formulated as

$$(1) \quad Z = Z/F * F/E * E/Y * Y/N * N,$$

where Z represents emissions, F fossil fuel consumption, E energy consumption, Y GDP and N population. Growth and decline of Z the depends on growth of population and per capita consumption, balanced by the energy intensity of the economy, the share of fossil fuels in energy consumption and the carbon intensity of fossil fuel consumption.

The decarbonisation process has two sides. It follows from equation (1) that the reduction of production and use of fossil energy implies an increased share of non-fossil energy (F/E = 1-NF/E, where NF is non-fossil energy. Consequently, the green economy of the individual regions is also characterized by the realization of its renewable energy potentials.

The links between economic growth and the loss of ecosystem services are not quite as simple. The loss of ecosystem services is mainly due to artificial land cover and degradation of natural ecosystems.

2. The GREECO NUTS2&3 datasets

The GRECO NUTS2&3 datasets are listed in Table 1 below. The table has links.

Table 1. GREECO NUTS2&3 datasets on decarbonisation and ecosystem services

Variable	Name	NUTS-version	Level	Years	File
Regional economic aggregates					
GDP	Gross domestic product	2010	0-3	2000-10	GREECO_GDP_N10_0-3_2000-10.xls
GDP05	Gross domestic product, deflated to 2005 price level	2010	0-3	2000-10	GREECO_GDP05_N10_0-3_2000-10.xls
GDPPPS	Gross domestic product in purchasing power standards	2010	0-3	2000-10	GREECO_GDPPPS_N10_0-3_2000-10.xls
GVA	Gross value added	2010	0-3	2000-10	GREECO_GVA_N10_0-3_2000-10.xls
GVA05	Gross value added, deflated to 2005 price level	2010	0-3	2000-10	GREECO_GVA05_N10_0-3_2000-10.xls
JOB	Employed persons by region of employment	2010	0-3	2000-10	GREECO_JOB_N10_0-3_2000-10.xls
LQ	Location quotients by broad branches of production	2010	0-3	2010	GREECO_LQ_N10_0-3_2000-10.xls
NFCr	Net Fiscal Contribution ratio	2010	0-2	2000-09	GREECO_NetTB_N10_0-2_2000-09.xls
RCI	Regional competitiveness index	2006	2	2010	GREECO_RCI_N06_2_2010.xls
RPOP	Resident population	2010	0-3	2000-10	GREECO_RPOP_N10_0-3_2000-10.xls
Decarbonisation					
AQ	Air pollutant exposure	2006	3	2005-10	GREECO_AQ_N06_3_2005-10.xls
Emint	Predicted air emissions and emission densities	2006	0-2	2010	GREECO_EmInt_N10_0-2_2010.xls
FEC_Prod	Final energy consumption, production	2010	0-2	2000-10	GREECO_FEC_Prod_N10_0-2_2000-10.xls
FEC_Res	Final energy consumption, residential	2010	0-2	2000-10	GREECO_FEC_Res_N10_0-2_2000-10.xls
FEC_Tot	Final energy consumption, total	2010	0-2	2000-10	GREECO_FEC_Tot_N10_0-2_2000-10.xls
FEC_Tran	Final energy consumption, transport	2010	0-2	2000-10	GREECO_FEC_Tran_N10_0-2_2000-10.xls
MR	Motorisation rate	2010	0-2	2000-10	GREECO_MR_N10_0-2_2000-10.xls
PV	Economic photovoltaic energy potential	2010	2	2009	GREECO_PV_N10_2_2009.xls

WP	Economic onshore wind energy potential	2006	2	2009	GREECO_WP_N2_2009_v1.xls
PCT	Decarbonisation related patent rates	2006	0-3	2000-10	GREECO_PCT_N06_0-3_2000-10.xls
Ecosystem services					
LCx	Land cover	2006	0-2	2009	GREECO_LCx_N06_0-2_2009.xls
SEI	Shannon Evenness Index of landscape diversity	2006	2	2009	GREECO_SEI_N2_2009_v1.xls
NAT	Natura 2000 and nationally designated nature areas	2010	2	2010	In process
WQRB	Environmental status of river basins	2006 / RBDcode	0-2	2011	GREECO_WQ_N2_RBD_2011_v1.xls

Table 2. GREECO NUTS2&3 datasets on investment and inclusion

Variable	Name	NUTS-version	Level	Years	File
Investing in a green economy					
Water and waste					
WW	Employment and GVA in the water and waste branches	2006	0-3	2009	GREECO_WW_N06_0-3_2009.xls
MW	Generation and treatment of municipal waste	2010	0-2	2000-09	GREECO_MW_N10_0-2_2000-09.xls
WC	Waste water system connection rate	2006	2	2005-09	GREECO_WC_N06_2_2005-09.xls
General innovation potential					
ADEDU	Adult education	2006	0-2	2000-11	GREECO_ADEDU_N06_0-2_2000-11.xls
HRST	Human resources in science and technology	2006	0-2	2000-11	GREECO_HRST_N06_0-2_2000-11.xls
HTJOB	Knowledge intensive employment	2006	0-2	2008-11	GREECO_HTJOB_N06_0-2_2008-11.xls
PA	Patent applications to EPO	2006	0-3	2000-09	GREECO_PA_N06_0-3_2000-09.xls
RD	Research intensity	2006	0-2	2009	GREECO_RD_N06_0-2_2009.xls
PCT	Patent application statistics	2006	0-3	2000-10	GREECO_PCT_N06_0-3_2000-10.xls

Social and regional inclusion

EALE	Early school leavers	2006	0-2	2000-11	GREECO_EALE_N06_0-2_2000-11.xls
NEET	Young people not empoyed and not participating in education	2006	0-2	2000-11	GREECO_NEET_N06_0-2_2000-11.xls
XCL	Social exclusion	2010	0-2	2000-10	GREECO_XCL_N10_0-2_2000-10.xls

3. Interpreting data for use in planning and policy

3.1. Expected indicators

However, as noted above, the necessary data are often not collected with the detail required to generate statistics at a NUTS level of 2 or 3. In this case it is useful to estimate expected indicators, that is estimates of would we would *expect* to find if such data were collected and processed.

The *change* in indicators based on *collected* data or *observations* are important indicators of the rate of progress of the transformations. They are useful in monitoring the performance of the economy and the success of the actions launched to support the transformations towards a green economy. The change in indicators based on estimates formed by regionalising national level indicators by regional distribution keys or proxy variables only reflect changes in the national levels and these distribution keys. The change in regional patterns of expected emissions estimated using population shares as a proxy variable, shows only the change in the regional distribution of the population. It is unaffected by any regional differences in the transformation to low emission production and consumption activities and differences in actions taken regionally to support these transformations.

4. Bibliography

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5. Annexes

1. Annex 1. Air quality (AQ)
2. Annex 2. CO_2 emissions (CO2)
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Annex 1. Air quality (AQ)

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1. Air quality monitoring

The air quality in Europe is monitored by a network of monitoring stations. The data are collected nd processed by the European Topic Centre on Air and Climate Change (ETC/ACC) under contract with the European Environmental Agency (EEA). The GREECO Air Quality dataset builds upon these data.

The dataset allows for analysing the distance between the current levels of air quality and the sustainable levels, that is, "levels that do not give rise to significant negative impacts on and risks to human health and the environment" (EC, 2008, 2012, p. 6). Moreover it allows for monitoring progress in the levels of air quality.

We focus on particulate matter (PM) and ozone (O_3) pollution as representatives of tropospheric air pollution.

Concentrations of particulate matter of diameters 10 x 10^{-6} m and 2.5 x 10^{-6} m (PM10 and PM25, respectively) are observed at the measuring stations.

A substantial share of the particulate matter is formed from emissions of SO_2, NO_X, VOC and NH_3. These pollutants are not directly included in the dataset, but indirectly to the extent they contribute to secondary formation of PM10 and PM25.

Ozone is formed through interaction of ozone formatting gasses in the presence of sunlight (photochemical smog) in particular NO_X and VOCs. Beyond a certain level, it has significant impact on human as well as environmental health.

Whereas the ozone problem dominates during summer time, the PM problem is most severe during winter.

The GREECO dataset contains indicators of the share of population in NUTS3 regions living in 10x10 km areas exposed to elevated concentration levels of these pollutants. That is, concentration levels that exceed the thresholds beyond which they represent a significant risk to human and environmental risk.

2. Health thresholds

The European Commission decides thresholds in the form of limit values and indicative target values for the concentration of air pollutants. The metrics chosen as basis for the

GREECO datasets include the number of instances when the concentration level has exceeded the threshold and the cumulated pressure of concentrations above the threshold level. This is because the impact on ecosystems and human health depends on the cumulated pressure.

For PM10, a set of limit values for daily as well as cumulated pressure has been valid since 2005. For PM25, the limit value will enter into force from 2015. Ozone concentration levels are only subject to a limit value from 2010 and there is no limit value or target value for the *cumulated* amount of ozone exceeding the threshold. Thus a science based indicator – SOMO35 - has been calculated to reflect the cumulative impact on human and environmental health of repeated exceedance of 70 µg/m^3. In some studies 6000 is used to distinguish between high and low levels. It does mark a “border” between the high levels of ozone in the south and the more moderate levels in the north of Europe (see, e.g., (De Smet P, Horálek J, Kurfürst P, Schreiberová M, De Leeuw F, 2012)

In the GREECO dataset, the thresholds shown in Table 3 are used.

Table 3. Values used to indicate thresholds beyond which pollutant concentrations represent serious health risks.

Pollu-tant	**Time aggregation of monitoring data**	**Threshold value**	**Unit**	**Type of threshold**
PM25				
	Average calendar year	25	µg/m^3	TG 2010, LV 2015
PM10				
	Average calendar year	40	µg/m^3	LV 2005
	36th maximum daily average value	50	µg/m^3	LV 2005
Ozone	26th highest daily maximum 8 hour average value	120	µg/m^3	LV 2010
	SOMO35: Annual sum of maximum 8 hour concentrations above 70 µg/m^3 (35 ppb)	6000	µg/m^3	Analytical

Source: European Commission (EC, 2013) and ETC/ACC (De Smet P, Horálek J, Kurfürst P, Schreiberová M, De Leeuw F, 2012).

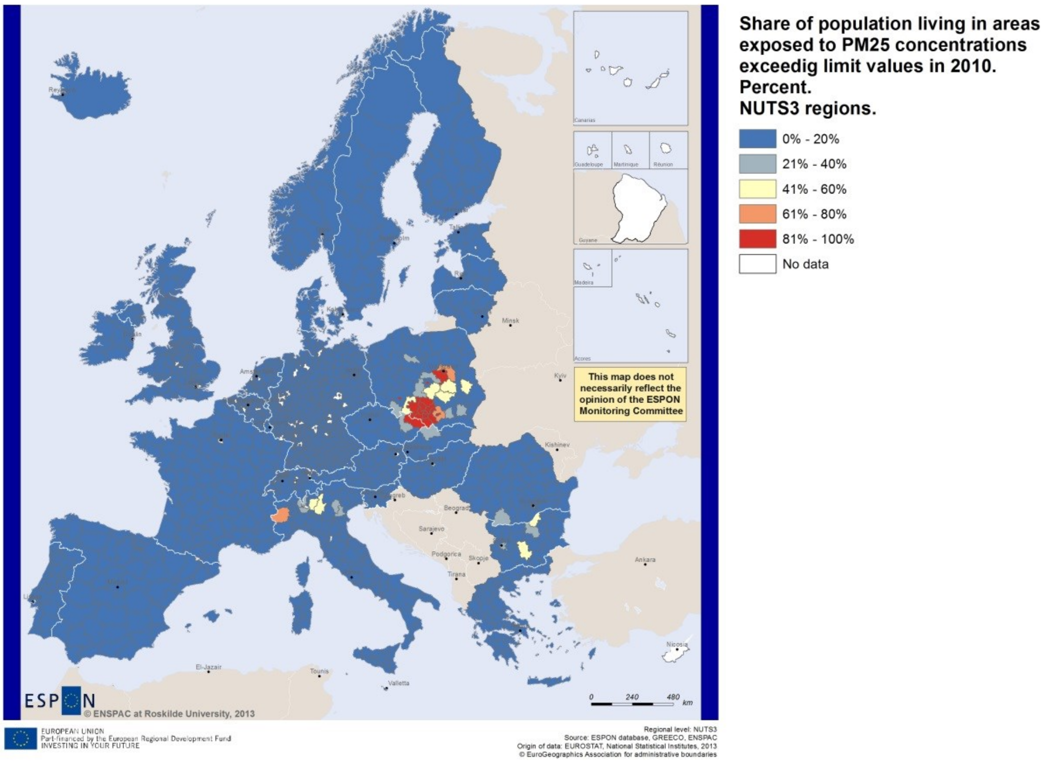
3. Data and indicators

The data for 2005, 2009 and 2010 used for the GREECO dataset are interpolated, processed and published in 10x10 km resolution GIS formats by the Netherlands RIVM (Rijksinstituut voor Volksgezondheid en Milieu (RIVM), 2013). These data were combined with The GEOSTAT 2006 population grid (European Forum for GeoStatistics, 2012). Assuming that the grid cell share of the NUTS3 population was equal to the 2006 share in all years, the share of the NUTS3 populations living in 10x10 km grid cells with concentration levels exceeding the thresholds was calculated.

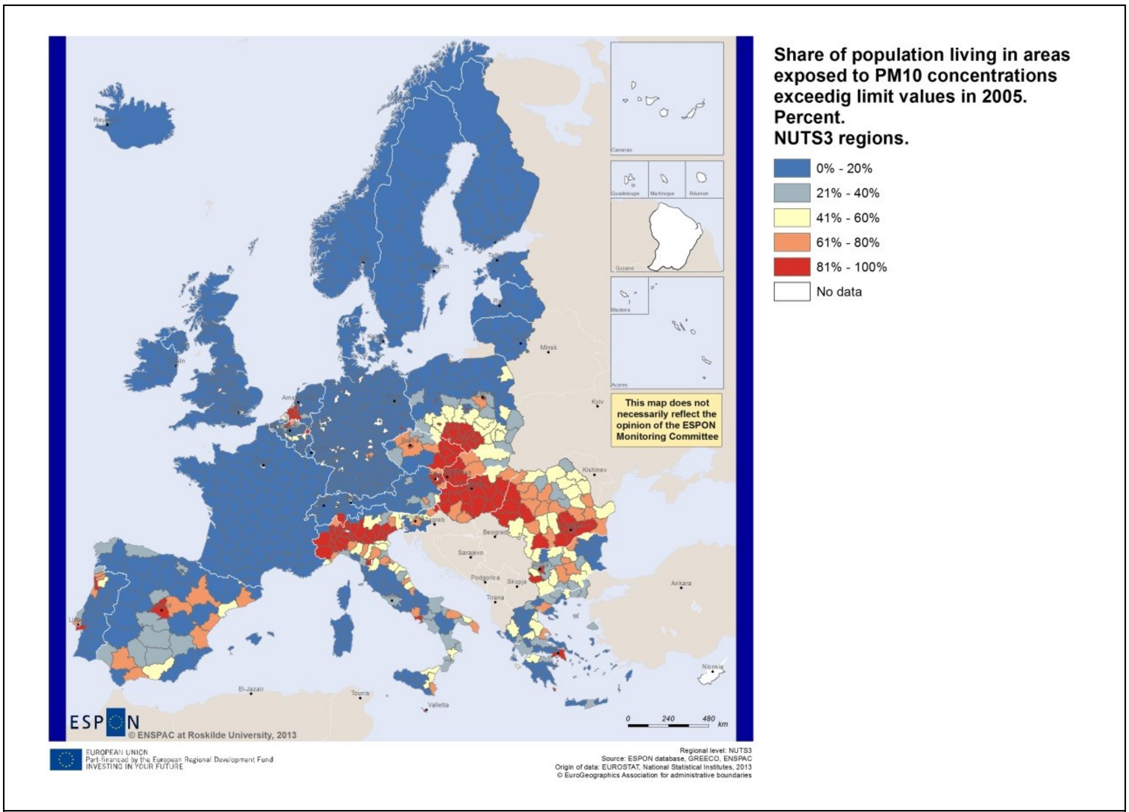
These variables indicate the degree of exposure of human population to air pollution risks, but not the exposure of crops or natural ecosystems.

4. Results

The very small particles indicated by the PM25 concentration has proven to be a serious environmental risk. The concentration levels in 2010 are compared to the limit values in force from 2015 in Map 1.



Map 1. Share of the population living in areas with PM25 consentration levels in exceeding limit values. 2010. Percent.


Share of population living in areas exposed to PM10 concentrations exceedig limit values in 2005. Percent. NUTS3 regions.
0% - 20%
21% - 40%
41% - 60%
61% - 80%
81% - 100%
No data
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Origin of data: EUROSTAT, National Statistical Institutes, 2013
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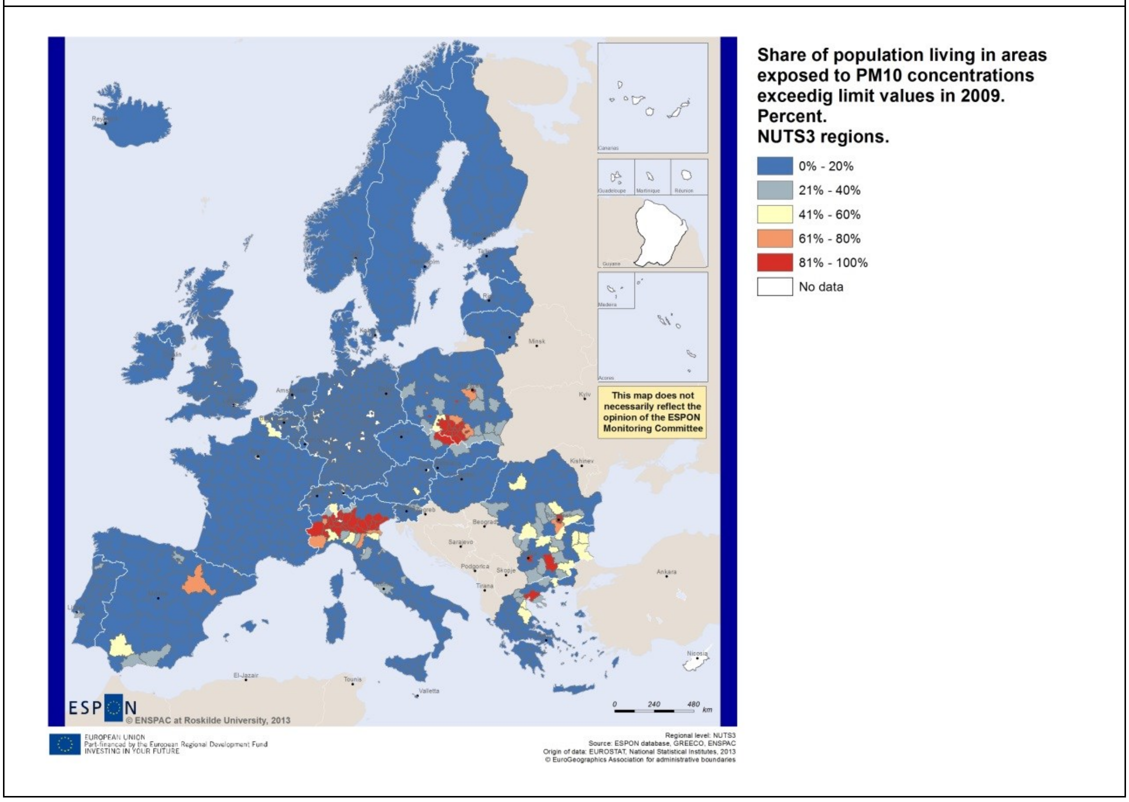
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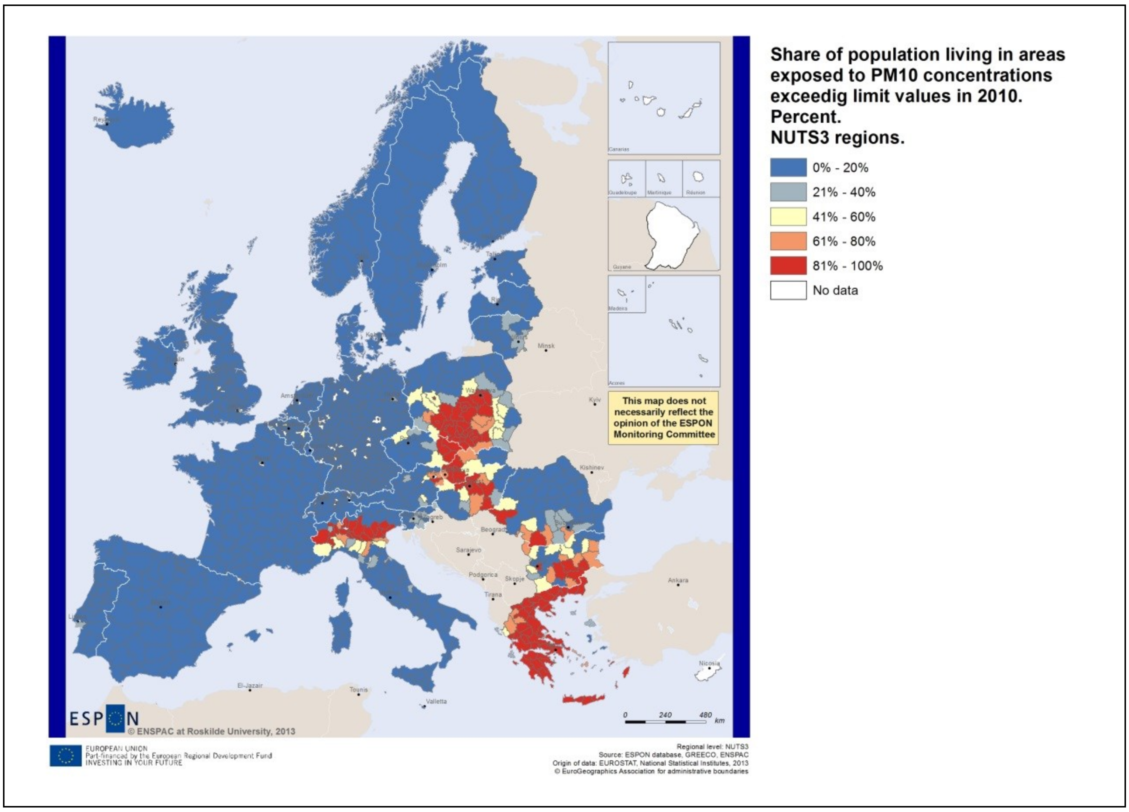
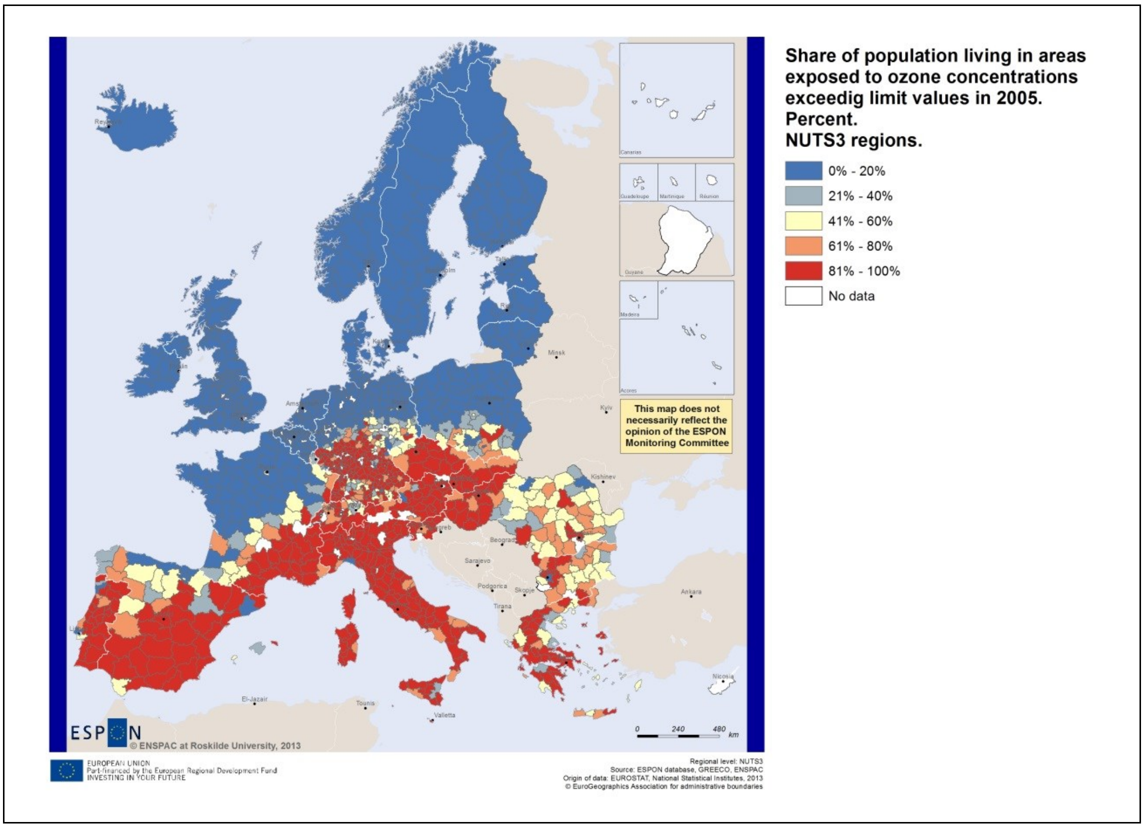
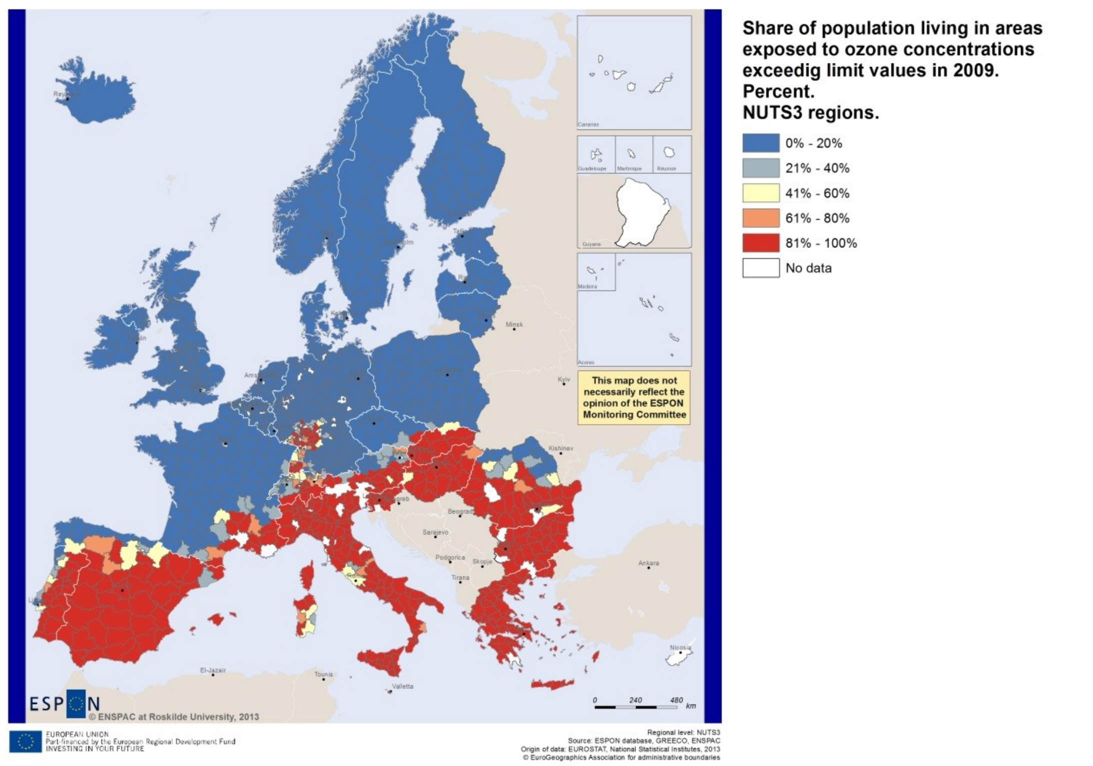
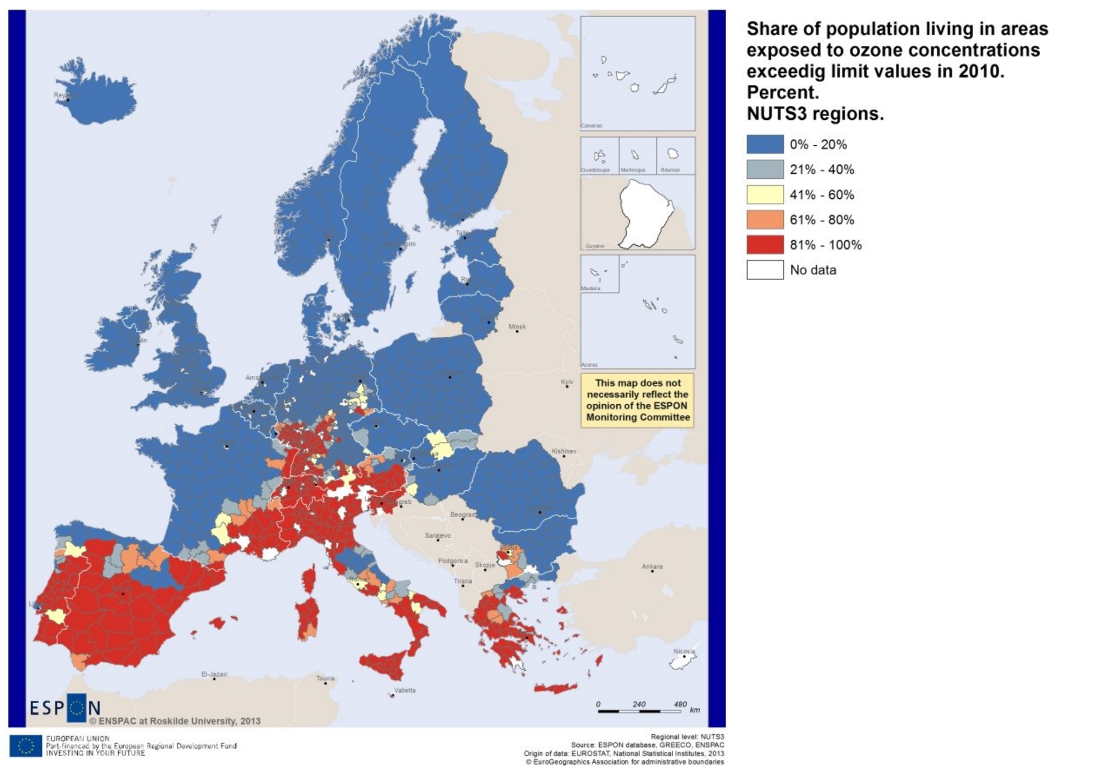


Map 2. Share of population living in areas with PM10 concentration exceeding limit values in NUTS3 regions. 2005, 2009 and 2010. Percent.







Map 3. Share of population living in areas with ozone concentrations exceeding threshold values in NUTS3 regions. 2005, 2009 and 2010. Percent.

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Annex 2. CO_2 emissions (CO2)

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Anders Chr. Hansen

1. The carbonisation-growth model

The concept of a “green economy” must be understood in a historic perspective. The green economy is a “low-carbon” economy, which is in sharp contrast to the increasingly “carbonised” economy of the 2oth century.

The unprecedented economic growth in Europe through the 20th century - despite two world wars – was closely related to the access to “easy” or relatively low cost fossil fuels.

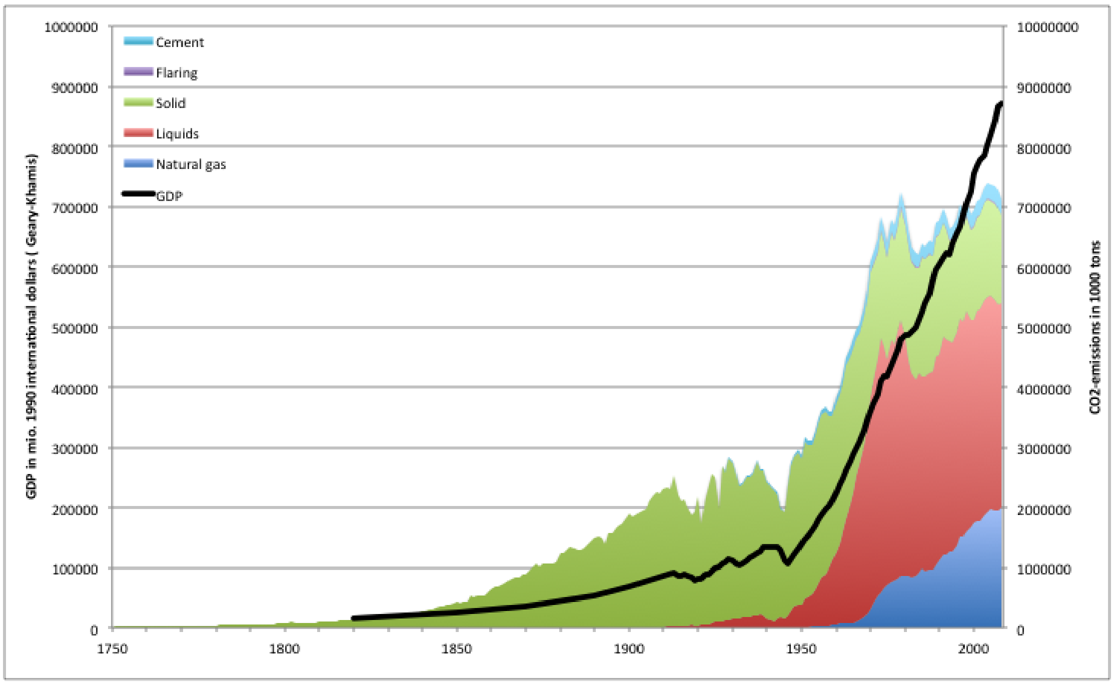


Figure 1. GDP and CO2 emissions (by source) of Western Europe. 1751-2008.

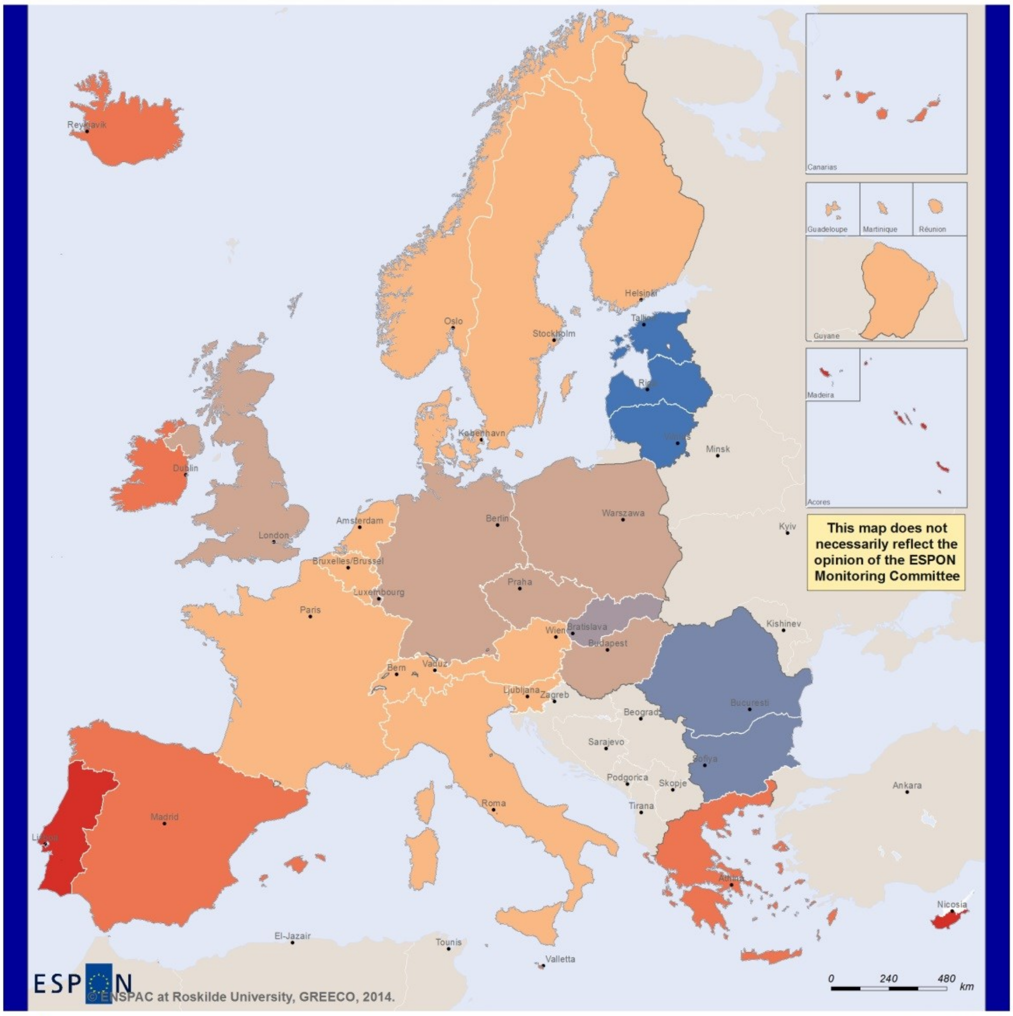
Authors calculations based on historical data (Andres et al., 2011; Maddison, 2006).

Figure 1 shows the *carbonisation* of the European economy in particular through the 20th century. The access to cheap fossil energy enabled the growth of not only value creation, but also heavy flows of materials through the economy. In the pre-industrial economy, the size of the population and its production depended to a high degree on the regional carrying capacity in terms of human controlled bio-productivity in the territory. The industrialisation was closely related to investment in capital designed to use coal - steam engines, power plants, furnaces etc. Without this early carbonisation, the industrial revolution had hardly been possible.

The period following the WW2 period during which the oil economy was built up has been called the second industrial revolution. The investment in oil infrastructure and combustion engines and the accelerated electrification enabled an unprecedented growth of value creation as well as material flows in the developed economies. GDP as well as CO_2-emissions tripled over three decades from the end of the 1940s. Of course, many other factors – not least science, education and international specialisation – contributed, but the oil economy made it physically possible.

During the most recent three decades the emissions rose only modestly compared to the dramatic increase through the three decades after WW2. The economic growth has continued, which shows that economic value creation does not have to be as closely linked to fossil energy use as it was in the 50s to 70s. This is an encouraging observation.

Part of this weakening of the carbon link could be explained by “carbon-outsourcing” as manufacturing industry is in decline and the products are imported from the emerging economies. Recent analyses based on the CO_2-emissions “embodied” in the consumed goods irrespective of their origin shows that the level of CO_2-emissions caused by the economic activity in the EU27 must be expected to be 20-25% higher than the CO_2-emissions emitted from the EU27 territories. The CO_2-emission trend from 1990 to 2010 is, however, more delinked from economic growth when defined as emissions embodied in consumption (Peters et al., 2012).



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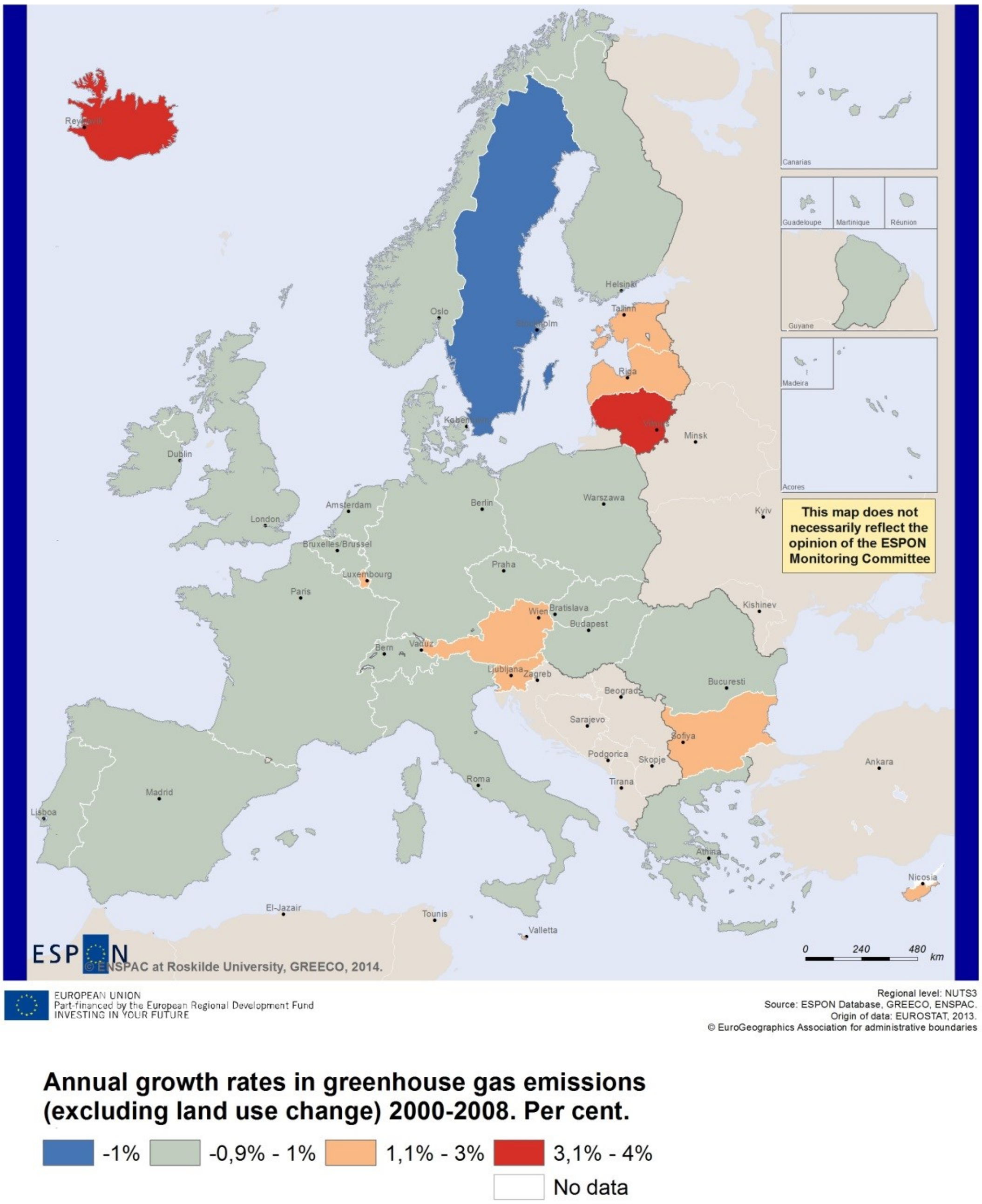
Regional level: NUTS3
Source: ESPON Database, GREECO, ENSPAC.
Origin of data: EUROSTAT, 2013.

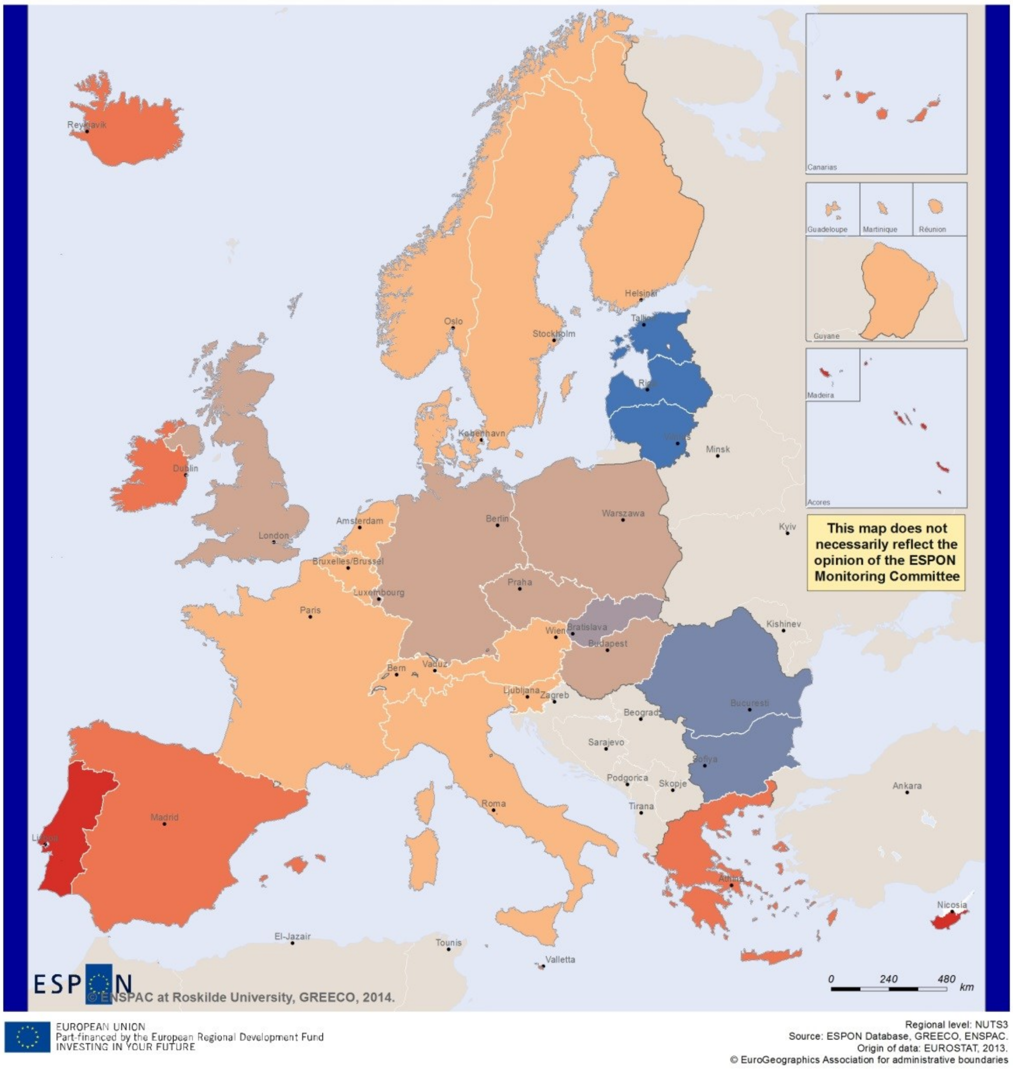
Annual growth rates in greenhouse gas emissions (excluding land use change) 1990-2000. Per cent.

- -9,2% - -7%
- -6,9% - -5%
- -4,9% - -3%
- -2,9% - -1%
- -0,9% - 1%
- 1,1% - 3%
- 3,1% - 5%
- No data



Map 4 shows the compound annual growth rates of GHG emissions in European countries in the 1990s and in the 2000s until 2008.

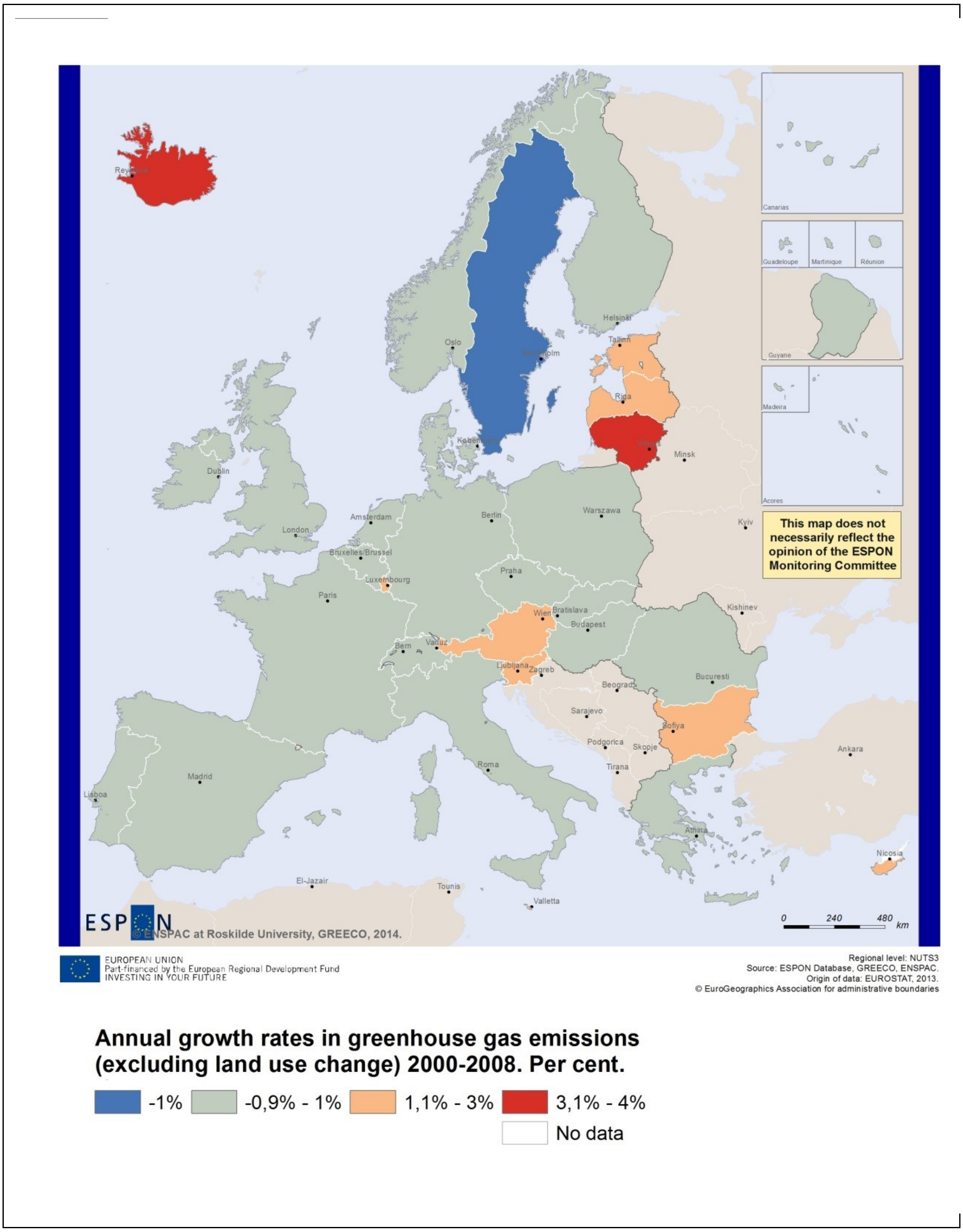
In the 1990s, the emissions declined dramatically in the countries of the former eastern block following the collapse of the fossil fuel intensive industry of these economies. At the same time a rapid economic growth in some economies such as Spain and Portugal led to high rates of emission growth.



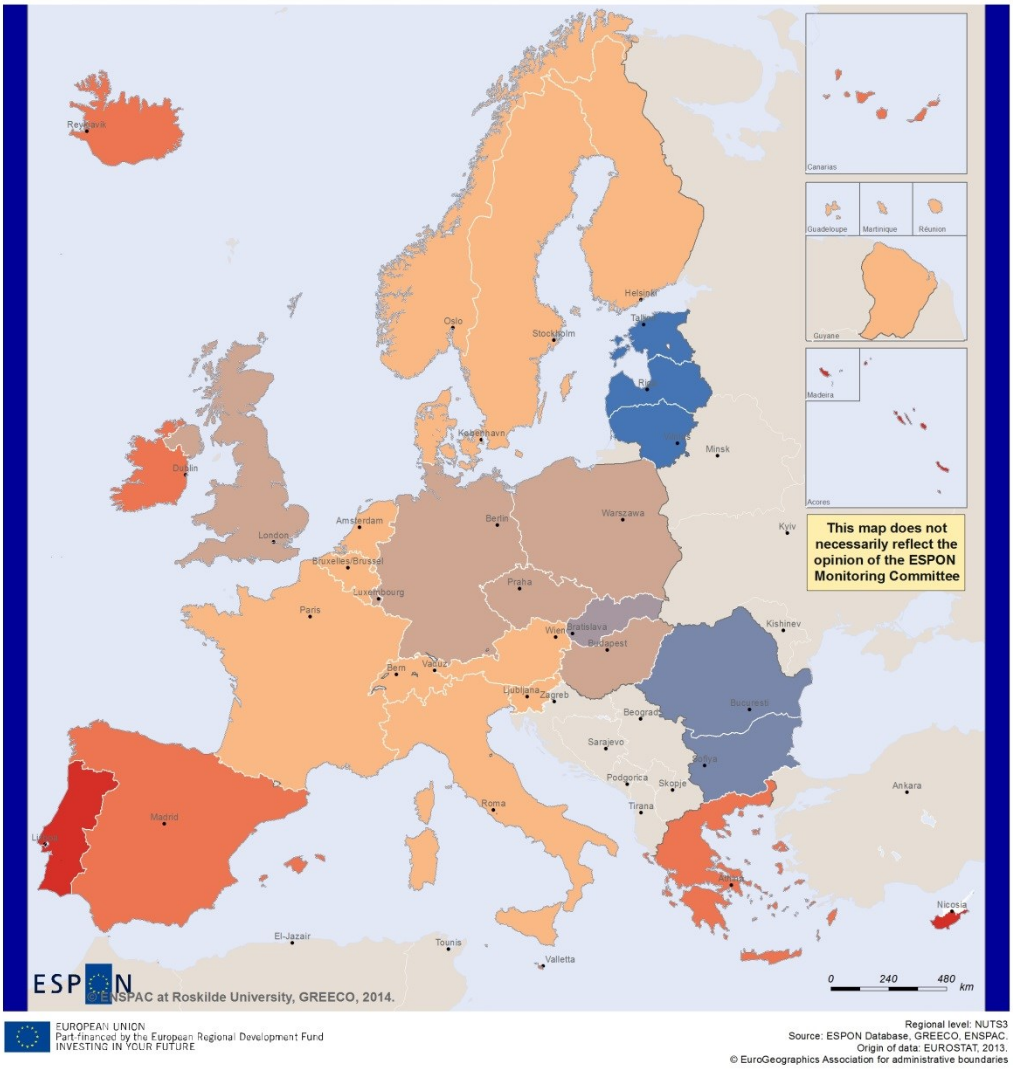
Annual growth rates in greenhouse gas emissions (excluding land use change) 1990-2000. Per cent.

-9,2% - -7% | -4,9% - -3% | -0,9% - 1% | 3,1% - 5%

-6,9% - -5% | -2,9% - -1% | 1,1% - 3% | No data

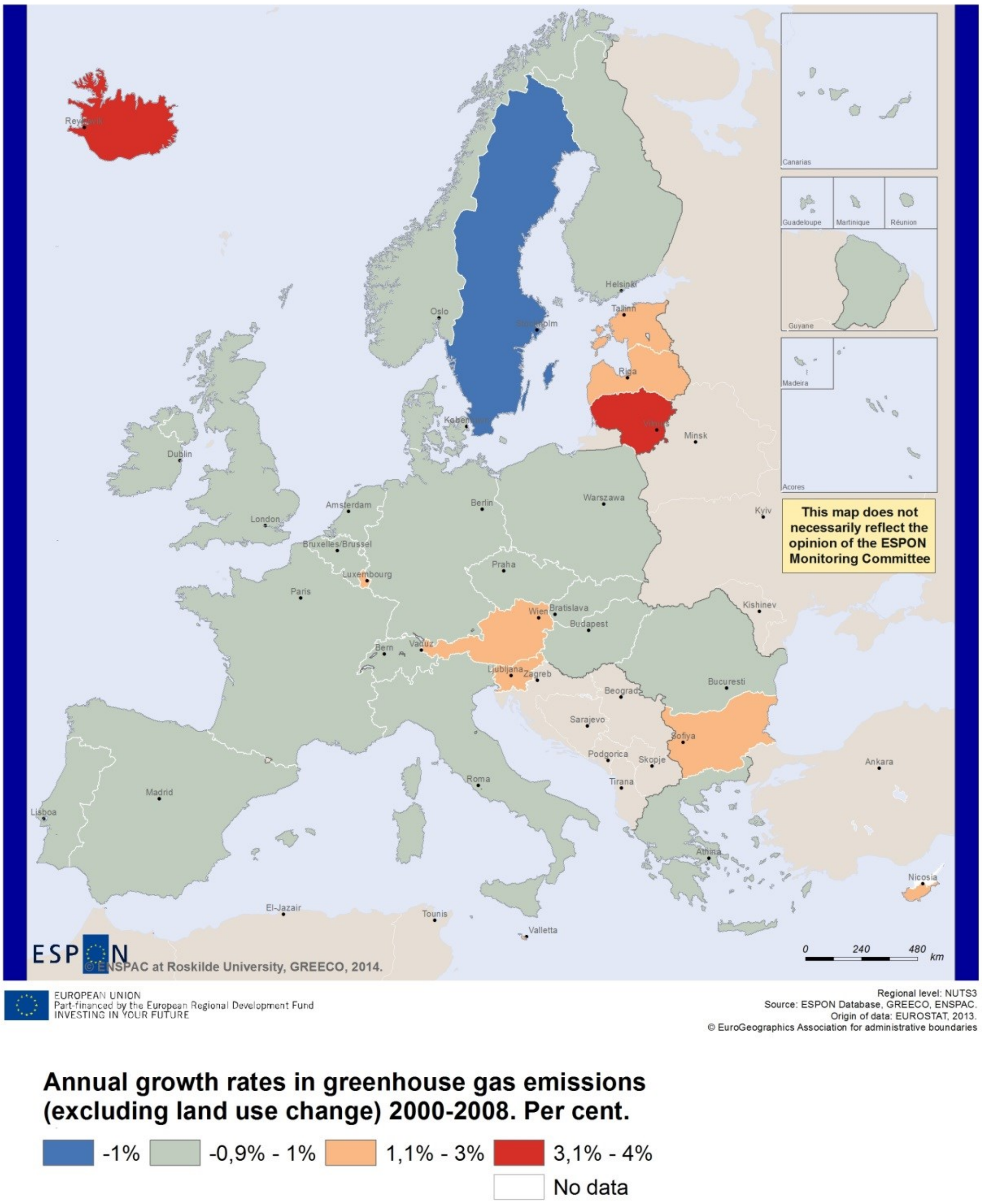


Map 4. Greenhouse gas emission growth in EEA countries. Reported change 1990-2000 and 2000-2008. Percent per year.



Annual growth rates in greenhouse gas emissions (excluding land use change) 1990-2000. Per cent.

-9,2% - -7% | -4,9% - -3% | -0,9% - 1% | 3,1% - 5%
-6,9% - -5% | -2,9% - -1% | 1,1% - 3% | No data



Map 4 also shows that despite high growth rates across Europe until 2008, the annual change of GHG emissions remained within the interval between +1% and -1% per year in most countries.

The EDGAR database contains gridded emission data predicted from national emission figures, that is, emissions one would expect to find locally given the national emission figures and the spatial distribution of economic activities. In this sense it represents an alternative to the emission accounts based on official emission inventories.

Figure 2 shows the EDGAR-database data on European emissions density.

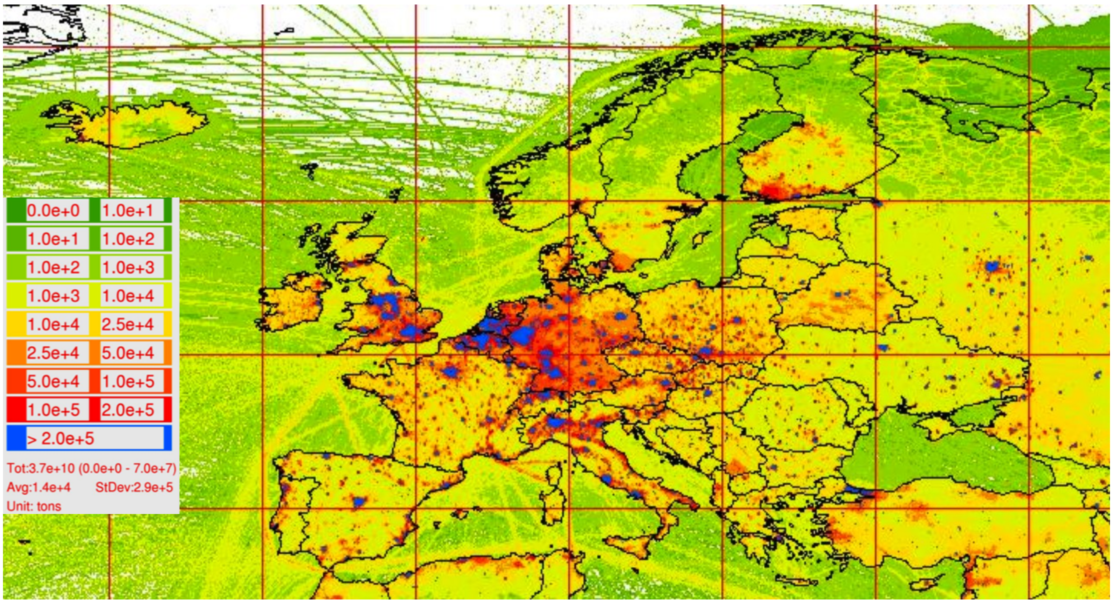


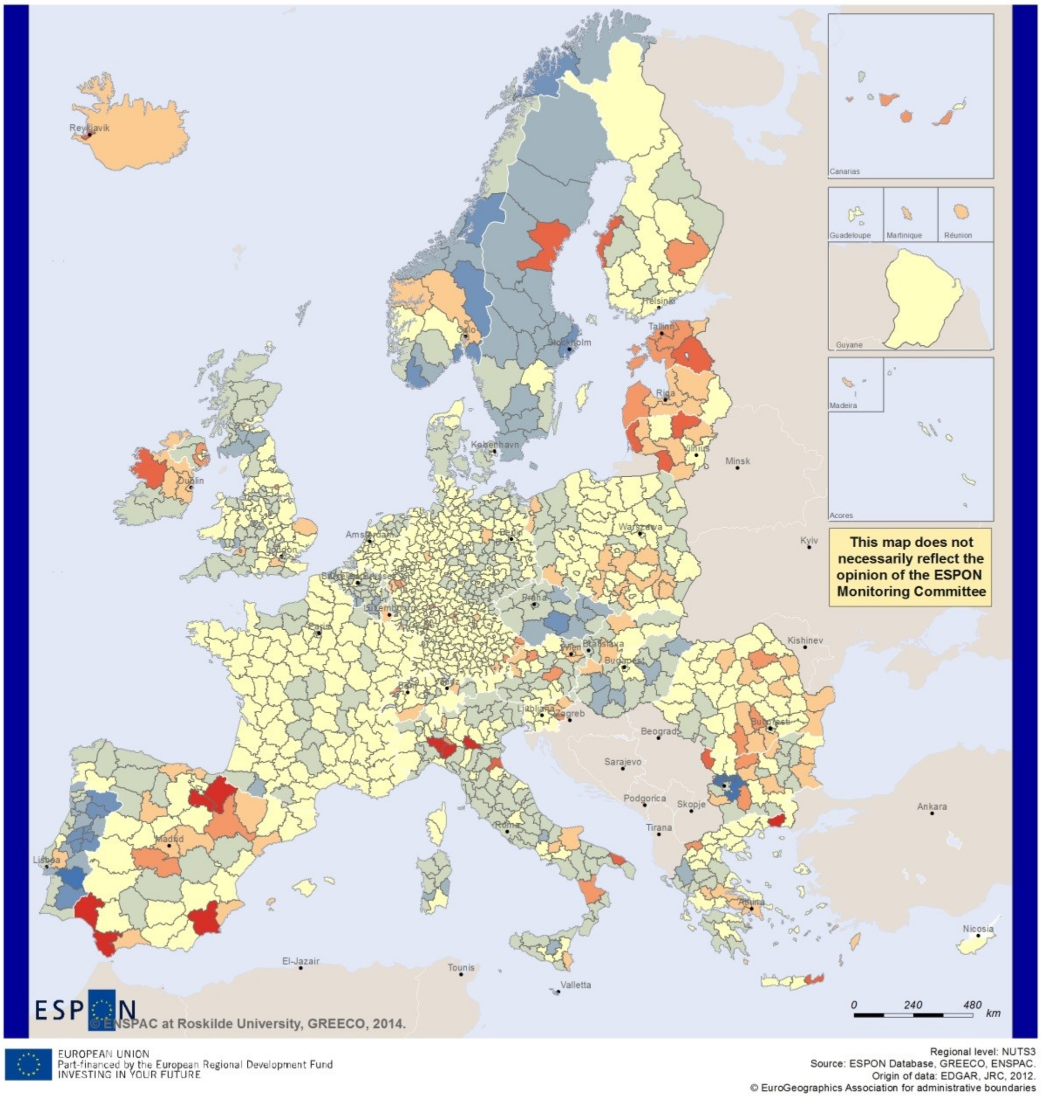
Figure 2. Predicted CO2-emissions (excluding biomass) in Europe 2008. Tg/0.1x0.1 degree grid cell.

Source: (JRC, 2012).

The CO_2-emissions shown in **Figure 2** include all emissions from fossil fuels and industrial processes including international transport. The data are based on officially reported CO_2 emission data adjusted by knowledge of fossil fuel use from energy statistics. The national level data was gridded using spatial patterns of population and economic data, but with the consistent methodologies applied for all countries.

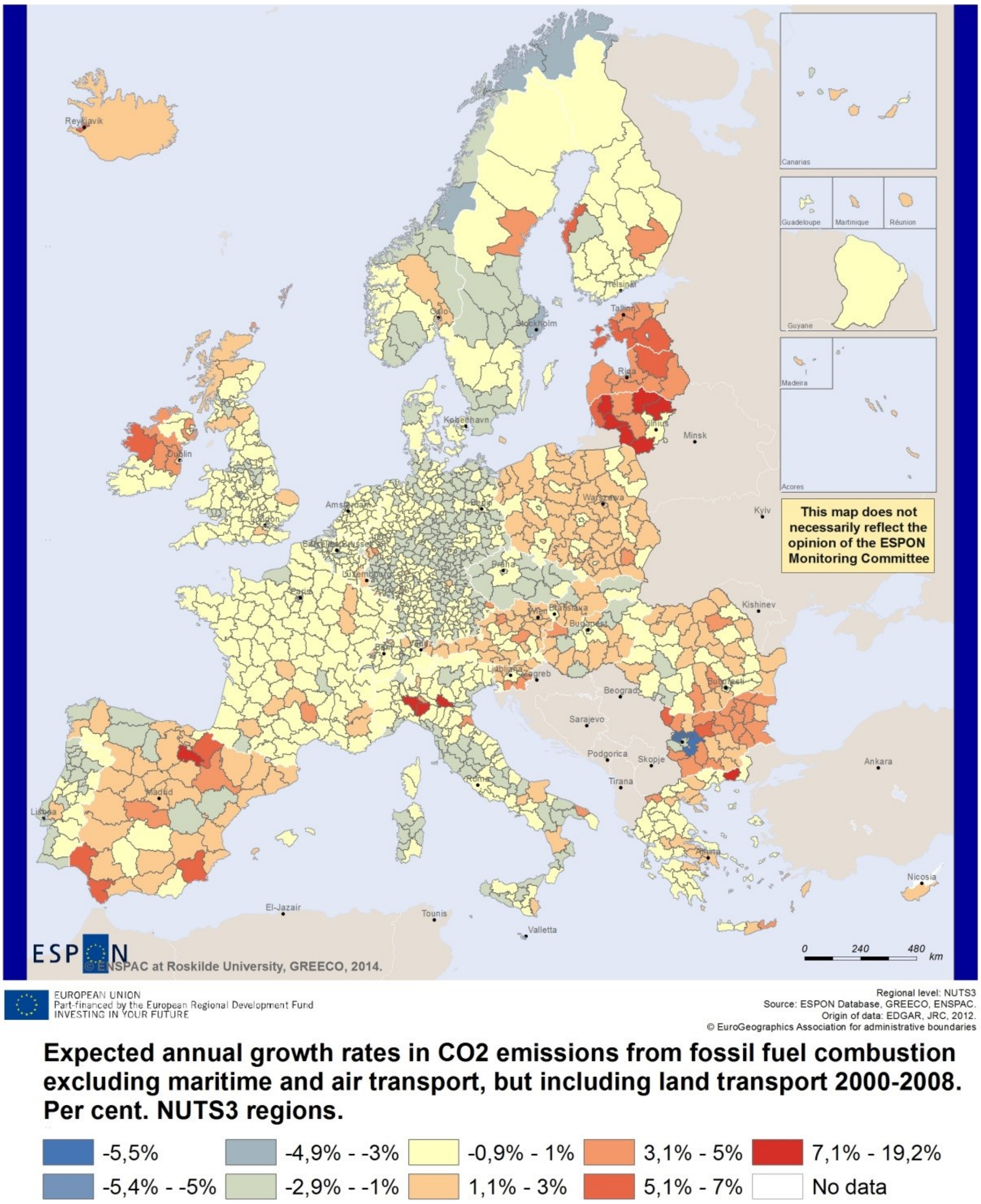
Consequently, it will add no new information to compare the spatial patterns of the regional emissions data to spatial patterns of the population and economic data. They are identical. The spatial patterns of the emission data can be interpreted as the predicted spatial patterns based on the national data.

The EDGAR database has been used to predict the regional (NUTS3) GHG emissions for 2000 and 2008 and the predicted change in emissions appears from map 5.



Expected annual growth rates in CO2 emissions from fossil fuel combustion excluding transport 2000-2008. Per cent. NUTS3 regions.

-8,8% - -7% | -4,9% - -3% | -0,9% - 1% | 3,1% - 5% | 7,1% - 25,5%
-6,9% - -5% | -2,9% - -1% | 1,1% - 3% | 5,1% - 7% | No data



Map 5. Predicted regional change in CO_2-emissions with (lower) and without (upper) ground transport. 2000-08. Percent.

Sources: Author's calculations based on the EDGAR database (JRC, 2012).

The emission data shown in map 5 are not observed emissions in the regions, but predicted emissions. Just like temporal predictions predict future developments from past patterns of development, the spatial predictions can predict emissions at a higher spatial resolution from statistics on national energy use and regional patterns of economic activity.

The spatial patterns expected on the basis of the EDGAR database if emission statistics had been collected at the regional level include a

This carbonisation-growth model of the 20th century is not sustainable and replicating it in the emerging and developing economies in the 21st century is not an option. It is unsustainable in many respects. First, it transfers carbon from the hydrocarbon reserves in the lithosphere through the economy to the atmosphere, where it has a greenhouse effect. Second, fossil fuel combustion emits air pollutants with severe effects on human and ecosystem health. Third, the fossil fuel resources are non-renewable and global economic growth increases the competition for a dwindling resource of decreasing quality. And fourth, the remaining reserves are controlled by a small number of countries that it would be undesirable for European countries to depend on for their energy security.

2. The carbon budget of Europe

Each of these four factors could justify a more or less restrictive carbon budget, but the greenhouse effect sets the effective constraint. In the following, the sustainable “carbon budget” refers to the greenhouse gasses that can be emitted without causing global warming beyond 2°C.

An alternative approach is to determine the “carbon budget” from the limited bio-productivity of land. The “ecological footprint” approach (Wackernagel and Rees, 1996) converts the carbon emissions to the forest area that would be needed for sequestering the CO_2 emissions in forest biomass. For the questions addressed by the GREECO project, however, it is preferred to use the direct accounts of emissions and the IPCC results about the carbon budget rather than conversions of the emission figures to hectares.

The total emissions of greenhouse gasses can be calculated with or without international bunkers, i.e., refuelling in European ports and airports. It is still debated how much of this should be distributed to the emission accounts of each country. **Figure 4** shows 2 sustainable emission paths assuming that international bunkers are fully included in accounts of the country of refuelling.

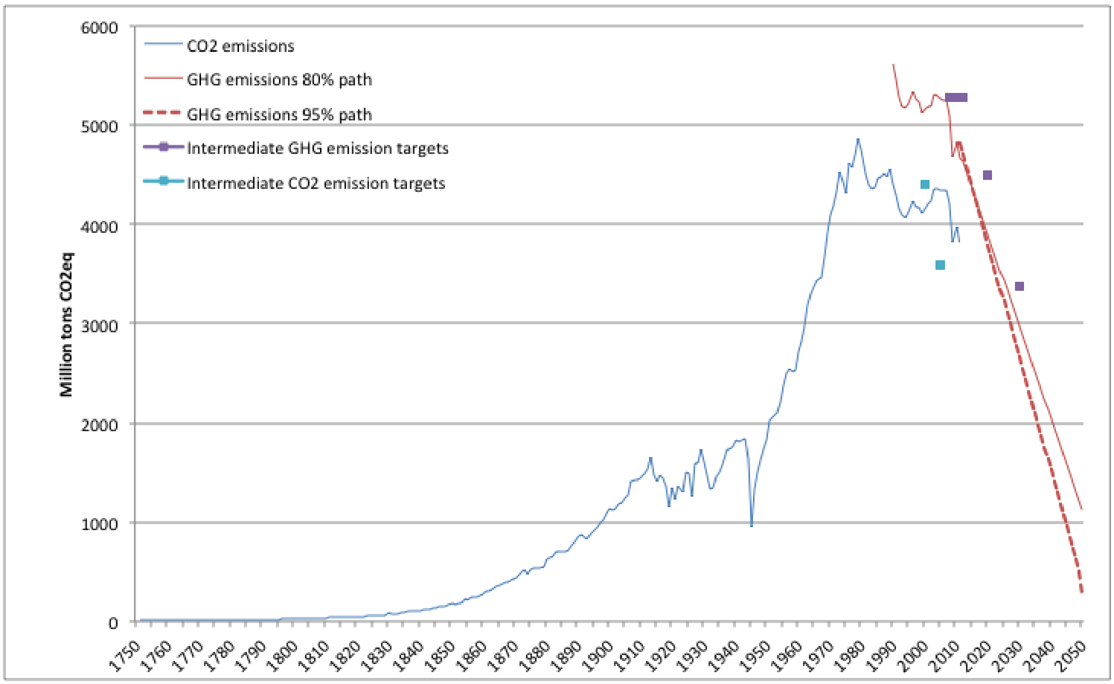


Figure 3. CO_2 emissions 1750-1989, officially reported GHG and CO_2 emissions 1990-2011 and sustainable GHG emission paths 2010-2050 from EEA countries (EU27+NO+IS+CH+LI). Million tons (Tg) CO_2 equivalents (including international bunkers and emission removals by land use change).

Authors calculations based on various sources (Andres et al., 2011; European Environment Agency (EEA), 2012).

Figure 3 shows the historic CO_2-emissions 1750-2010, the reported greenhouse gas emissions 1990-2010 and the paths for *sustainable emissions* from 2010 to 2050. According to the IPCC the global GHG emissions must be reduced by 50% from 1990 to 2050 in order to curb global warming to 2°C. The panel recommends that the developed economies reduce emissions by 80-95%. The EU has adopted this long-term target for decarbonisation. The end point is the general objective of the EU: "reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990, in the context of necessary reductions according to the Intergovernmental Panel on Climate Change by developed countries as a group" (EC, 2011).

The Fifth Assessment Report of the IPCC, the remaining global budget (2012-2100) is assessed to 140-210 GTC with a mean value of 270 GtC. It corresponds to a greenhouse gas emission budget of 991 $GtCO_2$. Keeping this budget should by more than 60% probability curb global irradiation to 2.6 W/m^2 by 2100 corresponding to a global warming of 2°C (Intergovernmental Panel on Cliamte Change (IPCC), 2013).

The sustainable greenhouse gas emission path of a developed economy region like EU leads to emission levels of 5-20% of the 1990 level in 2050. Consequently, the area under the sustainable emission curves can be interpreted as the "GHG emission budget" of Europe.

As milestones towards this end, the EU has adopted the target of reducing emissions by 20% of the 1990 emissions in 2020 (EC, 2010). The EU Commission has proposed a 40% emission reduction target for 2030 (EC, 2013a). The minimum GHG emission reduction consistent with the EU goal of delimiting global warming to 2°C is according to the IPCC 80% and this is the basis for the EU decarbonisation roadmap (EC, 2011). These decisions sum up to what can be characterised as a “20-40-80 carbon budget”.

Table 4. EU27 greenhouse gas emission budget. Reported annual changes in subperiods 1990-11 and planned emissions in subperiods 2011-50.

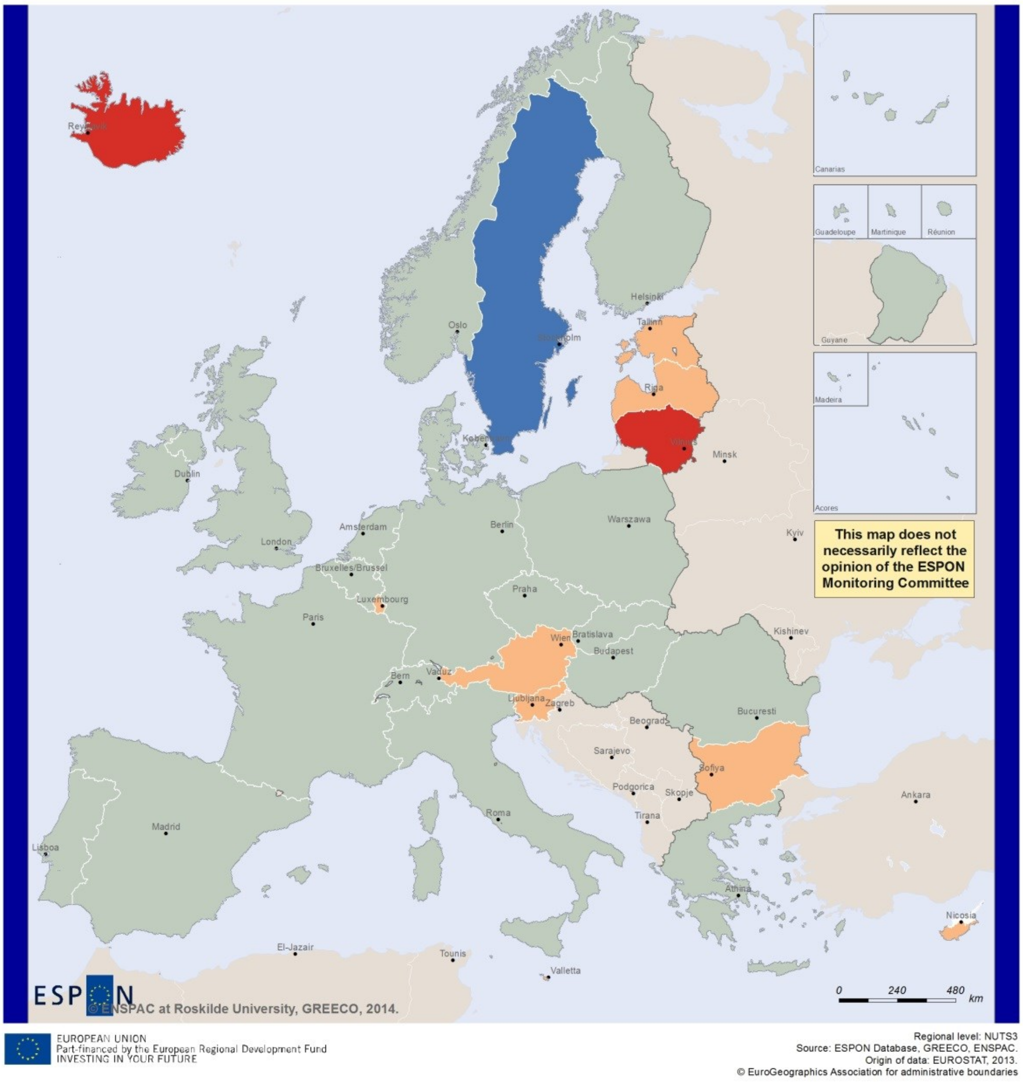
1990-00	2000-08	2008-11	2011-20	2020-30	2030-50
-1.0%	-0.3%	-2.8%	-0.2%	-2.8%	-5.3%

Assumptions on reduction targets: 2020: 20%, 2030: 40%, 2050: 80% of 1990 emissions.

Source: (EC, 2013a, 2011, 2010; European Environment Agency (EEA), 2013)

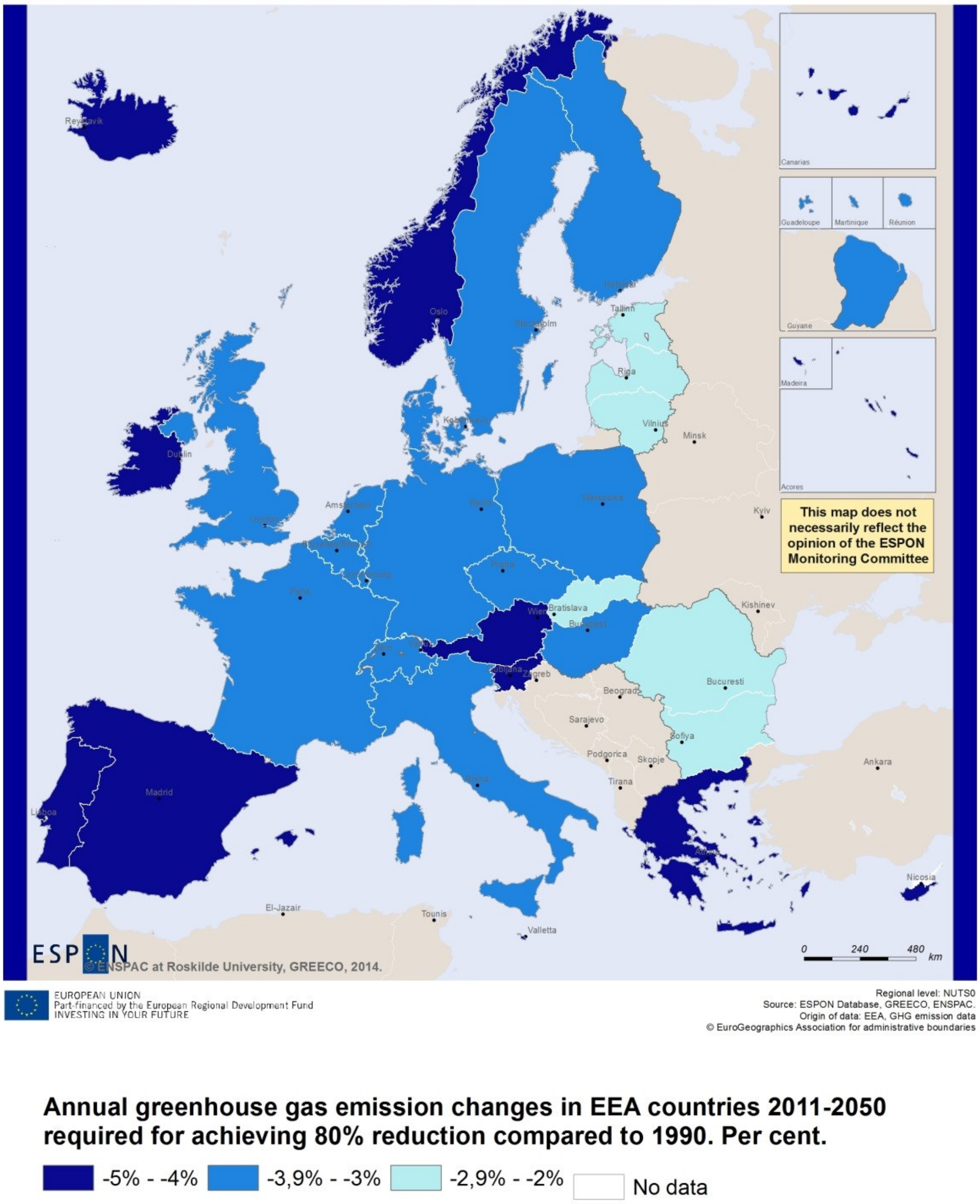
The EU 2020 target of 20% rather than the 30% emission reduction implies that a smaller budget is available for the 2020-50 period. The higher reduction rates in 2030-50 are also due to the reductions being imposed on a still small budget.

Map 6 compares the changes in greenhouse gas emissions required through 2011-2050 to arrive at 20% of the 1990-level in European countries with the emission changes through the 2008-2011 period.



Annual growth rates in greenhouse gas emissions (excluding land use change) 2000-2008. Per cent.

-1% | -0,9% - 1% | 1,1% - 3% | 3,1% - 4%
No data



Map 6. Greenhouse gas emission growth by EEA countries. Reported change 2008-2011 and required change for reducing by 80% of 1990 emissions in 2050. Percent per year.

As shown in **Map 6**, the subsequent years of a dramatic drop in GDP in 2008-09 followed by a temporary recovery 2009-11 contributed to a substantial reduction in GHG emissions in most of the European countries.

The carbon budgets are politically recognised when governments commit themselves to achieve targets either unilaterally or in international agreements.

The early targets for CO_2-emissions following the Toronto agreement in 1988 was to return to 1990 levels in year 2000 and reduce emissions to 80% of the 1988 emissions by 2005. The first target was achieved in Europe, but the 2005 emissions were far higher than the target. These targets, however, were not legally binding.

The Kyoto targets include all greenhouse gasses and offsets, but are legally binding. The common reduction commitment of the EU15 was 8% as an average of the emissions in 1990.

The EU adopted unilateral targets of 20% emission reduction in 2020 and the Commission has proposed 40% reduction in 2030, all relative to 1990. **Figure 4** shows that the 20% and 40% targets are above the linear emission reduction path starting in 2010. This is because the emission level in 2010-11 was lower than corresponding to a linear emission reduction path from 1990.

The 20% emission reduction target for 2020 is, however, not the preferred climate policy for the EU. Staying within the sustainable GHG emission budget calls for an emission reduction target of 30% of the 1990 emissions in 2020. If the rest of the world does not engage equivalently in climate policy, there is a risk that European industries lose competitiveness. Thus, as long as it is a unilateral commitment, the EU target is only a 20% reduction by 2020 (EC, 2010).

It should be noted that the Kyoto target is for emissions not including international bunkers whereas the one sided emission targets for 2020 and 2030 are for emissions excluding land-use change adjustments.

For the EU (+ Norway) as a whole, the carbon budget is divided between the ETS sector and the non-ETS sector. The ETS sector includes large fossil energy consumers defined as a starting point as plants with a boiler of 20MW effect or more. International aviation is also about to be integrated in the ETS-sector. The non-ETS sector includes residential and transport use of fossil energy as well as productive use outside the ETS sector and emissions of other greenhouse gasses. The role of the ETS sector emissions in the total GHG emissions from Europe appears from **Figure 4**.

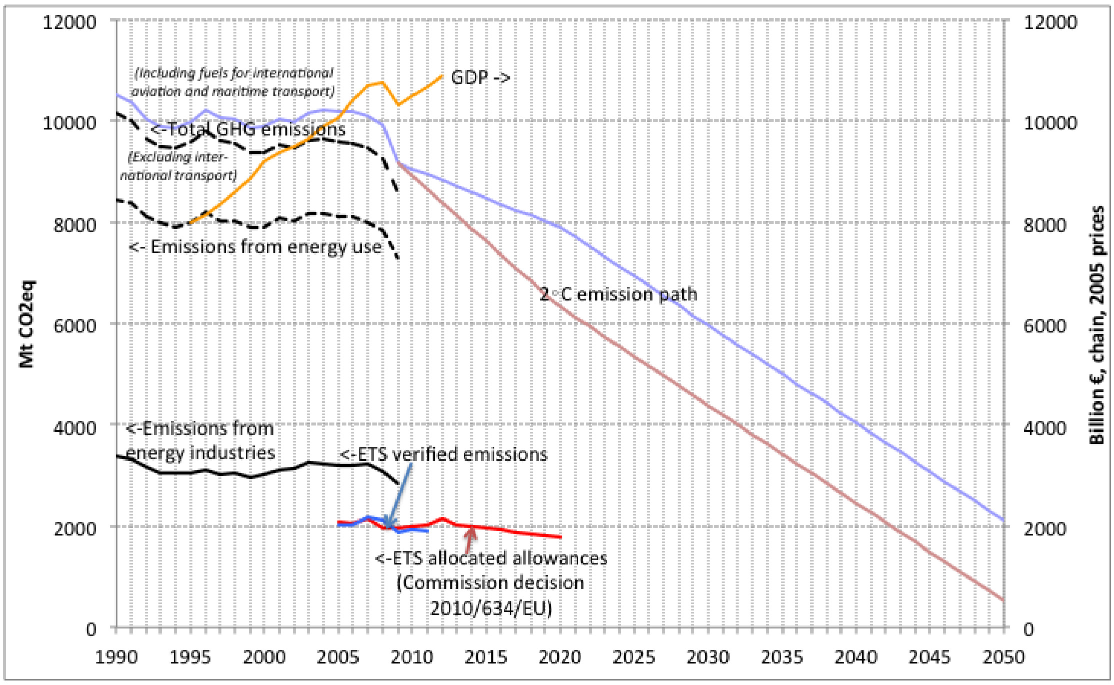


Figure 4. Greenhouse gas emissions 1990-09 and linear 2˚C emission path boundaries to 2050. EEA countries (EU27+IS+LI+NO).

Author's calculations based on various sources (European Environment Agency (EEA), 2012), (EC, 2009),(Carbon Market Data, 2013).

Figure 4 shows 2 sustainable emission paths assuming that all CO_2 emissions from international bunker fuels are included in accounts of the country of refuelling. The historic patterns of GHG emissions and economic growth are also shown. The ETS regulation represents an emission budget for the energy intensive industry. Most of the fossil fuel use, however, takes place outside the ETS sector.

The carbon budget for the ETS sector is laid down in the ETS directive (EC, 2009). The non-ETS emission budget is allocated to each member state in the effort sharing decision (EC, 2013b).

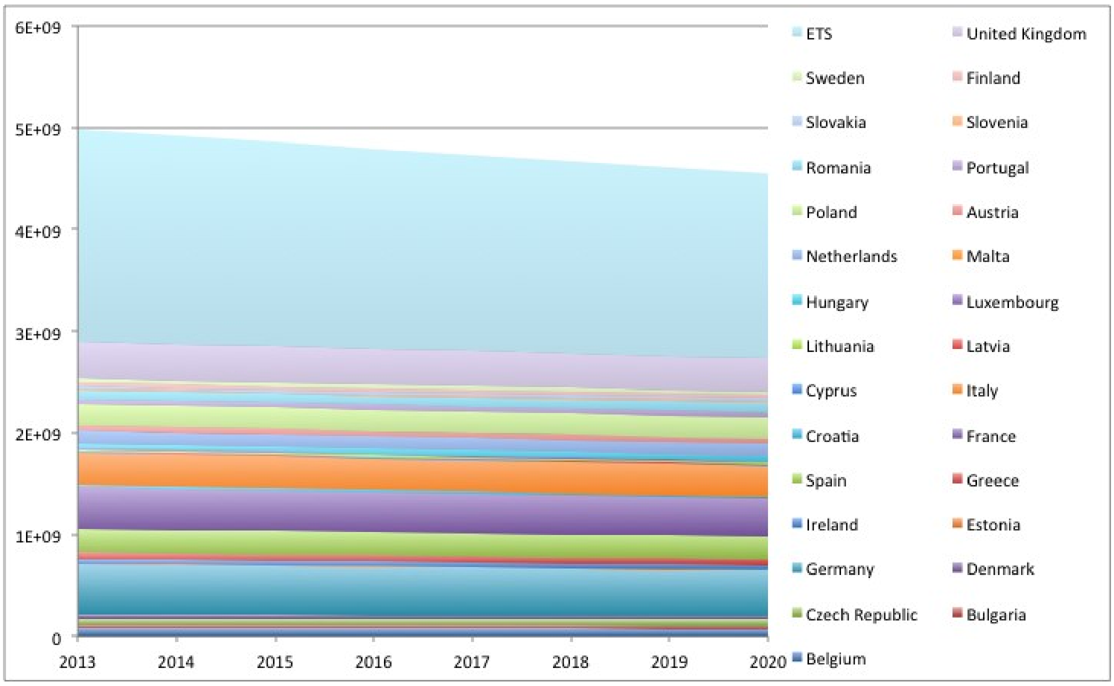


Figure 5. The EU GHG emission budget 2013-20 (Excl. international bunkring, offset credits and saved allowances). 1000 t.

Sources: Author's calculations based on the ETS directive (EC, 2009), EU Commission (EC, 2013c) and effort sharing decision (EC, 2013b).

The EU GHG emission budget in figure 5 is declining towards the 20% reduction target of 2020. There are, however, greenhouse gas emissions outside the budget. They include international bunkers (fuel for international shipping and aviation). Moreover, the budget will be expanded by offset credits (Emission Reduction Units (ERUs) and Certified Emission Reductions (CERs)). The Commission intends to postpone some of the ETS supply of EU allowances planned for the first years to later years in the period.

The non-ETS emission budget for each member-state is adjusted considering their prospective economic growth. It is generally expected that the future economic growth in the period depends on the per capita GDP at the outset. A country with a lower GDP per capita is expected to grow faster than a country with a higher GDP because it can take advantage of the technical and organisational solutions that have already successfully been implemented in the country with a higher GDP. This "catching up" hypothesis is supplemented with a distributional aspect, leaving a higher share of the EU effort with the economically stronger member-states.

The budgeted change in emission budgets is related to income levels as shown figure 6 below.

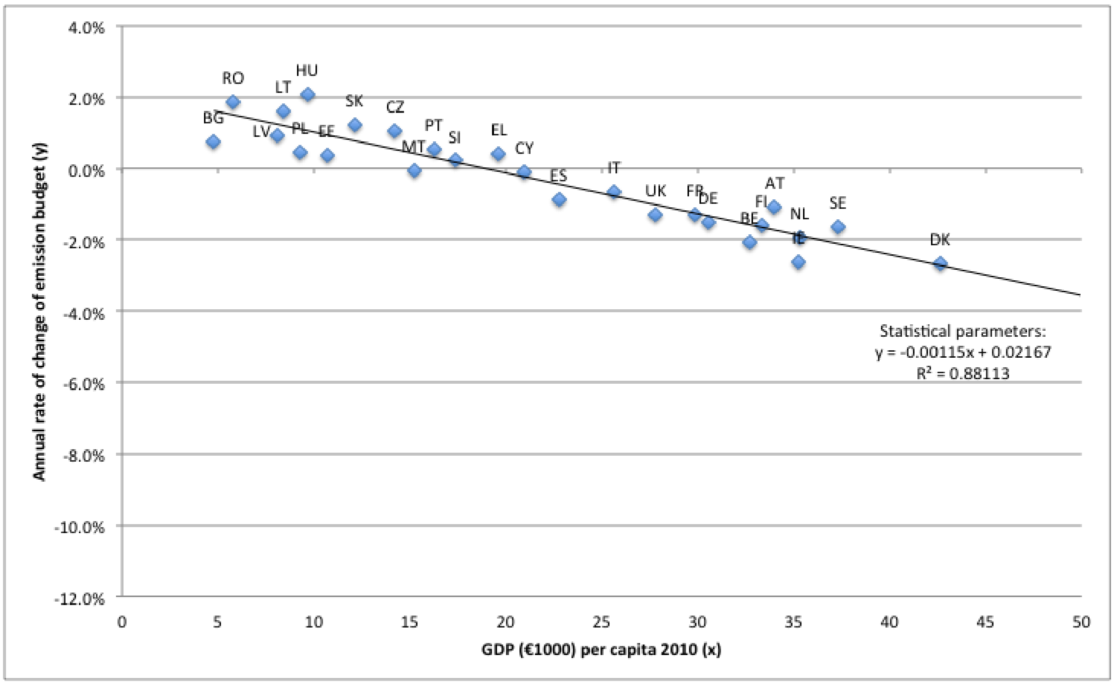


Figure 6. Dependency of reduction rate of annual non-ETS emission budgets to income level*.

Source: EU Commission (EC, 2013b) and EUROSTAT (EC, 2013d).

** Luxembourg is considered an outlier and excluded from the analysis due to its high income level.*

The income-adjusted emission reduction efforts shown in figure 6 actually allows for increased non-ETS emission in the new member states, Portugal and Greece. This is only compatible with a lower EU-wide budget if the emission reduction efforts of the other member-states are correspondingly stronger.

It should be noted that member-states might unilaterally adopt tighter emission budgets for the 2010s. The emission reduction target of the Danish government, for instance, is 40% in 2020 heading for a 100% decarbonisation in 2050 (Danish Energy Authority (Energistyrelsen), 2013).

There are important economic potentials in completing more of the decarbonisation process in the present decade rather than postponing it to later decades. Despite temporary fluctuations the relative prices of fossil fuels must be expected to be increasing in a business-as-usual scenario. Thus, advancing the decarbonisation allows the economy to mitigate the otherwise foreseen fossil fuel drag on the economy. The costs of decarbonisation are also higher the higher the pace of transformation. A more even pace of transformation will be better for cost competitiveness later on. There are costs, but also first mover advantages in terms of future export potentials of developing productive capacity in the future technologies before others. The cascade of crises and recessions since 2008 has left large productive potentials in Europe unused. Thus economies may gain from advancing future investments for decarbonisation to the present. These economic potentials are balanced against the prospective decline in the cost of the renewable energy and energy saving technologies, but at the European or global level this cost decline only materialise as a result of cumulative use of the technologies. The economies that have most to gain from a new, green technology either as producer or user or both are the more likely economies to be first-movers.

3. Regional emission budgets

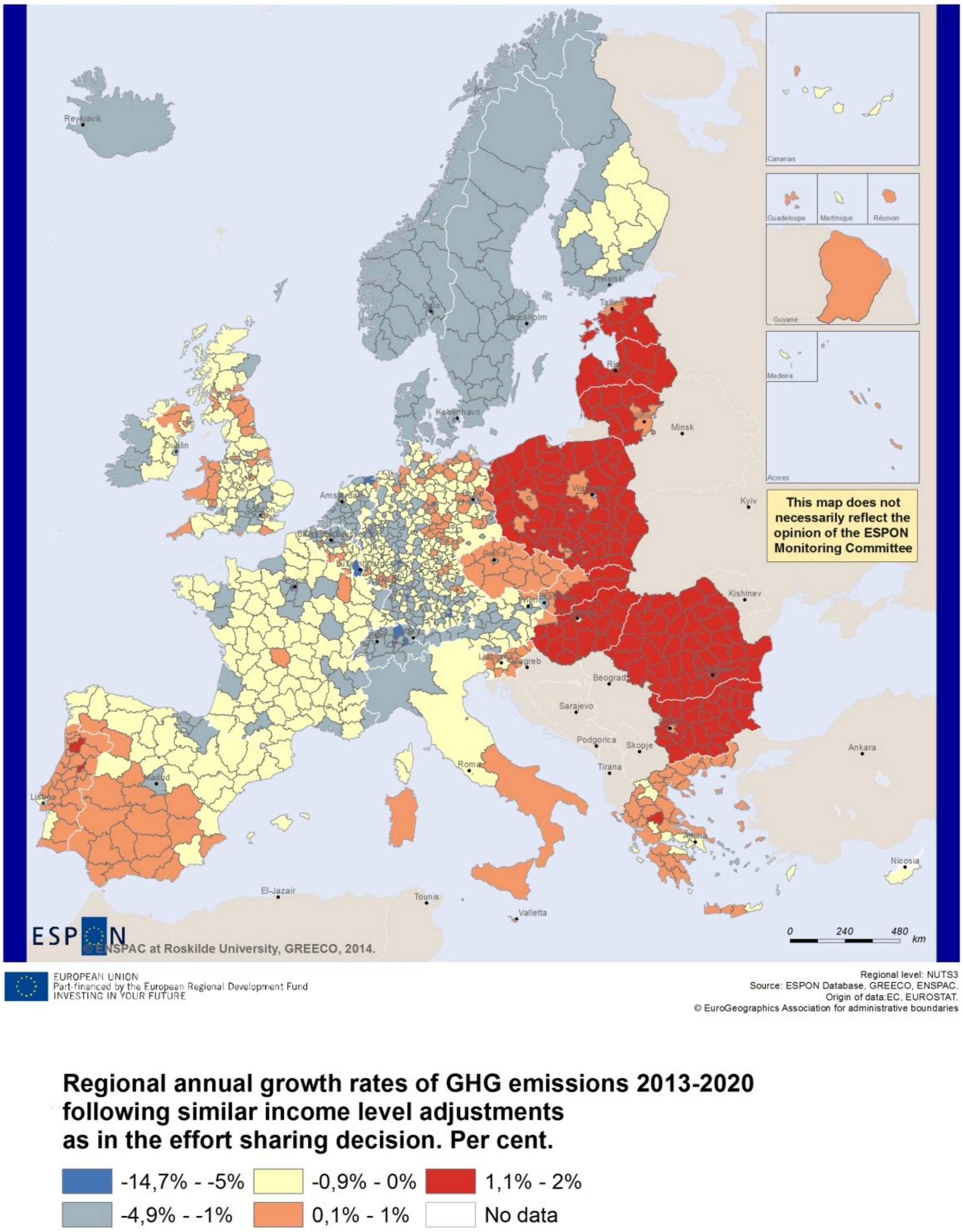
Regional economies may also achieve economic gains from advancing the decarbonisation targets relative to the EU 20-40-80 targets. The Covenant of Mayors is an EU initiative uniting municipalities and cities with ambitions of being on the more ambitious side of the EU targets (Covenant of Mayors, 2013). It now includes more than 5000 signatories. The city of Copenhagen, for instance, have decided to become the first carbon neutral capital by 2025 (Copenhagen Municipality (Københavns Kommune), 2013).

The member-state budgets are not allocated further to NUTS2 or NUTS3 regions. This would also be difficult as the regions play different roles in the division of labour inside the country and in the EU. Blast furnaces and paper mills are, for instance, not located in the City of London and the large bank head quarters not in rural areas. The energy requirement associated with this division of labour should be recognised in a regional budget allocation.

Nevertheless, it could be useful to have benchmark-figures reflecting the rate of non-ETS emission rate reduction typical for economies with the income level of the region. Regions must also be expected to differ substantially more by ETS sector than by non-ETS sector emissions.

An alternative approach to quantifying emission budgets of sub-national territorial units is the approach taken by the Covenant of Mayors. Signing the covenant commits the town, city or municipality to reduce CO_2-emissions from its territory by at least the 20% by 2020 required for the EU as a whole (Covenant of Mayors, 2013). This is, however, easier to do for a region in economic and population decline than for a growth region. Thus, the regional emission-budget should be adjusted accordingly.

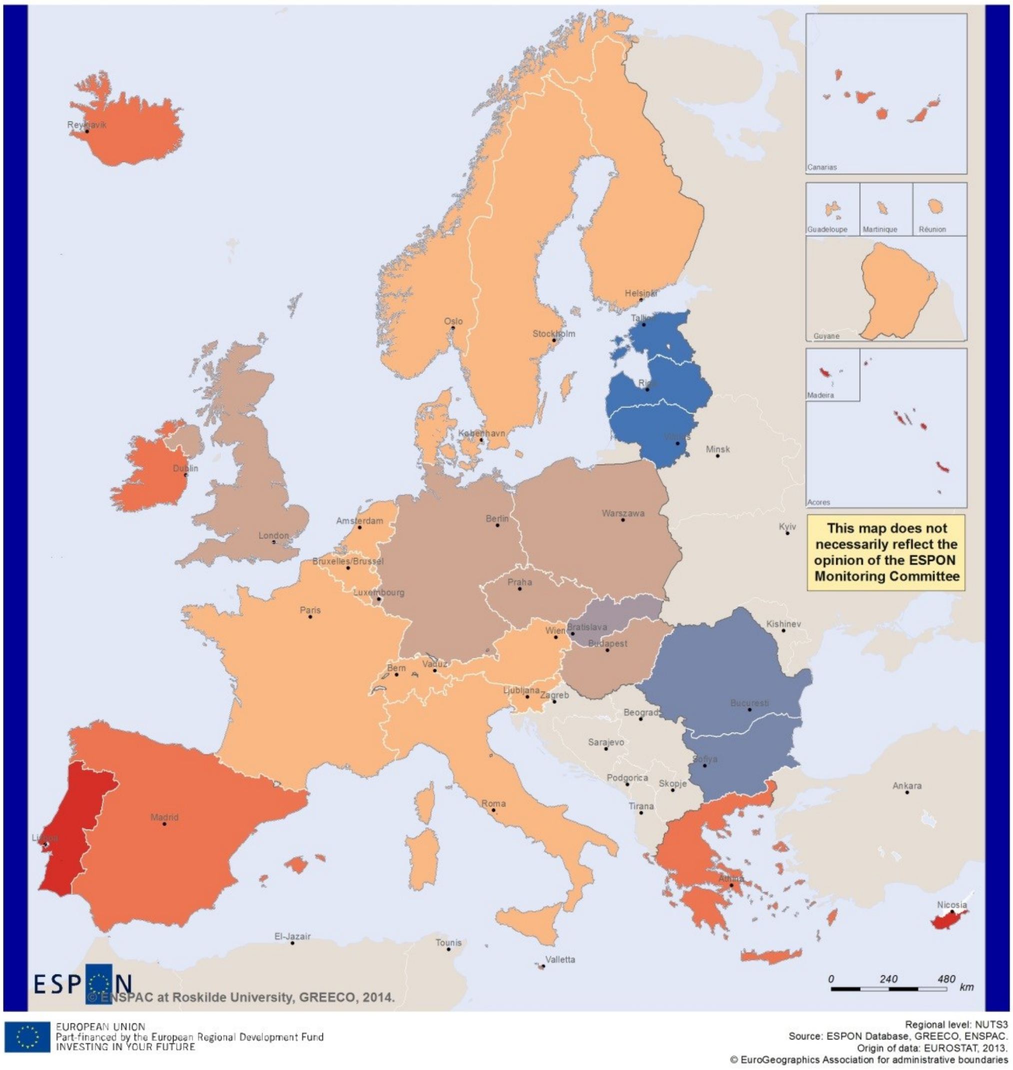
The conclusion is, that a useful regional benchmark figure for non-ETS emissions would be the income-adjusted rate of emission change (cf. figure 6) plus the rate of population change. Map 7 below shows the income-adjusted rate of emission change by NUTS3 regions following the statistical pattern of figure 6.



Map 7. Benchmark rates of change for budgets for non-ETS GHG-emissions from NUTS3 regions 2013-20. Regionally differentiated by GDP per capita following the effort sharing principle of differentiation. Percent per year.

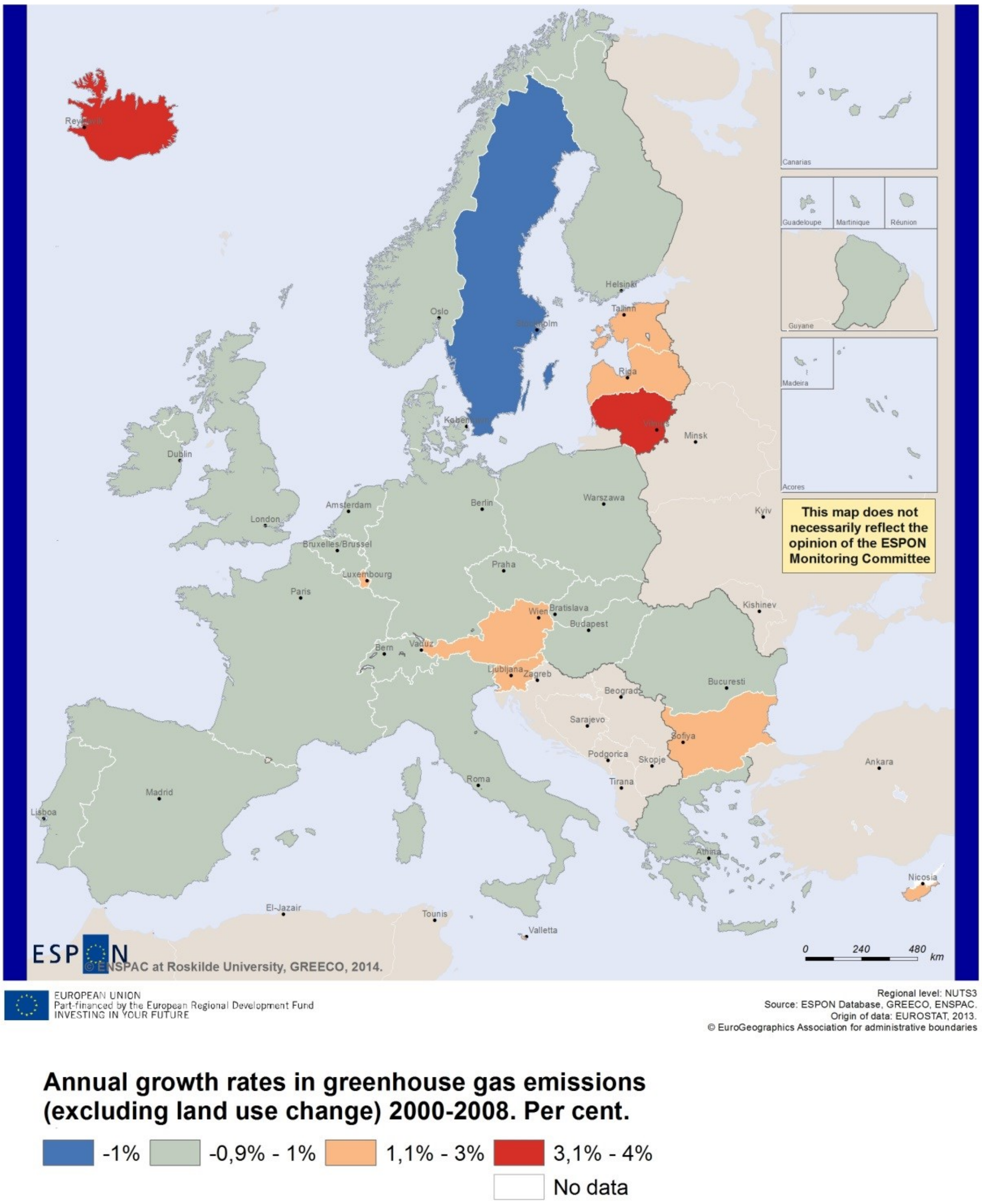
The regional income-adjusted benchmark rates follow the same pattern as that of figure 6. In addition, the emission budgets of high-income regions in countries with more average income levels would be reduced at a faster pace following these income-adjustments.

The whole idea of regional emission budgets or targets, however, requires that energy statistics is collected with a regional coverage that enables statistics at least by NUTS2 regions, but preferably at as high a spatial resolution as possible. At the present, data on the use of fossil fuels at a level of detail enabling regional statistics are only collected in some countries. The predictions shown in



Annual growth rates in greenhouse gas emissions (excluding land use change) 1990-2000. Per cent.

-9,2% - -7%	-4,9% - -3%	-0,9% - 1%	3,1% - 5%
-6,9% - -5%	-2,9% - -1%	1,1% - 3%	No data



map 4 and map 5 are in the nature of the case not useful as indicators of the actual emissions.

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Annex 3. Final energy consumption (FEC)

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1. Introduction

The Energy use of this paper is to document the method used in the collection of the "final energy consumption dataset"[1]. The documentation includes

- the EUROSTAT source and type of national (NUTS0) level final energy consumption data
- national source and type of regional final consumption data used to "regionalise" the EUROSTAT NUTS0 level data to NUTS2 level
- adjustment algorithms to fill in gaps and irregularities in the national source regional data

For reasons of clarity each type of regional source data will be labelled according to the label given in the actual document. This will allow further investigation of the method and ensure easy access to the source.

The database includes data between 2000 and 2010, but the availability of 2010 data was at the time of data collection still very limited.

Availability of data at the NUTS3 level is also very limited and this database thus only involves data between NUTS0 and NUTS2.

A big challenge with the collection and handling of these data was the often inexplainable difference between the sum of the national source regional data and the EUROSTAT NUTS0 level data.

Thus a margin of around +/- variations was deemed acceptable, as long as the yearly development correlated.

[1] The dataset is available as an appendix to this paper called ENERGY_CONSUMPTION_NUTS1-3_GREECO.XLSX

2. Methodology

The dataset is based on the EUROSTAT energy statistical database on quantities of energy supply and consumption of all energy commodities in all EU countries (nrg_100a). The final energy consumption is reported according to the consuming sector. These sectors are aggregated in three main sectors: *Transport*, *residential* and *production* as shown in Table 5 for the EU27 as a whole.

Table 5. Final energy consumption in EU27 by consuming sector, 2000-2010 (EJ and %).

EJ	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Production	20	21	21	22	22	22	22	21	21	19	20
Residential	12	13	12	12	13	13	13	12	12	12	13
Transport	14	14	15	15	15	15	16	16	16	15	15
Transport incl. int bunker	16	16	16	17	17	17	18	18	18	17	17
Final energy consumption	47	48	47	49	50	50	50	49	49	47	48
Int bunker	2	2	2	2	2	2	2	2	2	2	2
% of final energy consumption											
Production	43%	44%	43%	44%	44%	44%	43%	43%	43%	41%	42%
Residential	26%	26%	26%	25%	25%	25%	25%	24%	25%	26%	27%
Transport	30%	30%	31%	30%	31%	31%	31%	33%	32%	33%	32%
Transport incl. int bunker	34%	34%	35%	34%	35%	35%	36%	37%	37%	37%	36%
Int bunker	4%	4%	4%	4%	4%	4%	4%	5%	5%	4%	4%

Source: (EC. 2012).

Table 5 shows the total final energy consumption in the EU27 as the sum of the final energy consumption of the three energy consuming sectors. For completeness it also includes sales of bunker fuels for international maritime transport in the EU27 ports. International maritime transport is also final energy consumption, but it is excluded from the statistics on final energy consumption due to the convention of accounting energy consumption by the territory at which it takes place. Due to the difficulties of assigning international transport activity to a single country – and even more so a single region – it is not included in the national accounts and is similarly excluded from the regional accounts below.

Comparable data as those in Table 5 are available for all EU countries, Iceland, Norway and Switzerland. These national or NUTS0 level data are distributed on NUTS2 regions by means of the regional level energy statistics of EUROSTAT and the national statistical institutes or other providers of energy statistics at the regional level in the individual countries. The small deviations that are observed are eliminated by deriving a distribution key for the regional distribution and multiplying it with NUTS0 level figure.

For a few countries the regional shares of energy consumption can be found in the EUROSTAT dataset "Energy: primary production and final consumption by NUTS 2 regions - 1 000 tonnes of oil equivalent (env_rpep)" (20.05.12 update). For many countries however, there are wide data gaps or serious deviations from the statistics presented in Table 5. Thus, these data have been used to regionalise national final energy consumption only in cases where the average deviation from the national total was not larger than 10%.

For most of the countries, regional data have been collected from national statistical institutes and other national data sources.

3. Regionalisation of final energy consumption in the individual countries

Austria

Energy use	Distribution key	NUTS	Missing years
Total	Sum	2	
Residential	EUROSTAT env_rpep	2	
Transport	EUROSTAT env_rpep	2	
Production	EUROSTAT env_rpep	2	

Belgium

NUTS 1 data was extracted from the individual regions and used as the distribution key.

Energy use	Distribution key	NUTS	Missing years
Total	Sum	1	
Residential	Regional authority data	1	

Transport	Regional authority data	1	
Production	Regional authority data	1	

Brussels

Intitut Bruxellois pour la Gestion de l'Environnement - IBGE

http://documentation.bruxellesenvironnement.be/documents/Bilan_energetique_RBC_2009_FR.PDF?langtype=2060

http://documentation.bruxellesenvironnement.be/documents/Bilan_energie_RBC_2010_FR.PDF

Flanders

Energie- en milieu-informatiesysteem voor het Vlaamse Gewest (EMIS)

http://www.emis.vito.be/energiebalans

http://www.emis.vito.be/sites/default/files/pages/1125/2012/balansen_1990-2011.xlsx

Wallonia

Portail de l'énergie en Wallonie

http://energie.wallonie.be/fr/bilan-energetique-wallon.html?IDC=6288

http://energie.wallonie.be/fr/2009.html?IDC=7491

Bulgaria

Energy use	Distribution key	NUTS	Missing years
Total			
Residential	EUROSTAT env_rpep	2	2009
Transport			
Production			

Cyprus

No regional distribution needed since NUTS 2 equals NUTS 0

Czech Republic

The national statistical office of Czech Republic provides regional data on energy consumption 2008-2010 (regional statistical yearbooks), but they don't allow for derivation of the final energy consumption.

http://www.czso.cz/eng/redakce.nsf/i/summary_data_on_the_czech_republic

Denmark

Energy use	Distribution key	NUTS	Missing years
Total	Sum	2	2000-06
Residential	Residential: Remainder of regionalised household energy consumption.	2	2000-06
Transport	Consumer expenditure survey, transport fuel expenditure and regionalised gross inland energy consumption in the transport and trade branch	2	2000-06
Production	Production activities other than transport: Remainder of regionalised gross energy consumption in production	2	

(Danish Energy Agency - Energistyrelsen. 2013)

(Region Syddanmark. 2013)

(Danmarks Statistik. Statistics Denmark2013)

Estonia

No regional distribution needed since NUTS 2 equals NUTS 0

Finland

Data on regionalised consumption of electricity and district heating as well as energy consumption of industries have been localised, but they did not suffice for regionalising final energy consumption.

France

Energy use	Distribution key	NUTS	Missing years
Total	Regional energy use statistics	2	2000, 01, 03
Residential	Regional energy use statistics	2	2000, 01, 03

Transport	Regional energy use statistics	2	2000, 01, 03
Production	Regional energy use statistics	2	2000, 01, 03

Energy consumption in the overseas regions is not covered by the standard energy statistics. Some very rough estimates based on the very few consistent figures that are available was used in the accounting framework, but they are not adequate for use in the analysis of energy consumption in these departments.

(Ministère de l'Écologie, du Développement Durable et de l'Énergie, Commissariat général au Développement durable. 2013)

Germany

Energy use	Distribution key	NUTS	Missing years
Total	Regional energy use statistics	1	2009
Residential			
Transport	Regional energy use statistics	1	2009
Production			

The final energy consumption in a Hamburg (2000-02) and in Niedersachsen (2001, 2003, 2005, 2007, 2009) are interpolated with reference to the energy consumption change in similar lander.

(Länderarbeitskreis Energiebilanzen. 2013)

Greece

No regional data found

Hungary

Energy use	Distribution key	NUTS	Missing years
Total			
Residential	EUROSTAT env_rpep	2	
Transport			
Production	EUROSTAT env_rpep	2	

Iceland

No regional distribution needed since NUTS 2 equals NUTS 0

Ireland

No regional data found

Italy

Energy use	Distribution key	NUTS	Missing years
Total	Sum	2	2009
Residential	Regional energy use statistics	2	2009
Transport	Regional energy use statistics	2	2009
Production	Regional energy use statistics	2	2009

(ENEA. 2013)

Latvia

No regional distribution needed since NUTS 2 equals NUTS 0

Liechtenstein

(Landesverwaltung Fürstentum Liechtenstein. 2013)

Lithuania

No regional distribution needed since NUTS 2 equals NUTS 0

Luxembourg

No regional distribution needed since NUTS 2 equals NUTS 0

Macedonia

No regional distribution needed since NUTS 2 equals NUTS 0

Malta

No regional distribution needed since NUTS 2 equals NUTS 0

Netherlands

No regional data found

Norway

Energy use	Distribution key	NUTS	Missing years
Total	Regional energy use statistics	2	2000-04
Residential	Regional energy use statistics	2	2000-04
Transport	Regional energy use statistics	2	2000-04
Production	Regional energy use statistics	2	2000-04

(Statistisk Sentralbyrå. Statistics Norway2013)

Poland

Energy use	Distribution key	NUTS	Missing years
Total	Regional energy use statistics	2	2000-05
Residential	Regional energy use statistics	2	2000-05
Transport	Regional energy use statistics	2	2000-05
Production	Regional energy use statistics	2	2000-05

The regional energy use statistics was converted to TJ. The total final energy use indicator were derived by excluding the energy consumption of the conversion sector for each energy commodity in each region. Energy consumption by households and non-energy productive activities was extracted and formed distribution keys for residential and production use of energy. Use of energy for transport was derived as the residual.

(Główny Urząd Statystyczny (Central Statistical Office). Główny Urząd Statystyczny2013)

Portugal

Energy use	Distribution key	NUTS	Missing years
Total	Regional energy use statistics	1	2000-06
Residential			
Transport			
Production			

(Instituto nacional de estatistica (Statistics Portugal) 2012)

Romania

No regional data found

Slovakia

No regional data found

Slovenia

No regional data found

Spain

The final energy consumption by fuel is calculated by the Statistical Institute of Spain along with a statistics on regionalised energy expenditure. The energy expenditure data was used as the distribution key to regionalise the final energy consumption data.

Regionalised data on final energy consumption for production Energy uses are included in the EUROSTAT regionalised energy statistics, but they are inconsistent with the national level data.

(Instituto Nacional de Estadística (National Statistics Institute). 2013)

Sweden

Energy use	Distribution key	NUTS	Missing years
Total	Regional energy use statistics	2	2005-09

Residential	Regional energy use statistics	2	2005-09
Transport	Regional energy use statistics	2	2005-09
Production	Regional energy use statistics	2	2005-09

For 2005-09 the dataset is characterised by multiple gaps due to confidentiality concerns.

(Statistiska Centralbyrån (Statistics Sweden). 2013)

Switzerland

No regional data found

Turkey

No regional data found

United Kingdom

Energy use	Distribution key	NUTS	Missing years
Total	Regionalised energy use statistics	2	2000-04
Residential	Regionalised energy use statistics	2	2000-04
Transport	Regionalised energy use statistics	2	2000-04
Production	Regionalised energy use statistics	2	2000-04

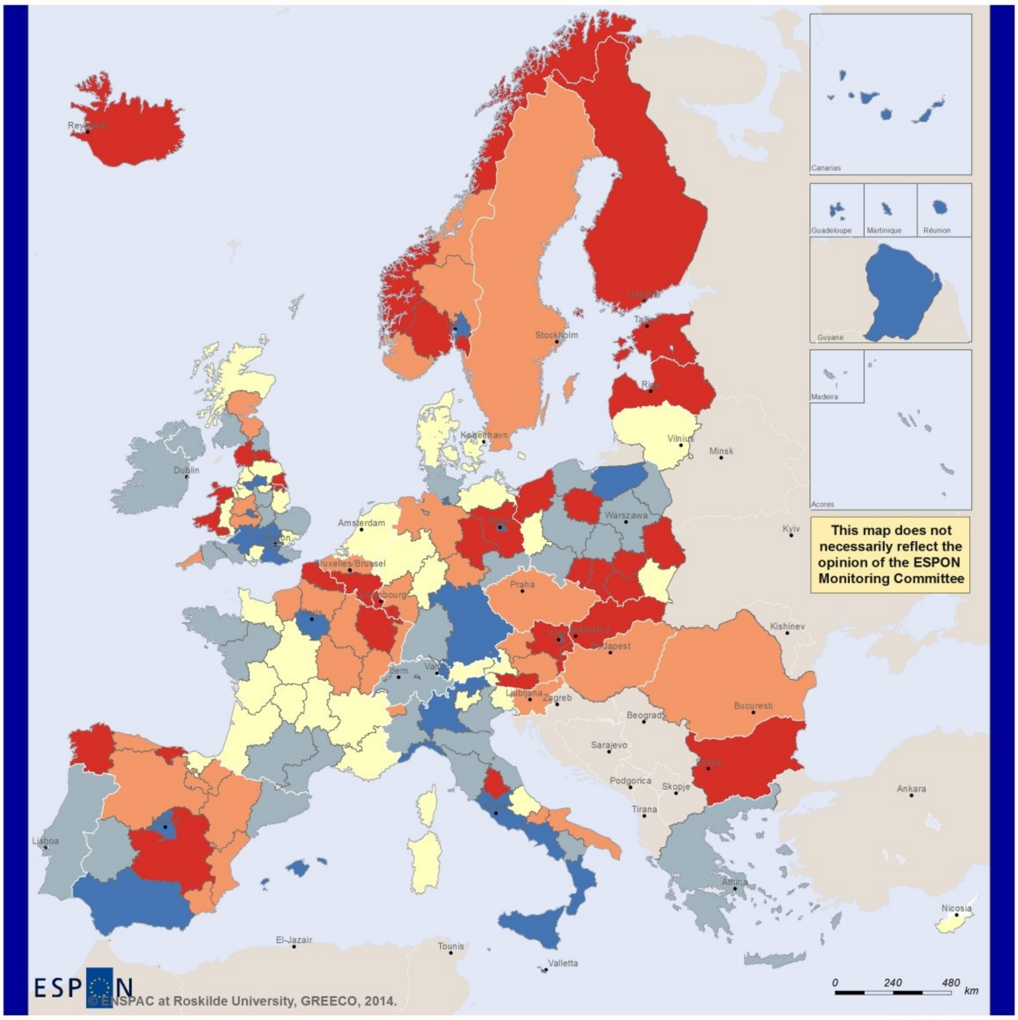
The energy accounts are based on LAU1 level data by fuel.

(Department of Energy and Climate Change (DECC). 2013)The original database is split into LAU1 regions and into energy carriers as well as sectors.

To calculate the NUTS values, the LAU1 values where aggregated according to their LAU code and to find total values in each region, the different carriers where equally aggregated.

4. The final energy consumption dataset

Based on the above data, a partly regional and partly national level dataset has been generated. It covers 2000-09 with varying degrees of regional detail. The results are shown below.



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Regional level: NUTS2/1/0
Source: ESPON Database, GREECO, ENSPAC.
Origin of data: EUROSTAT, Nstional staitistical institutes, 2013r
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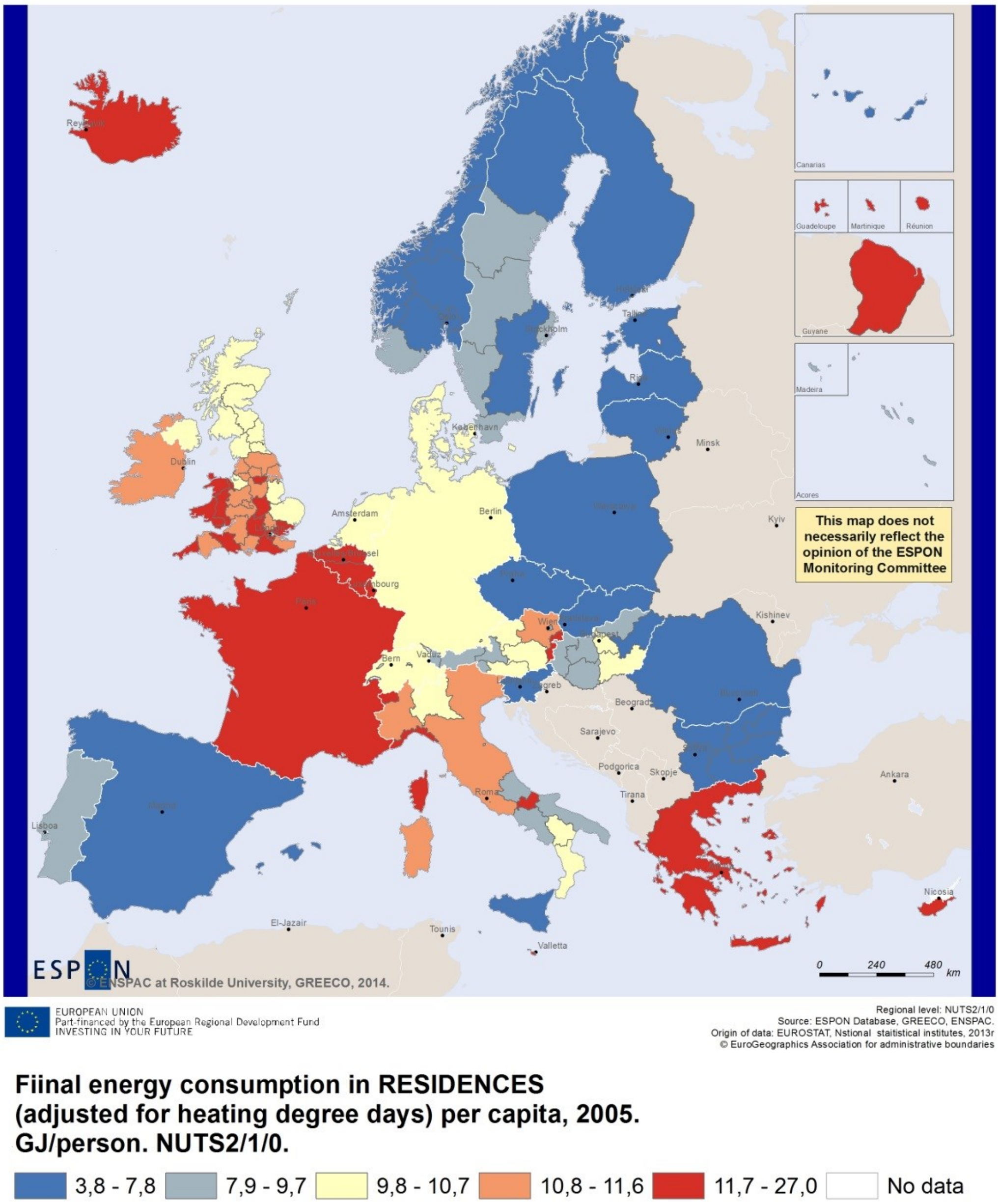
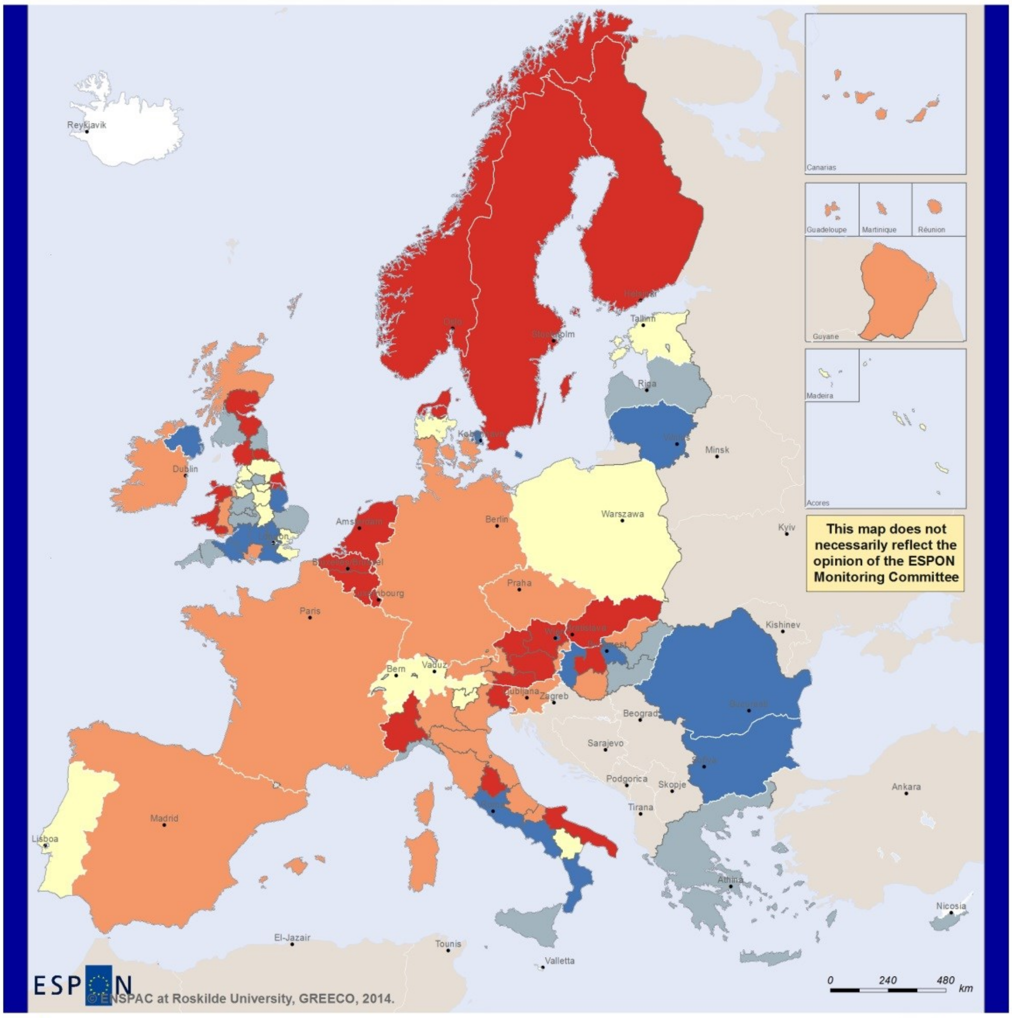
Total final energy consumption per GDP, 2005.
MJ/EURO (PPS, 2005). NUTS2/1/0.

1,0 - 3,8 | 3,9 - 4,5 | 4,6 - 5,2 | 5,3 - 6,3 | 6,4 - 24,8 | No data



Map 8. Total final energy use per gross value added (MJ/Euro) and residential final energy use per resident (GJ/person) 2007.

Source: Author’s calculations based on GREECO datasets (Hansen, 2013).



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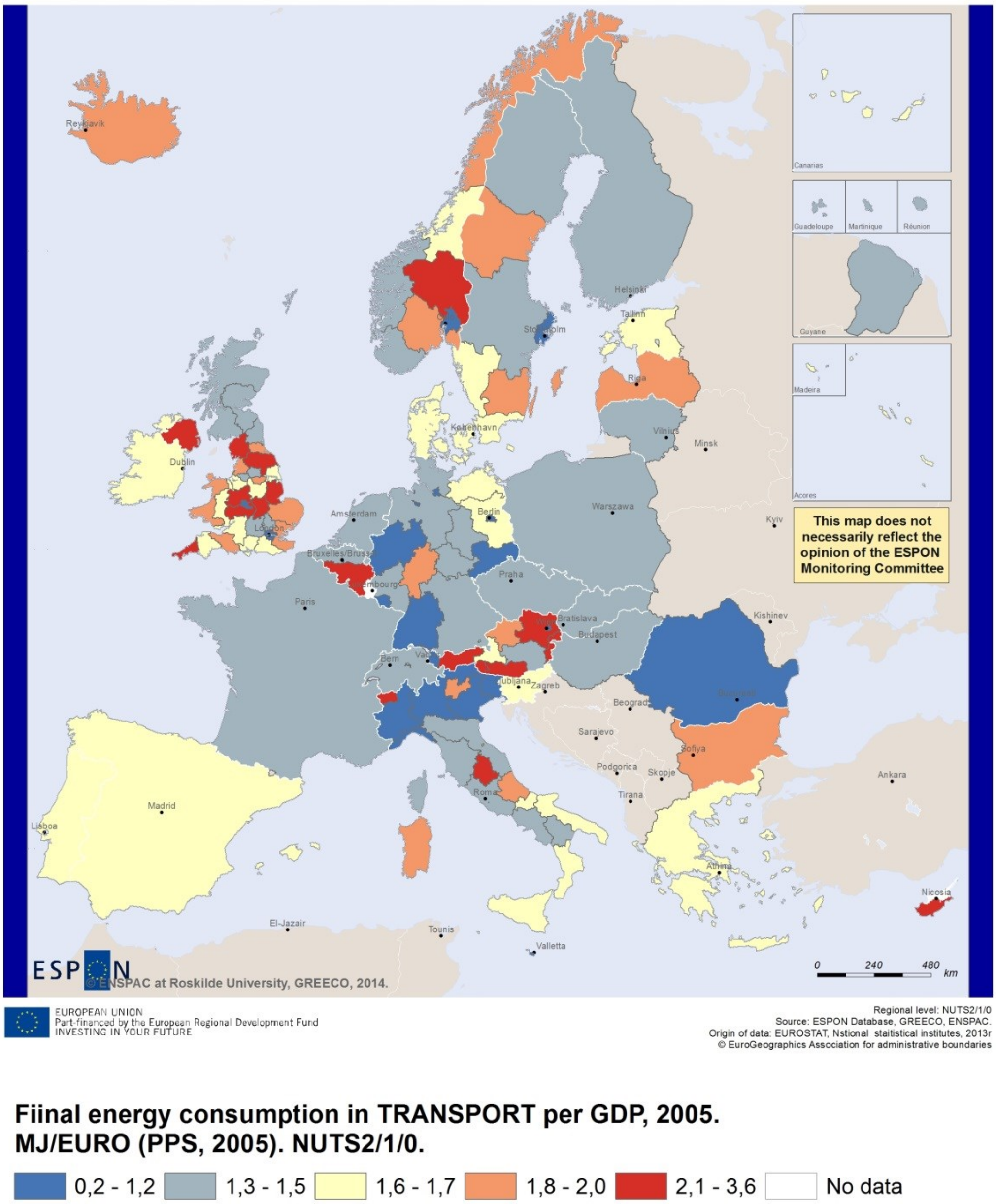
Regional level: NUTS2/1/0
Source: ESPON Database, GREECO, ENSPAC.
Origin of data: EUROSTAT, Nstional staitistical institutes, 2013r
© EuroGeographics Association for administrative boundaries

Final energy consumption in PRODUCTiON per employed person, 2005. GJ/person. NUTS2/1/0.

35 - 59 | 60 - 70 | 71 - 91 | 92 - 116 | 117 - 297 | No data



Map 9. Final energy use in production and in transport per employee (GJ/person) 2007.

Source: Author's calculations based on GREECO datasets (Hansen, 2013).

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Annex 4. GVA and GDP (GVA_GDP)

List of authors

Anders Chr. Hansen

Jacob Byskov

1. Gross Value Added (GVA) and Gross Domestic Product (GDP)

The regionalised GVA and GDP in current prices reflect the aggregate economic value created/income earned in the regions. By definition, the GDP equals GVA plus indirect taxes, net of subsidies. In the regional income accounts published by EUROSTAT the GVA accounts form the basis to which the regionalised revenue of indirect taxes net of subsidies is added. The distribution key for regionalisation follows in some countries the regional distribution of GVA and in other countries the regional distribution of expenditure linked to direct taxation bases though regional input-output accounts (EC, 2012).

EUROSTAT publishes regional GDP and GVA estimates in current prices for most EU countries according to the NUTS 2010 classification. They are subject to major updates in March and minor updates quarterly.

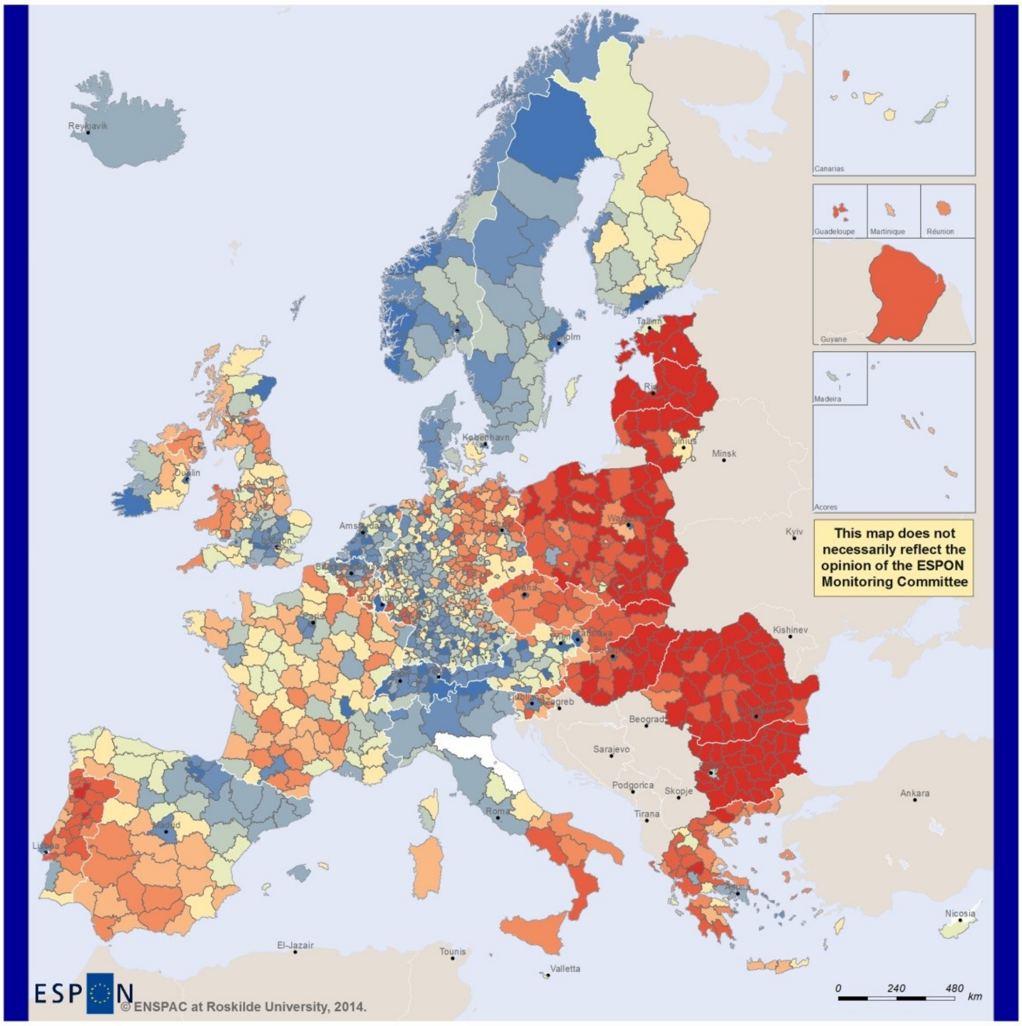
The national accounts data (including GDP, GVA, GDP05, GVA05, GDPPPE, JOB, and RPOP below) are derived from EUROSTAT (EC, 2013a) and supplemented with data from the AMECO database (EC, 2013b).

Data for Iceland are from AMECO (EC, 2013b). The data source for Norway is (Statistics Norway, 2013) and for Liechtenstein (Amt für Statistik Liechtenstein, 2013(VGR2010_tabellen.xls)). Data for Switzerland are provided by (Statistics Switzerland, 2013). For 2008-10 GDP and GVA data, for 2000-05: National GDP and GVA distributed according to “Kantonale Volkseinkommen”. Distribution keys for 2006 and 2007 are interpolated from the 2005 and 2008 regional shares.

2. Gross Domestic Product in purchasing power standards (GDPPPS)

Euros have different purchasing power in different countries due to different price levels. EUROSTAT adjusts for these differences by accounting for GDP in purchasing power standards (PPS).

Due to lack of regional price statistics the regional level GDP and GVA in PPS are computed with national level PPS conversion rates.



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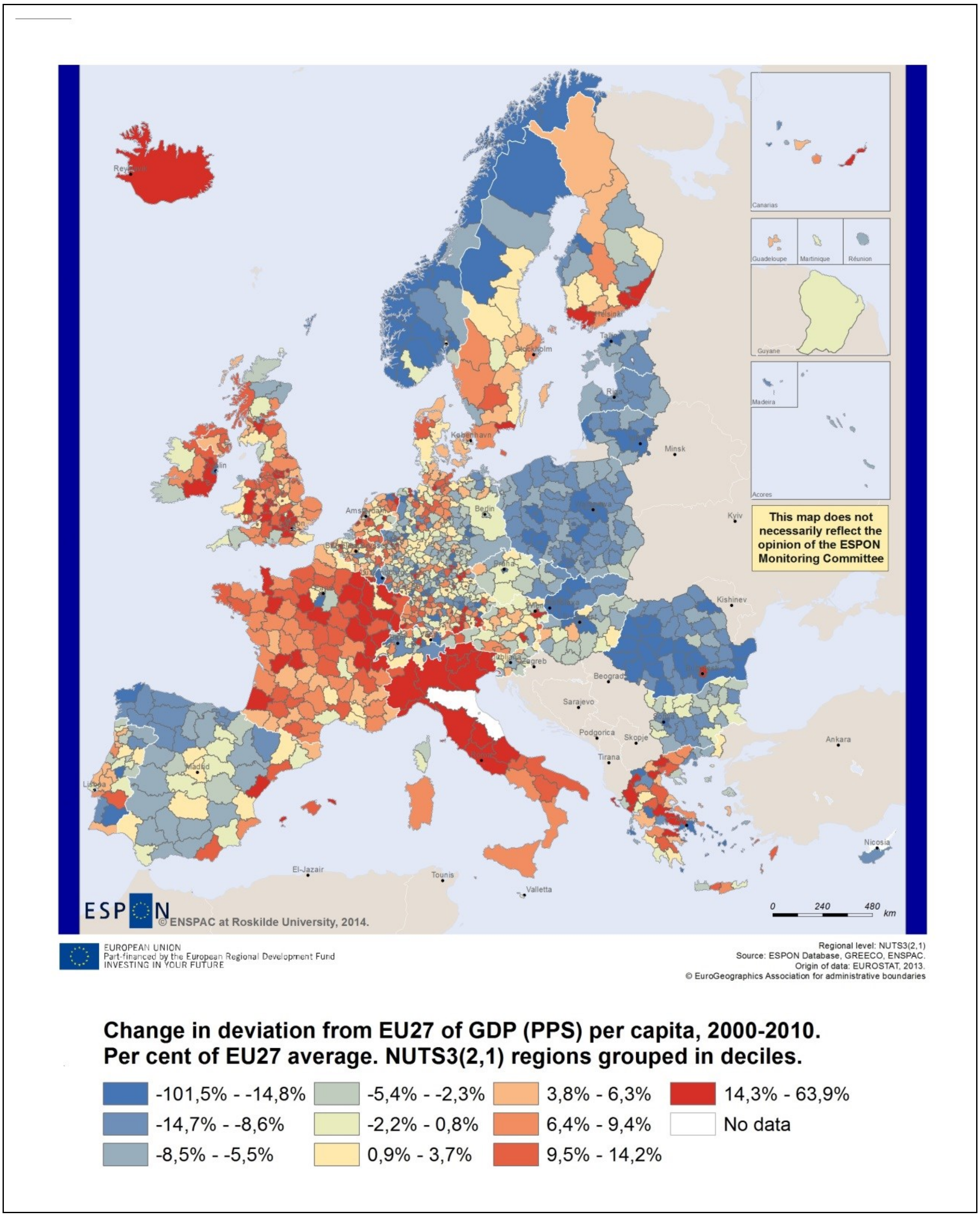
Regional level: NUTS3(2,1)
Source: ESPON Database, GREECO, ENSPAC.
Origin of data: EUROSTAT, 2013.

GDP (PPS) per capita, 2010.
Per cent deviation from EU27 average.
NUTS3(2,1) regions grouped in deciles.

- -87,8% - -52%
- -51,9% - -34,8%
- -34,7% - -25,3%
- -25,2% - -18,1%
- -18% - -10,4%
- -10,3% - -3,2%
- -3,1% - 7,1%
- 7,2% - 17,7%
- 17,8% - 39,9%
- 40% - 493,4%
- No data



Map 10. GDP per capita in European regions. Level 2010 and change 2000-10. Deviation in % from EU27 average GDP per capita measured in PPS.

The position of the European regions relative to the EU27 average of GDP per capita is shown in Map 10. The upper map shows the dispersion of income levels in 2010. The sharpest contrast in average income level is still between the EU 15 and the new member states. Income levels in almost all regions of the new member states were still in 2010 far below EU average. The lower map shows a general pattern of reduced income deviations from 2000 to 2010. Most regions with low income levels have reduced the gap to the EU27 average and the gaps of high income level regions are reduced symmetrically. Still, the regional disparities as to GDP per capita are only slightly reduced in 2010 compared to year 2000. Moreover, some of the regions at the top and some regions at the bottom seem to have increased their distance to the EU27 average.

3. GVA and GDP deflated to the 2005 price level (GVA05 and GDP05)

EUROSTAT does not produce constant price or volume index series for regional GVA and GDP. The dataset GVA and GDP in current prices are deflated to the 2005 price level using the national level implicit GVA and GDP deflators respectively. Thus, these indicators cannot be interpreted as GVA and GDP in 2005 prices, but rather as the real value of regional income generation measured in EUROs with the same purchasing power as they had in 2005 in the country in question.

Estimates of GVA and GDP in 2005-prices are calculated at the national level using a double deflation procedure. Using the same procedure at the regional level would require a level of detail in regional prices and quantities that is not available. The estimates generated here can be interpreted as the purchasing power of regional income generated expressed in.

National level deflators are used because the price statistics required for calculating price indices at regional (NUTS2 and NUTS3) levels is not available. To the extent there has been regional differences in inflation rates through the period, the use of national level deflators will lead to overestimation of real economic growth in regions with a higher rate of inflation and underestimation in regions with lower rates of inflation.

Deflators are derived from EUROSTAT (EC, 2013c) and AMECO (EC, 2013b).

The changes in the economic position of the regions depend on changes in the in the productive capacity per capita of the region. A key indicator is the growth rate of gross value added in constant prices adjusted for changes in the population. **¡Error! No se encuentra el origen de la referencia.** shows the trends in these changes through 2000-10.

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Annex 5. Location Quotients (LQ) and a Regional Competitiveness Index (RCI)

List of authors

Anders Chr. Hansen

1. Location quotients by branches of production (LQ)

The challenge of transforming the economy to a green economy depends on its industrial structure. The regional differences in industrial structure can be quantified with the location quotient, which is a standard indicator of industrial specialisation. The indicator is calculated as

(1) $$LQ_{ri} = (X_{ri} / X_r) / (X_{Ni} / X_N) = (X_{ri} / X_{Ni}) / (X_r / X_N),$$

where X_{ri} is the production of region r in branch i and X_r is the total production of region r. Similarly, X_{Ni} is the production in branch i and X_N the aggregate production of the benchmark economy, in this case the national or the EU27 economy. Similar estimates can be calculated based on employment or exports.

The dataset contains the following location quotients:

Specialisation relative to EU27:

LQ_A_EU

Agriculture, forestry and fisheries share of gross value added generated in the region relative to the same ratio in EU27

LQ_B-F_EU

Industrial branches share of gross value added generated in the region relative to the same ratio in EU27

LQ_C_EU

Manufacturing industries share of gross value added generated in the region relative to the same ratio in EU27

LQ_G-J_EU

Trade, transport and communication share of gross value added generated in the region relative to the same ratio in EU27

LQ_K-N_EU

Financial sector, real estate and professional services share of gross value added generated in the region relative to the same ratio in EU27

LQ_OU_EU

Public and other services share of gross value added generated in the region relative to the same ratio in EU27

Specialisation relative to EU27:

LQ_A_N0

Agriculture, forestry and fisheries share of gross value added generated in the region relative to the same ratio of the national economy

LQ_B-F_N0

Industrial branches share of gross value added generated in the region relative to the same ratio of the national economy

LQ_C_N0

Manufacturing industries share of gross value added generated in the region relative to the same ratio of the national economy

LQ_G-J_N0

Trade, transport and communication share of gross value added generated in the region relative to the same ratio of the national economy

LQ_K-N_N0

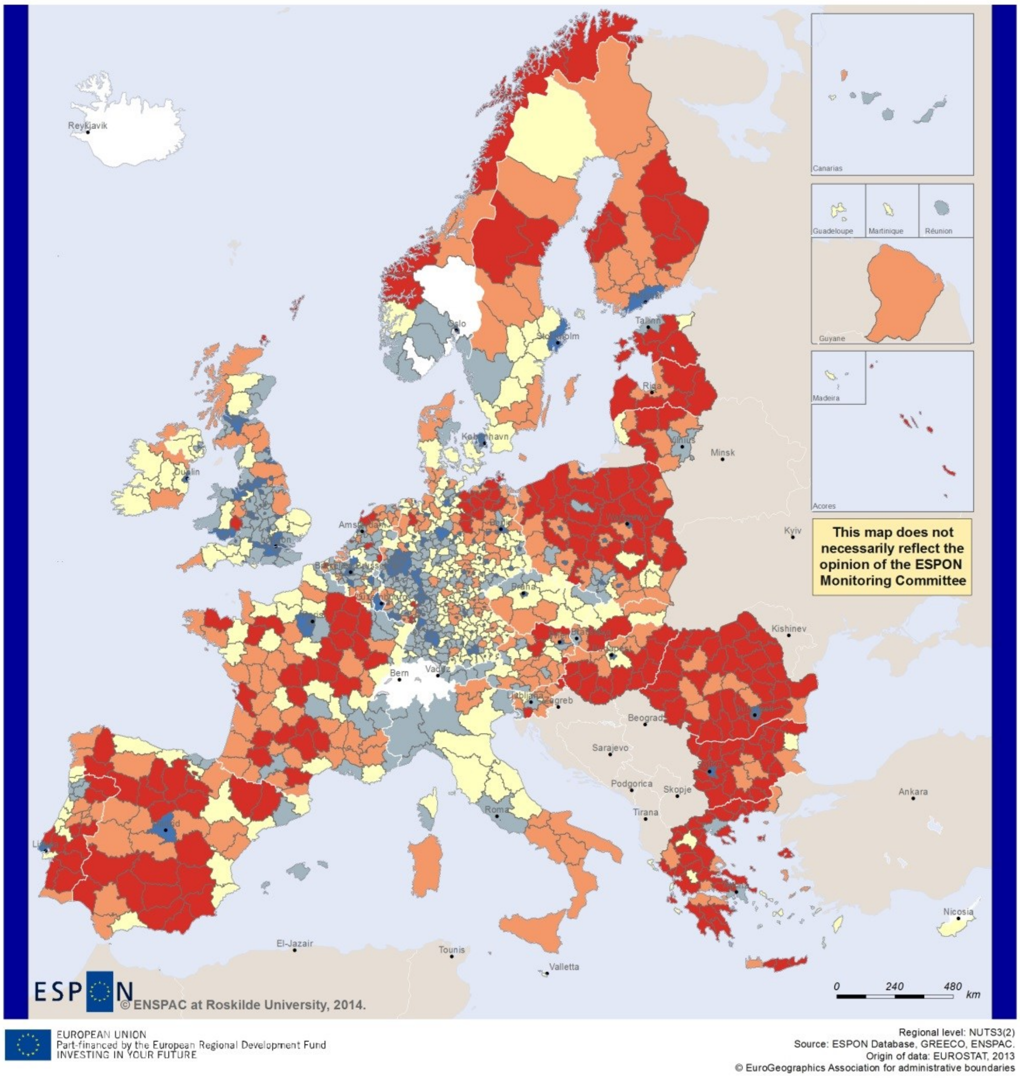
Financial sector, real estate and professional services share of gross value added generated in the region relative to the same ratio of the national economy

LQ_OU_N0

Public and other services share of gross value added generated in the region relative to the same ratio of the national economy

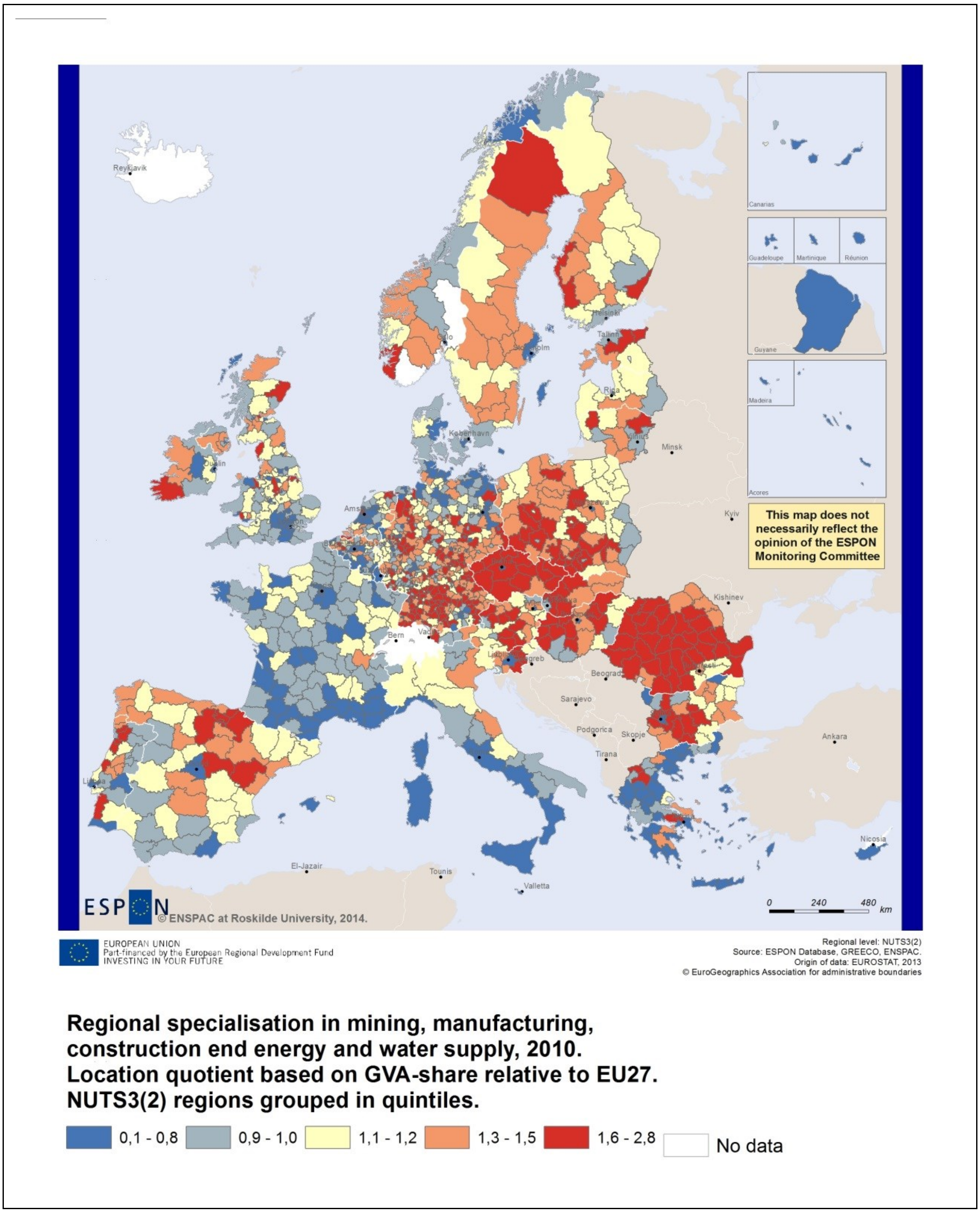
(EC, 2013)

The specialisation patterns of the European regions on “primary and secondary sectors” are shown in Map 11. The regions are more different with respect to the combined agriculture, forestry and fisheries sector than any of the other broad industrial sectors analysed. The share of this sector in the regional GDP is up to 13 times the EU27 average in some regions. Large areas are dominated by strongly specialised regions in the Balkans, the Baltic states and Iberia. The densely populated Fenno-scandian areas and many regions in France are also strongly specialised in this sector. It should, however, be noted that the sector only contributed 1.6% of the gross value added in the EU in 2010. The industry sectors (mining, manufacturing, construction and energy & water supply) contributed 25% and it’s share amounts to 2-3 times the EU average in some regions.

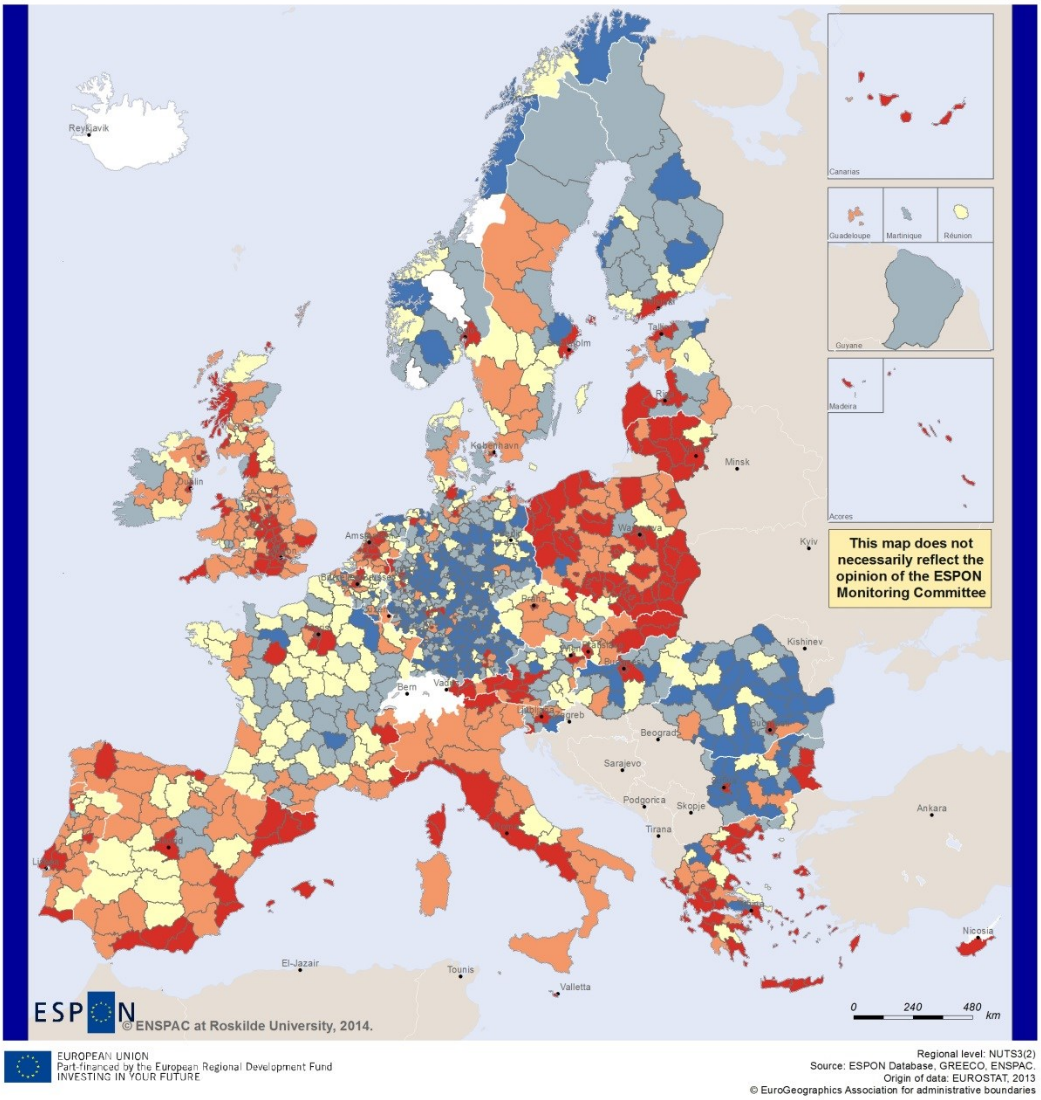


Regional specialisation in agriculture, forestry and fisheries, 2010.
Location quotient based on GVA-share relative to EU27.
NUTS3(2) regions grouped in quintiles.

0,0 - 0,2 | 0,3 - 0,9 | 1,0 - 1,6 | 1,7 - 3,1 | 3,2 - 15,0 | No data

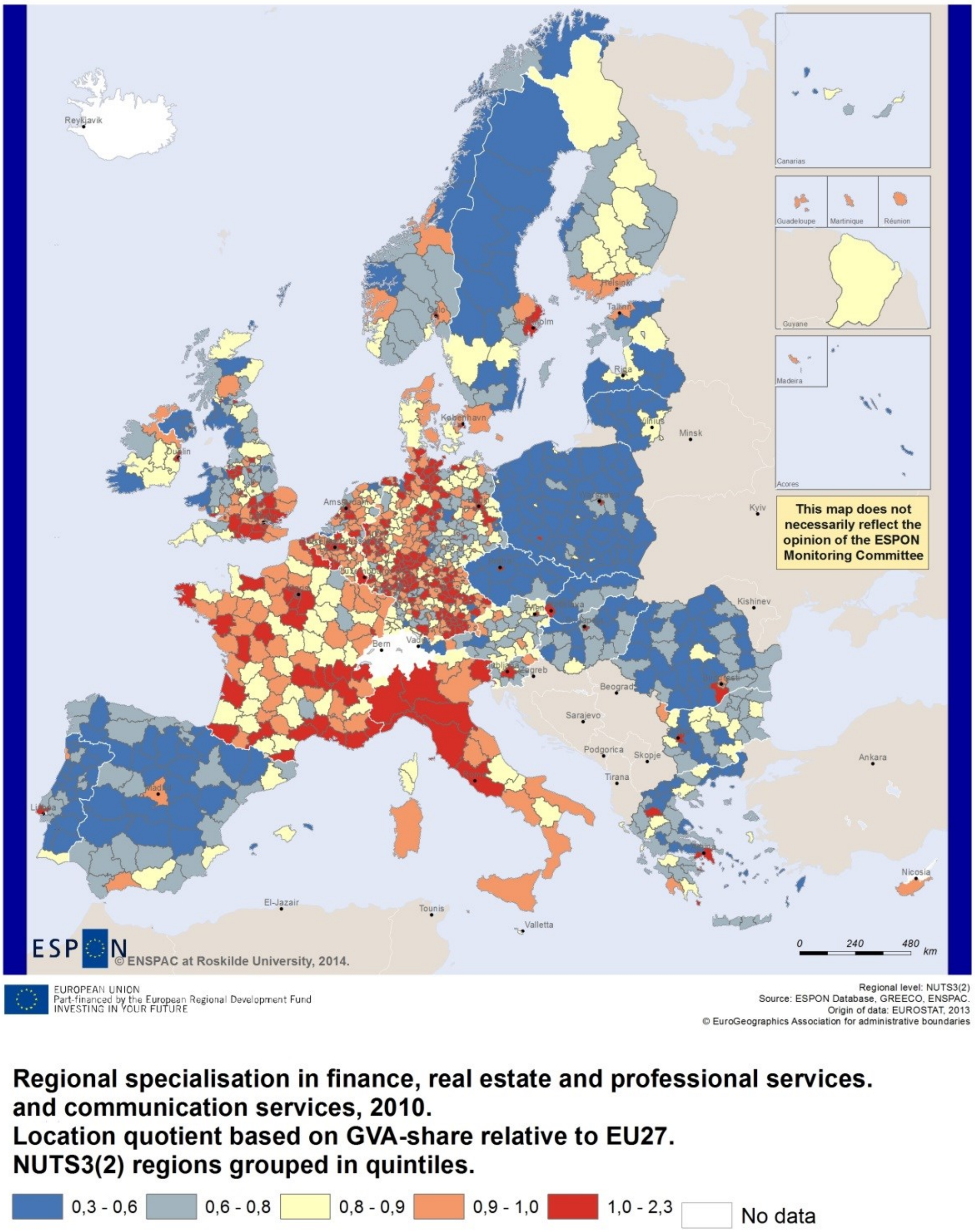


Map 11. Regional specialisation in commodity-producing sectors. Upper map: agriculture, forestry and fisheries. Lower map: Mining, manufacturing, construction and energy & water supply. 2010.



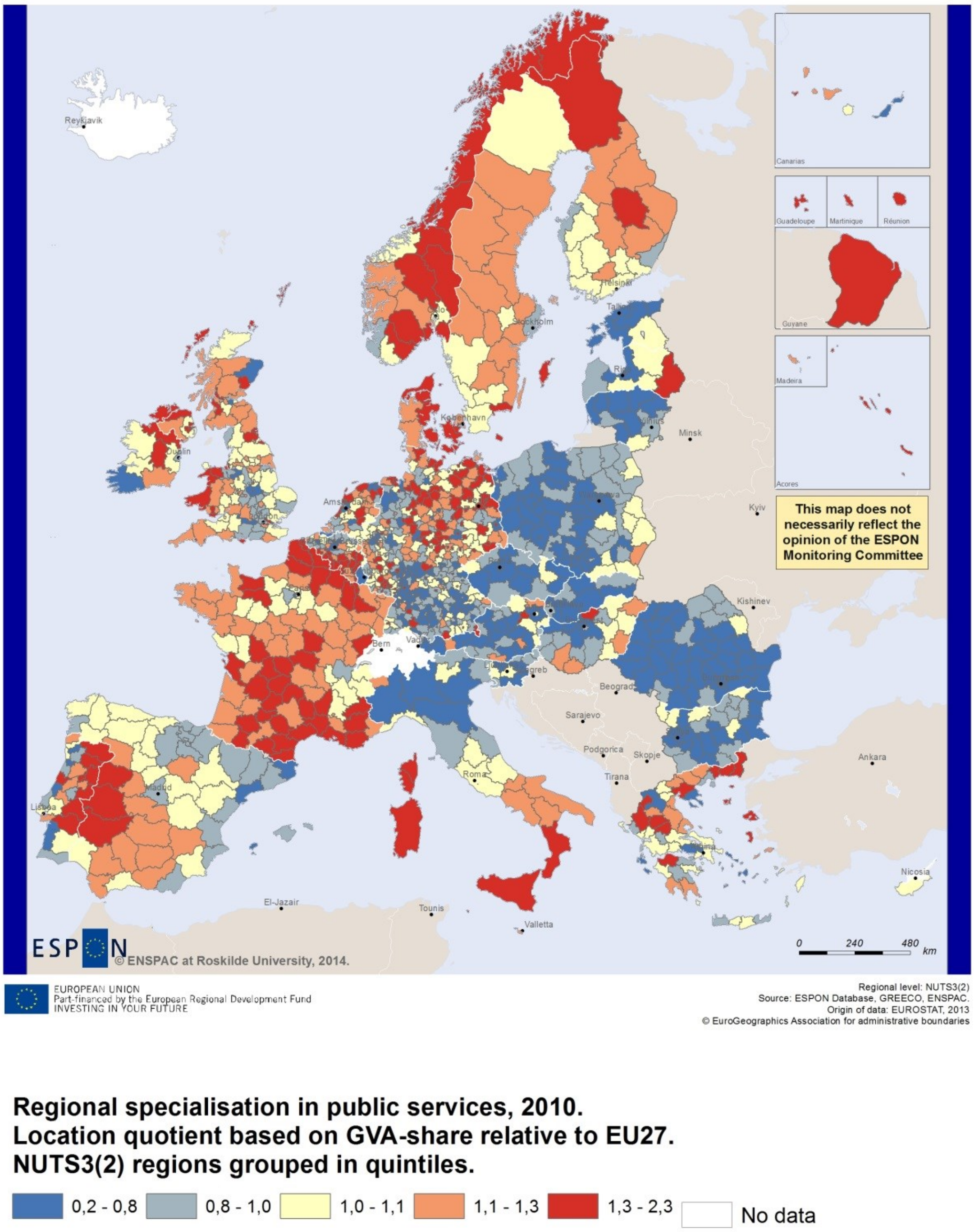
Regional specialisation in trade, transport, food and accomodation and communication services, 2010.
Location quotient based on GVA-share relative to EU27.
NUTS3(2) regions grouped in quintiles.

0,3 - 0,7 | 0,7 - 0,8 | 0,8 - 0,9 | 0,9 - 1,1 | 1,1 - 2,6 | No data



Map 12. Regional specialisation in private service sectors: Upper map: physical services (trade, transport, food & accommodation and communication). Lower map: Intellectual services: Financial, real estate and professional service sectors. 2010.

The private service sector may be grouped in physical and intellectual services. The physical services deal with the distribution, repair, operation etc. of commodities and physical infrastructures. 24% of the EU27 GVA was created in these service sectors in 2010. The intellectual services handle finance, rights, property, consultancy and similar services. They contributed with 26% of the EU27 GVA in 2010.



Map 13. Regional specialisation in the public sectors (upper map) and in manufacturing sectors (lower map). 2010.

The public sectors contributed with 23% of EU27 GVA in 2010. This rate is slightly higher in many regions of the EU15 countries, but generally much lower in regions in the new member states.

The manufacturing industries created 15% of the GVA in the EU27 in 2010. The regional differences in specialisation in manufacturing are wider than differences in specialisation in the service sectors.

2. Regional competitiveness index (RCI)

The regional competitiveness index (RCI) is an experimental index composed by various factors assumed to have a positive impact on the competitiveness of a region or its industries.

An index combining indicators related to competitiveness to a composite index of competitiveness. The sub-indices are grouped in BASIC, EFFICIENCY and INNOVATION pillars, the weights of which differ by development stage classification of the region: Medium, Intermediate and High. The index contains per capita GDP and a number of other sub-indices that are closely correlated to it and is thus closely correlated with the per capita GDP.

The index is thoroughly described in DG for Regional Policy: A New Regional Competitiveness Index: Theory, Methods and Findings.

(Dijkstra et al., 2011)

The data are available in:

http://ec.europa.eu/regional_policy/sources/docgener/studies/xls/2010_competitiveness_rci_data.xls

3. Bibliography

EC, 2013. Gross value added at basic prices by NUTS 3 regions (NACE Rev. 2) [nama_r_e3vab95r2] [WWW Document]. Eurostat Statistics Database. URL http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_r_e3vab95r2&lang=en (accessed 7.23.13).

Annex 6. Waste and recycling (MW)

List of authors

Anders Chr. Hansen

1. Throughput and circular materials flows

The indicator is based on the EUROSTAT statistics on municipal waste. It accounts for the type of treatment of generated waste: Energy recovery, recycling, composting, incineration without energy recovery and landfill deposition.

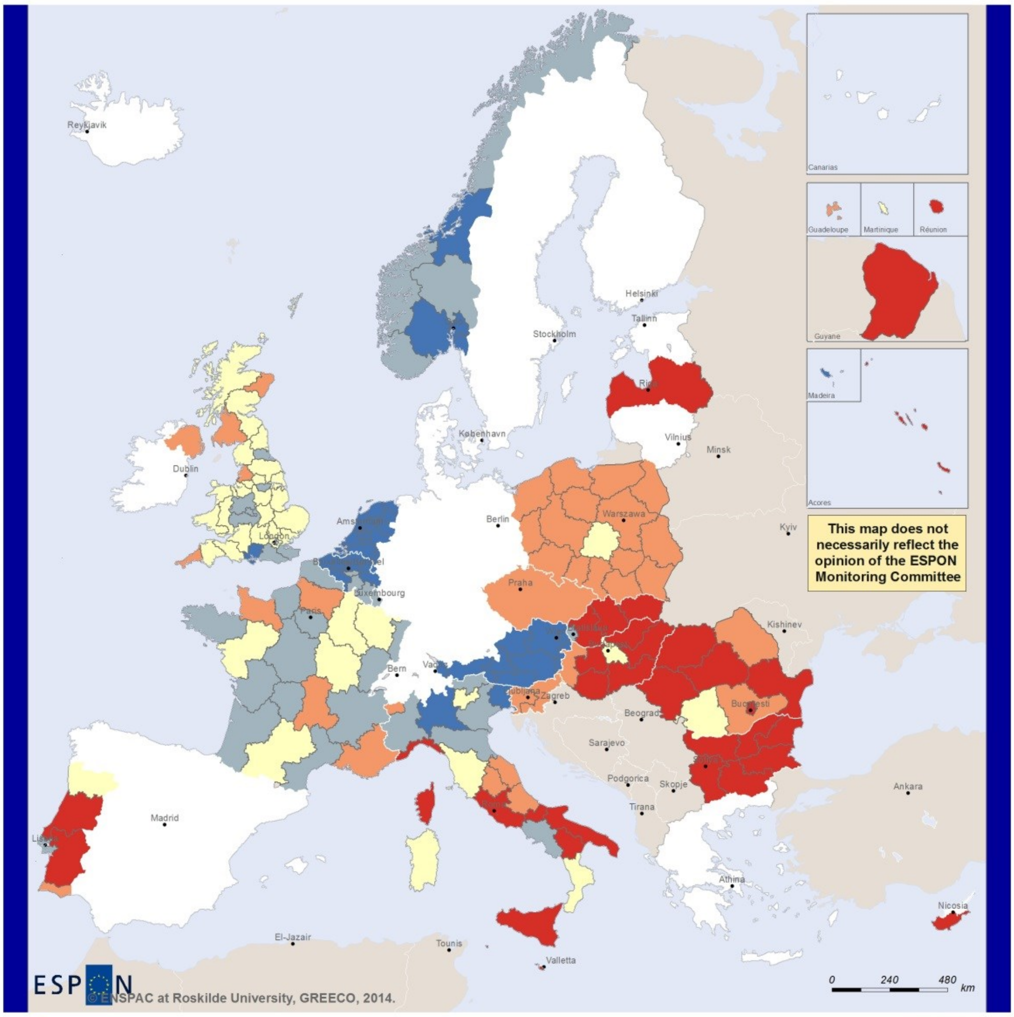
The data included in the data set appears from table 6.

Table 6. Indicators included in the waste dataset.

MWg	*Municipal waste generation growth rate*	*Trend municipal waste grwoth rate 2000-08*
MWRr	*Municipal waste recycling ratio*	*The share of municipal waste recycled, average 2008-09*
MWRrC	*Municipal waste recycling ratio annual change*	*Annual change of municipal waste recycling ratio, average 2000-09*
MWDr	*Municipal waste desposition ratio*	*The share of municipal waste deposited, average 2008-09*
MWDrC	*Municipal waste deposition ratio annual change*	*Annual change of municipal waste deposition ratio, average 2000-09*

The recycling and deposition rates have the best regional coverage in 2008-09. They are showed in map 14.

The domestic material consumption and inter-industrial flows (recycling) outside the municipal waste flows are not covered by comparable regional statistics.



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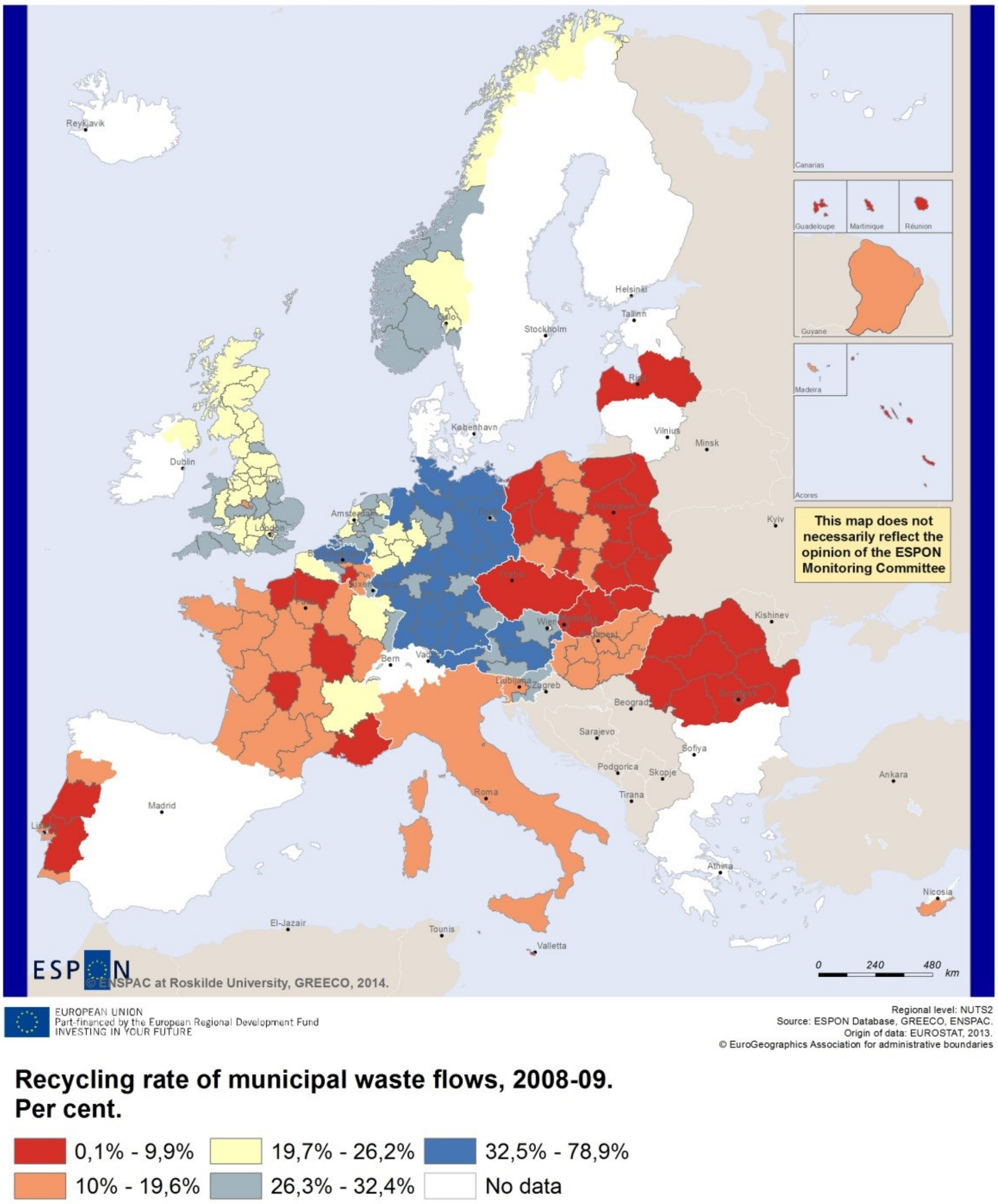
Regional level: NUTS2
Source: ESPON Database, GREECO, ENSPAC.
Origin of data: EUROSTAT, 2013.
© EuroGeographics Association for administrative boundaries

Deposition rate of municipal waste flows, 2008-09.
Per cent.

0,2% - 16,3%
16,4% - 46,5%
46,6% - 59,3%
59,4% - 79,7%
79,8% - 97,7%
No data



Map 14. Municipal waste deposition and recycling shares. Average 2008-2009. Per cent.

Source: Author' s calculations based on EUROSTAT data (EC, 2013).

2. Bibliography

EC, 2013. Generation and treatment of municipal waste (1 000 t) by NUTS 2 regions [env_rwas_gen] [WWW Document]. EUROSTAT Database. URL http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database (accessed 10.10.13).

Annex 7. Green patents (PCT)

List of authors

Anders Chr. Hansen

1. Patent applications

The OECD patent database offers data on all patent applications filed under the international Patent Co-operation Treaty (PCT) and the European Patent Office (EPO) (OECD, 2013). The PCT applications are not really patent applications, but serve the purpose of securing an option to file for patent. The EPO applications are actual applications.

The GREECO dataset includes applications to the EPO classified as environment-related patents according to the International Patent Classification (IPC) codes and the Cooperative Patent Classification (CPC).

The patent applications are split in environment-related and other patents and the environment-related in general environmental management technology and climate and energy technology.

The patent applications are assigned to NUTS3 or NUTS2-regions[2] according to the address of the inventor on the patent application.

The dataset contains the following indicators:

Table 7. Total and green patent applications in the GREECO dataset.

TOT9099	*Total patent applications 1990-99*	*Total patent applications filed 1990-99 to the EPO.*
ENV9099	*Green patent applications 1990-99*	*Green patent applications filed 1990-99 to the EPO.*
AWW9099	*General environment patent applications 1990-99*	*General environmental management (air, water, waste) patent applications filed 1990-99 to the EPO.*
CE9099	*Energy and climate patent applications 1990-99*	*Energy and climate patent applications filed 1990-99 to the EPO. Includes Technologies specific to climate change mitigation, Combustion technologies with mitigation potential (e.g. using fossil fuels, biomass, waste, etc.), Energy efficiency in buildings and lighting andEnergy generation from renewable and*

[2] In the case of Germany to planning-regions that can not be aggregated to a lower level than NUTS1.

		non-fossil sources
TOT0009	*Total patent applications 2000-09*	*Total patent applications filed 2000-09 to the EPO.*
ENV0009	*Green patent applications 2000-09*	*Green patent applications filed 2000-09 to the EPO.*
AWW0009	*General environment patent applications 2000-09*	*General environmental management (air, water, waste) patent applications filed 2000-09 to the EPO.*
CE0009	*Energy and climate patent applications 2000-09*	*Energy and climate patent applications filed 2000-09 to the EPO. Includes Technologies specific to climate change mitigation, Combustion technologies with mitigation potential (e.g. using fossil fuels, biomass, waste, etc.), Energy efficiency in buildings and lighting andEnergy generation from renewable and non-fossil sources*
ENV9099rt	*Green patent share of total 1990-99*	*Green patent share of total filed 1990-99 to the EPO.*
AWW9099rt	*General environment patent share of total 1990-99*	*General environmental management (air, water, waste) patent share of total filed 1990-99 to the EPO.*
CE9099rt	*Energy and climate patent share of total 1990-99*	*Energy and climate patent share of total filed 1990-99 to the EPO. Includes Technologies specific to climate change mitigation, Combustion technologies with mitigation potential (e.g. using fossil fuels, biomass, waste, etc.), Energy efficiency in buildings and lighting andEnergy generation from renewable and non-fossil sources*
ENV0009rt	*Green patent share of total 2000-09*	*Green patent share of total filed 2000-09 to the EPO.*
AWW0009rt	*General environment patent share of total 2000-09*	*General environmental management (air, water, waste) patent share of total filed 2000-09 to the EPO.*
CE0009rt	*Energy and climate patent share of total 2000-09*	*Energy and climate patent share of total filed 2000-09 to the EPO. Includes Technologies specific to climate change mitigation, Combustion technologies with mitigation potential (e.g. using fossil fuels, biomass, waste, etc.), Energy efficiency in buildings and lighting andEnergy generation from renewable and non-fossil sources*

2. Bibliography

OECD, 2013. Patents by regions [WWW Document]. URL /content/data/data-00509-en

Annex 8. Photovoltaic energy potential (PV)

List of authors

Anders Chr. Hansen

1. Photovoltaic energy potential assessment in Europe

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 7. 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.

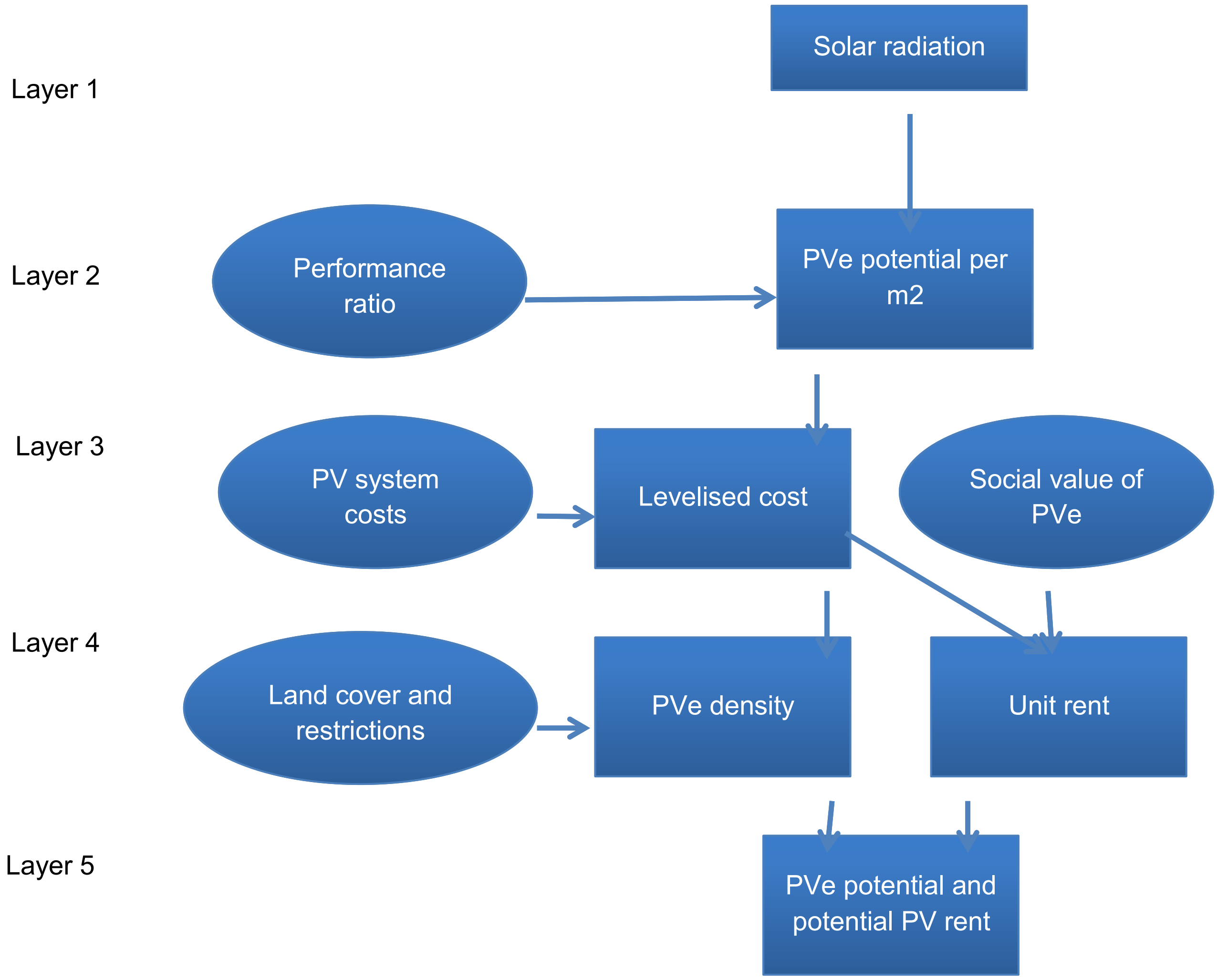


Figure 7. GIS-based progression for the assessment of the potential for photovoltaic electricity generation in Europe

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.

2. Input layer definitions

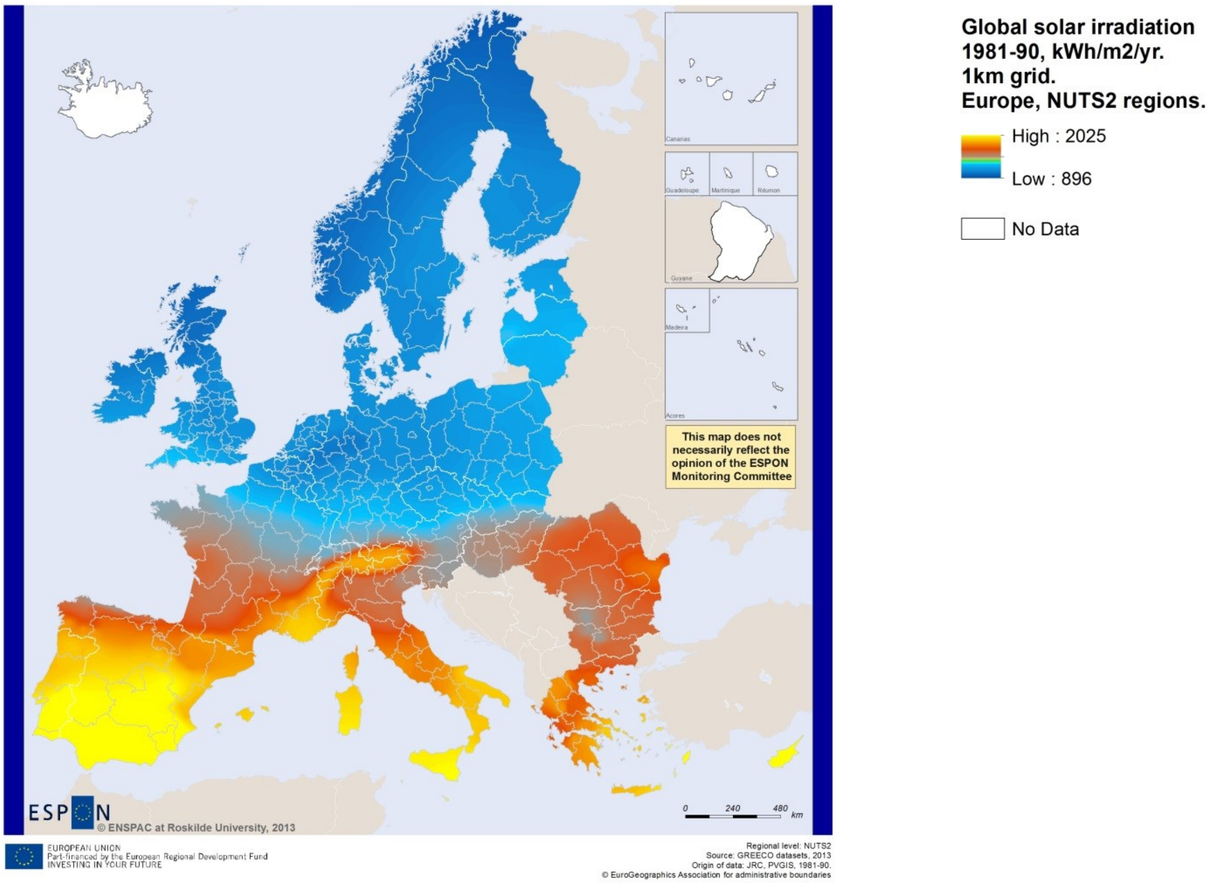
This section provides a specific description of the methodology used in the creation of each individual layer. This includes a specific description of the data involved as well as the uncertainty associated within the calculations of each layer.

2.1. 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 15 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 15. Global irradiation in Europe (kWh/m^2).

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

2.2. PV technology and performance (Layer 2)

The yearly sum of irradiation per m^2 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.

2.3. 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

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

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 **16**.

2.4. 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[3] 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

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

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.

2.5. 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 8**).

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:

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

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 17.

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 8**. 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 8. 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.

2.6. Model overview

Table 9. 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 8**	0	0.3
h	Ratio of PV suitable area to ground floor area	km^2	See **table 8**	0	0.2
j	USPV suitable area	km^2	See **table 8**	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.

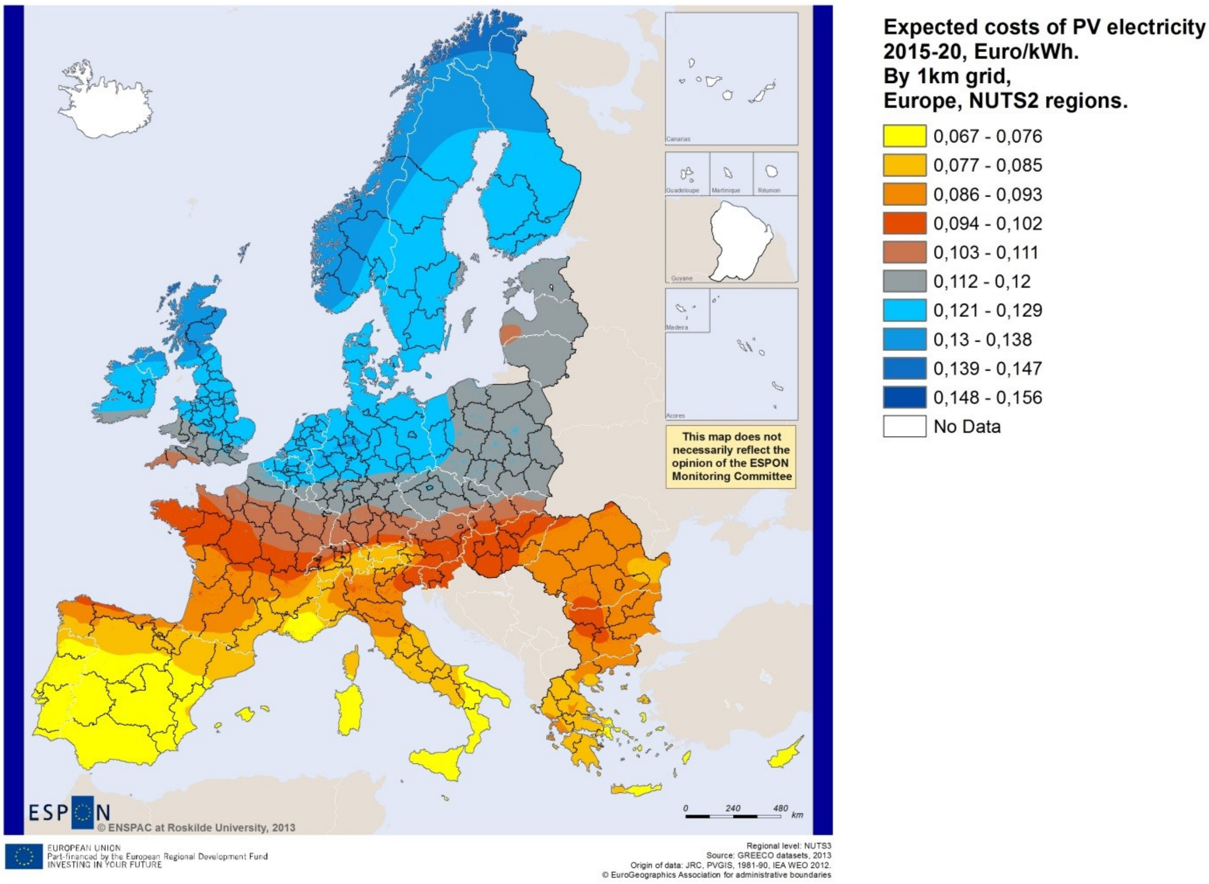
(5) $V = (12\text{-}11)(N_{12} - N_{10}) + (12\text{-}9)(N_{10} - N_{8}) + (12\text{-}7)N_{8}$,

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

3. Results

3.1. PV energy generation costs

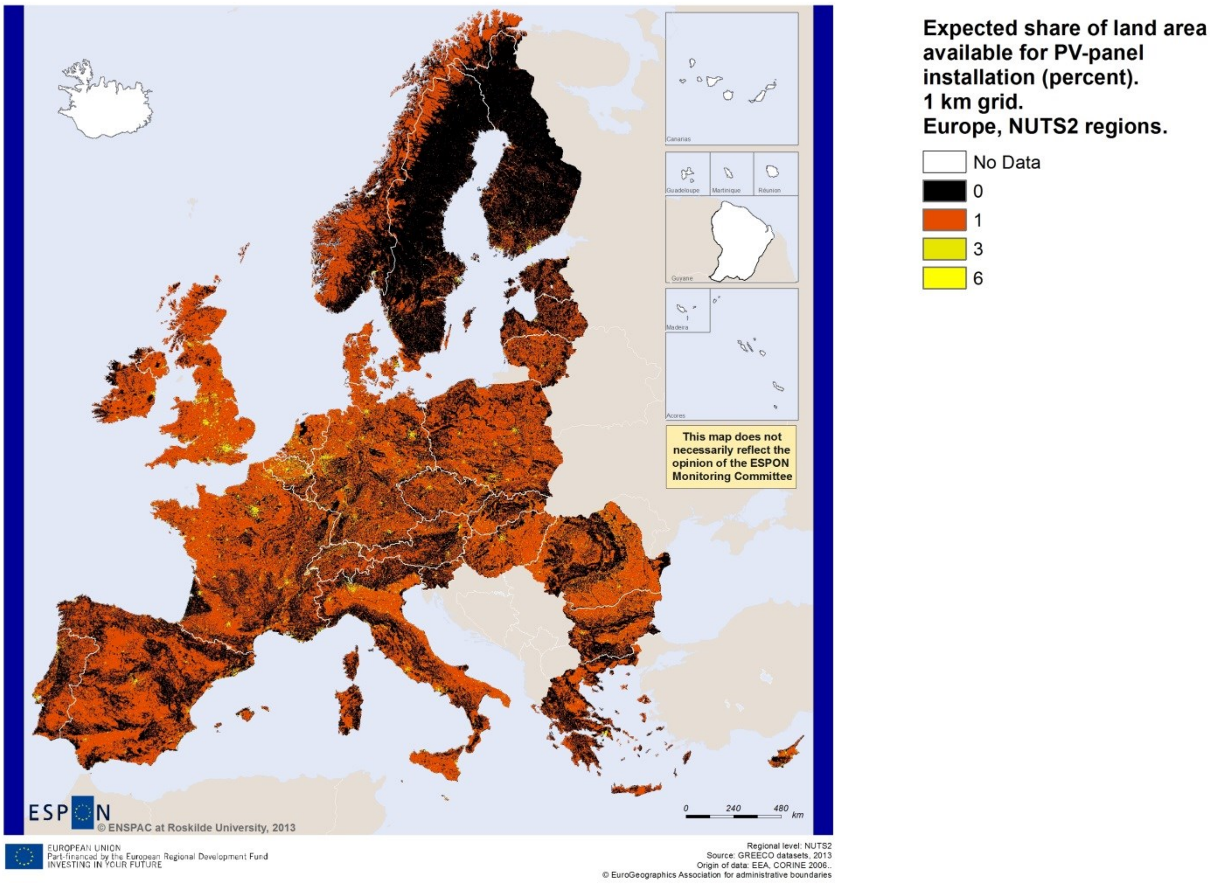
The levelised costs of PV energy – installed according to the standard conditions described above – vary by the solar irradiation and thus by local conditions such as latitude, patterns of cloud cover and absorption by the atmosphere. This also means that the spatial patterns of levelised costs displayed in map **16** shows high cost pockets at latitudes otherwise dominated by low costs and *vice versa*.



Map 16. Costs for photovoltaic electrical power generation, given in €/kWh produced.

The spatial patterns of levelised costs displayed in map **16** 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 8**) combined with the environmental restrictions (Layer 5). Map 17 shows the amount of PV suitable area available for each 1 x 1 km grid cell under the above conditions.

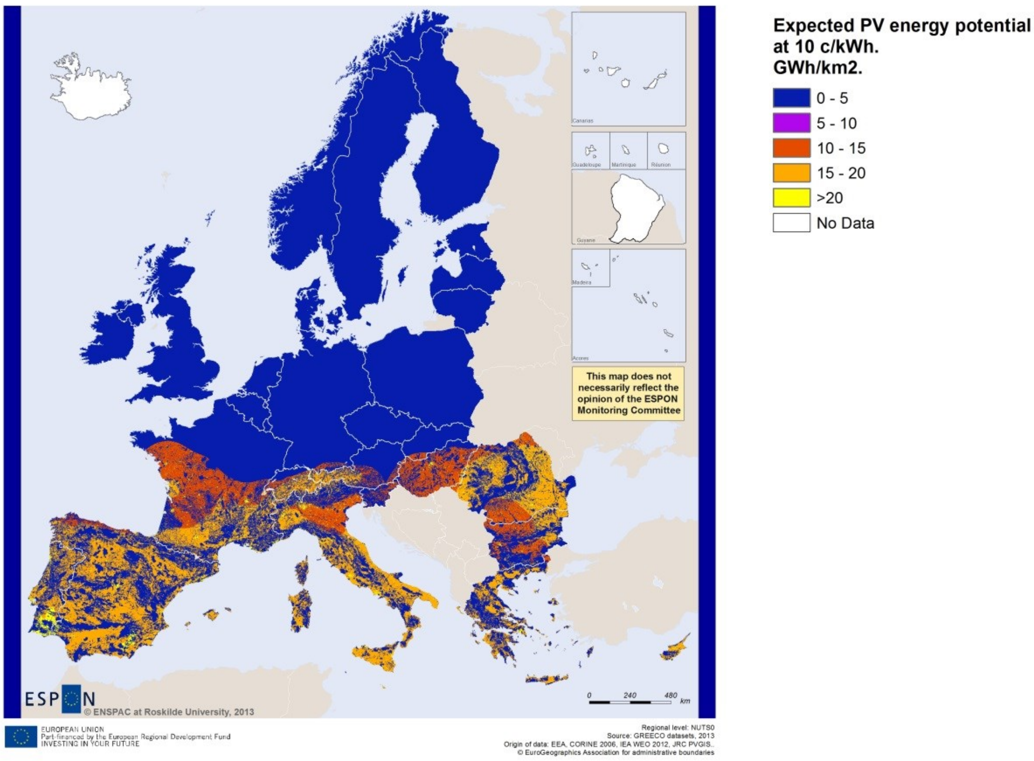


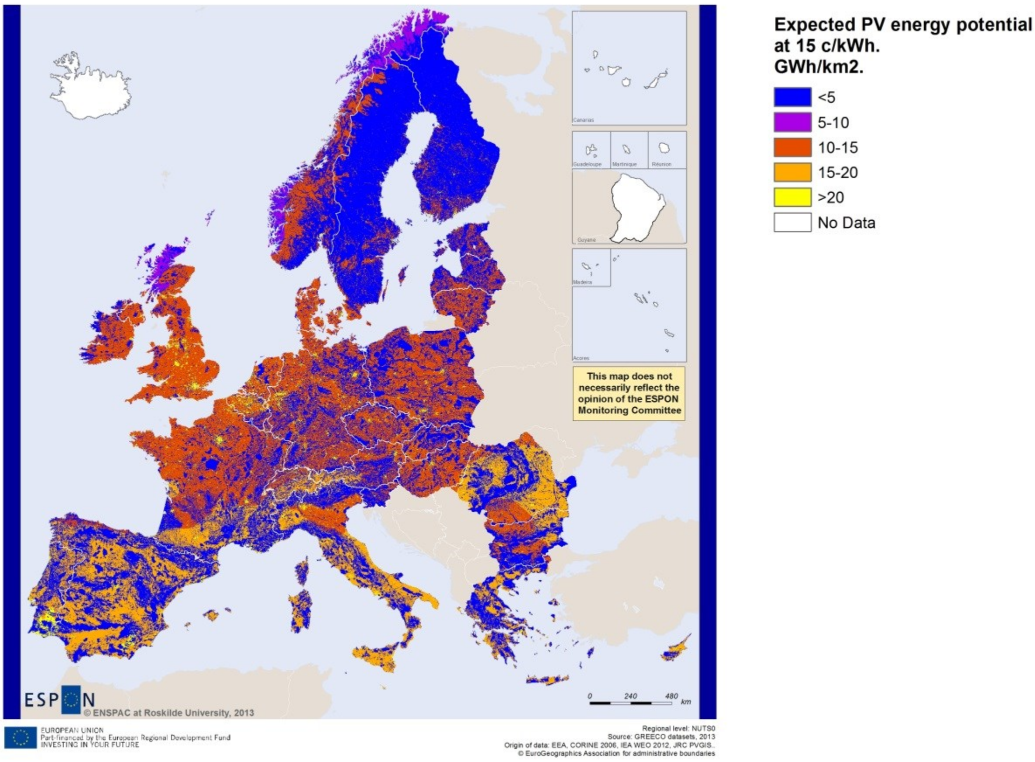
Map 17. Expected maximum PV panel density. Suitable (>0%) and non-suitable (0%) areas for PV-panel installations.

Overall, for 30% of the total land area it is not possible to have PV production (black in map 17). This is particularly apparent in Sweden and Finland, where the large forested areas prevent the possibility for PV production. According to the assumptions in **table 8** 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 17) . 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 17.

3.2. 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 18. 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 18. 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 18 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 8** – 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 10.

Table 10 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 10. Aggregate PV energy potential and potential PV resource rent by country.

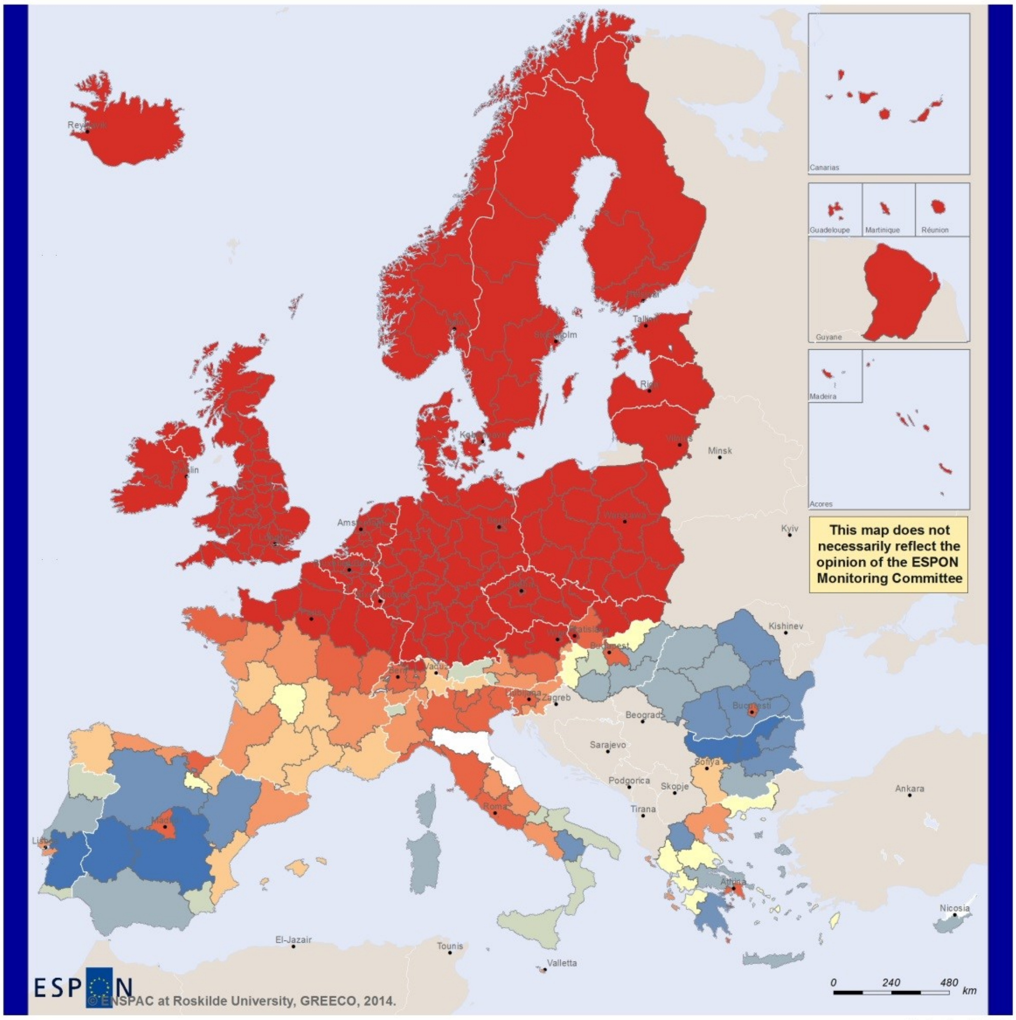
		PV12	PV10	PV8	PV12R	PV10R	PV8R
			TWh			€mio	
AT	**Austria**	75960	37221	13628	1777	645	136
BE	**Belgium**	2231	0	0	22	0	0
BG	**Bulgaria**	93870	91869	0	2776	919	0
CH	**Switzerland**	48477	36459	17652	1567	718	177
CY	**Cyprus**	13925	13925	13925	696	418	139
CZ	**Czech Republic**	62077	0	0	621	0	0
DE	**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 reflected in the level of public support to PV electricity generation.

The resource rents in table 10 are calculated under the assumption of social values that are uniform across 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.



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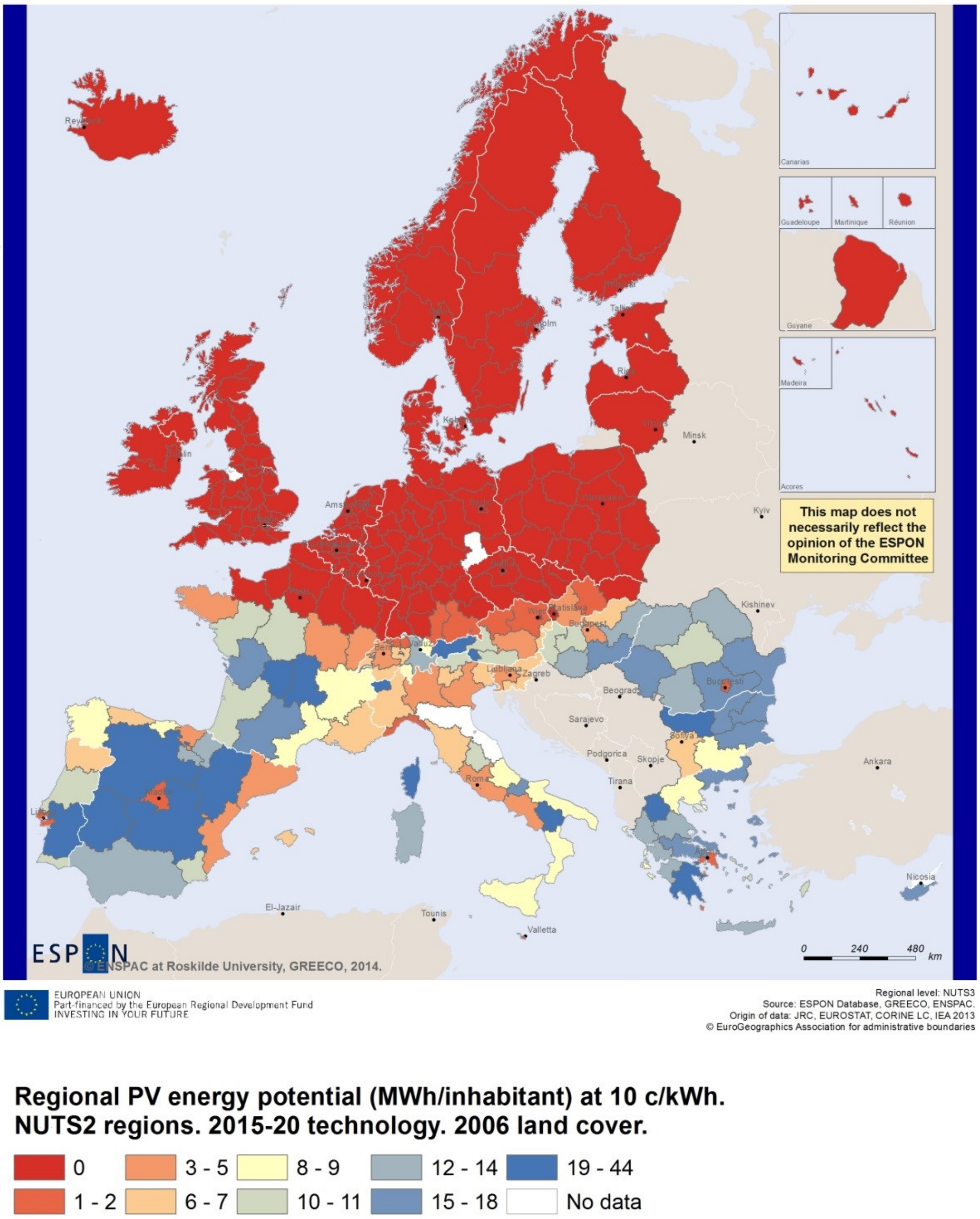
Regional level: NUTS2
Source: ESPON Database, GREECO, ENSPAC.
Origin of data: EC: JRC, EUROSTAT, EEA: CORINE LC, 2013
© EuroGeographics Association for administrative boundaries

Regional potential PV resource rent at 10 c/kWh in per cent of regional GVA (2009). NUTS2 regions. 2015-20 technology. 2006 land cover.

0% | 0,3% - 0,6% | 1% - 1,3% | 2,1% - 3,2% | 5,4% - 10,2%

0,1% - 0,2% | 0,7% - 0,9% | 1,4% - 2% | 3,3% - 5,3% | No data



Map 19. PV energy potential per capita (MWh/person) and potential PV resource rent (% of GVA) at 10 c/kWh.

Source: Author's calculations based on GREECO datasets (Hansen, 2013).

Map 19 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.

4. 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 assessment 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 distinguish 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 remuneration 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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Annex 9. Population (RPOP) and employment (JOB)

List of authors

Anders Chr. Hansen

Jacob Byskov

1. Resident population (RPOP)

The population concept is the average *resident* population. “Average” refers to the population during the year rather than at a specific date and the average population is used for the non-EU countries. “Resident” corresponds to the “national” concept in the European Statistical Accounts.

Sources: EU countries: (EC, 2013a), Iceland, Norway, Switzerland and Liechtenstein: (EC, 2013b).

Over the period 2000 to 2010, population declined in regions with low levels of income – primarily the new member states and some regions of the EU15 countries. Population did, however, grow in many metropolitan areas in the new member states as well.

2. Employment (JOB)

The employment concept comparable to GDP and GVA statistics must be a flow concept following the national accounts (NACE Rev. 2) conventions. The “JOB” variable includes persons employed in the region (as opposed to employed residents of the region) during the year. Thus it corresponds to the "domestic" as opposed to “national” concept in the European Statistical Accounts.

The unit is “1000 persons” irrespective of their average work effort.

Sources: (EC, 2013c), (EC, 2013d),(EC, 2013e),

Raising the employment rate is a central objective of the European economic policy. This makes the ratio of employment growth to population growth an important indicator of economic progress.

Very few regions left the 2000-10 decade with a higher ratio of employment to resident population than they entered it with. The overall picture is less employment per inhabitant. Exceptions to this are found in some regions of the new member states although the decline in employment has exceeded the decline in population. Few regions in other European countries experienced a similar job growth.

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Annex 10. Tax-to-GDP ratio (T2GDP) and net fiscal contribution (NFC)

List of authors

Anders Chr. Hansen

1. Tax-to-GDP ratio (T2GDP)and Net Fiscal Contribution ratio (NFC)

Investment in human capital, infrastructure, social services and other public good assets and services are critical for sustainable development. However, markets cannot adequately meet the demand for many of these services. National government subsidies, Regional Fund programmes and other fiscal arrangements support the take-off of regional economic development. As the development takes of, it becomes increasingly important to regions to mobilise public funds themselves to sustain the development.

The post 00s fiscal regime in the EU – known as the Six Pack and the Fiscal Compact – has further institutionalised the commitment of the member states to follow sustainable fiscal policies. The bubble growth of the 00s was in many member states supported by a reluctance to collect the taxes necessary to cover government expenditures. The austerity policies through 2011-13 did on the other hand contribute to the double dip recession in 2013. To avoid austerity policies during recessions, fiscal consolidation in boom years requires also putting aside for future recessions. Thus, regional patterns of contributions from the household sector to the government budgets are important.

At the national level tax-to-GDP or government-revenue-to-GDP ratios are used as indicators for benchmark studies of this potential. The most appropriate income concept for normalising tax revenues would be the net national income (NNI) since its definition is most in accordance with the taxable and potentially consumable primary income of the economy. The accounts of fixed capital consumption – the difference between gross and net - lack, however, often accuracy and are additionally at the regional level incomplete.

The net primary income concept – wages, salaries, interest, rent, etc. - comes closer to this concept than GDP. These data are available at NUTS2 level in the allocation of primary income accounts published by EUROSTAT (EC, 2010, f. nama_r_ehh2p). They only include the household sector and not the business sector and the public sector. The household income of interest and rents is included, but net of the interest and rents payable to the other sectors.

The tax basis of income taxation does, however, to varying degrees also include transfers from the public budget to households. Regional differences in the weight of such transfers in the regional income tax base would lead to biases in the regional tax-to-income ratio if household primary income was used as the income concept.

Consequently, the GREECO dataset on contributions to public budgets normalises regional tax revenues by regional GDP. To the extent GDP reflects the regional distribution of final expenditure, this approach will reflect the level of taxation of the resident population. The approach also makes the indicator more directly comparable to the national level tax-to-GDP ratio or revenue-to-GDP ratio routinely used in analysis of public finance. Note, however, that in regions with asymmetric commuting patterns with neighbouring regions, regional GDP can differ considerably from the regional income tax base.

The tax statistics is not complete at the regional level, but the available data on direct taxes and social contributions from households account for most of the regional tax revenue. The aggregate of these estimates still leaves a gap with respect to taxes payable from the business sector, but several of these are in any case difficult to attach to specific regions. Thus, the direct taxes (including social contributions) constitute the key component in the analysis of regional tax contributions.

The contribution of households by direct taxes – taxes on income and wealth – and social contributions are available at NUTS2 level in the allocation of primary income accounts published by EUROSTAT (EC, 2010, f. nama_r_ehh2p), (EC, 2013) and GDP and GVA data above.

Households not only contribute to public funds by direct taxes, but also through indirect taxes such as VAT, fuel taxes and import taxes. By definition the revenue of indirect taxes (net of subsidies) – equals the difference between the GDP and the GVA. This property is used at the regional level to estimate the regional ratios of indirect taxes (net) to the primary income of households. GVA is the basis for the EUROSTAT regional accounts and the national level net indirect taxes are regionalised with GVA as distribution key for most countries.

Due to this methodology the ratio of the difference between GDP and GVA to GDP or GVA at the regional level will show very limited regional disparities within each country. In particular, regional differences in flows of agricultural subsidies will not be reflected in this indicator. Neither will the Regional Fund and central government subsidies to economically weak regions.

The ratio of direct taxes on households (including social contributions) to household primary income or to GDP increases with the level of income of the European regions. The similar ratio of indirect taxes to income shows a slightly decreasing pattern across the regions. The aggregate (direct + indirect) taxes-to-GDP ratio does, however, reveal a persistent pattern of increasing with the regional income level. This pattern is likely to be more pronounced if the accounts of indirect taxes, net of subsidies, was reflecting differences in agricultural and other subsidies accurately.

Figure 8 shows the pattern of the aggregate ratio of tax-to-GDP relative to the GDP per capita (measured in purchasing power standards) in the European NUTS2 regions. Purchasing power standards are EUROs with the same purchasing power in all countries. The tax-to-GDP ratio is computed as:

(1) T2GDP
=(Direct taxes and social contributions from households + net indirect taxes)/GDP
= (Direct taxes and social contributions from households + GDP-GVA)/GDP

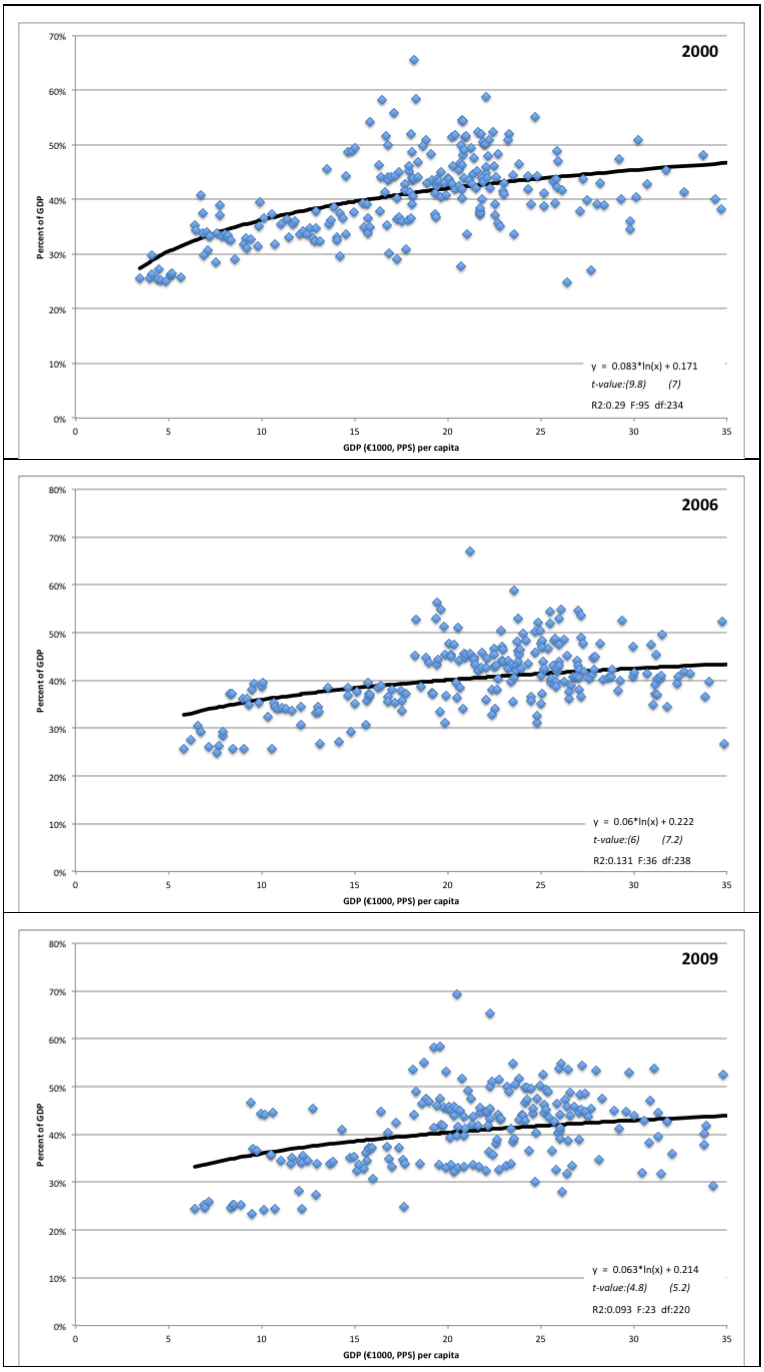


Figure 8. Regional tax-to-GDP ratios (including social contributions, but excluding business sector taxes) by GDP per capita (in PPS*) of NUTS2 regions. 2000, 2006, 2009.

** Purchasing Power Standards. GDP is measured in PPS to adjust for regional differences in the purchasing power of a EURO or the national currency equivalent.*

As shown in Figure 8 higher levels of regional average income are associated with higher ratios of tax-to-GDP. This pattern is slightly more moderate in 2006 and 2009 than in 2000, but this may be due to missing data for economies in the lower end of the income scale. The modest R^2 statistics reflect that many other factors, which are not correlated with the current GDP, contribute to explaining the regional disparities in tax-to-GDP ratios. The regression coefficients, however, are significant in all three years.

The intra-national regional disparities are due to regional requirements of public funds as well as redistribution across regions. The social redistribution through income and wealth dependent taxes and transfers such as pensions and unemployment benefits also has a regional dimension. Measuring the interregional redistribution thus, requires data on tax payments out of the region and transfer and subsidy payments into the region. On this basis the net fiscal contribution of the region to the general public budget of the country can be computed. This contribution is also an indicator of the realised economic potential of the region.

The Net Fiscal Contribution ratio (NFC) is defined as the direct and indirect taxes paid by the region net of subsidies and transfers to the region. These net payments are related to the primary income of the households.

$$(2) \quad NFC = (T2GDP - \text{transfers to households})/GDP$$

The patterns of regional disparities are shown in Figure 9

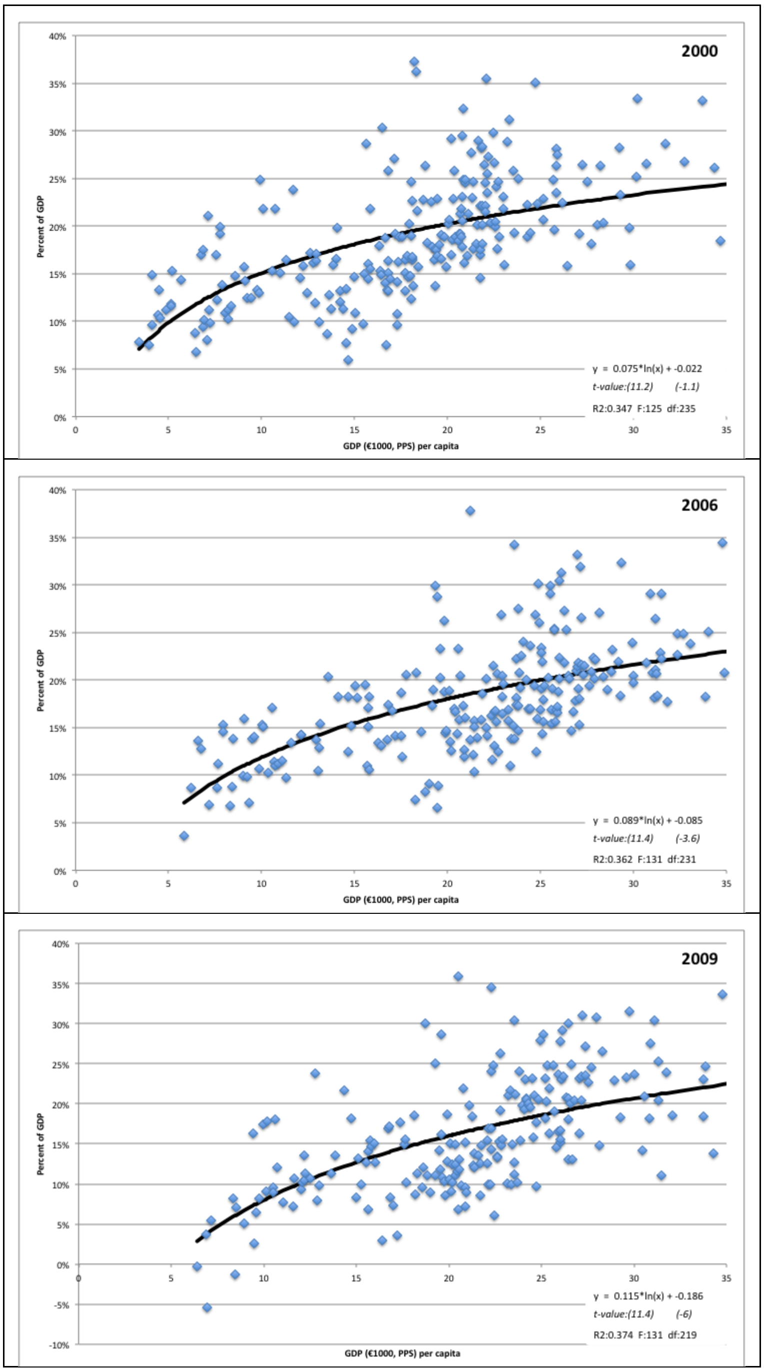
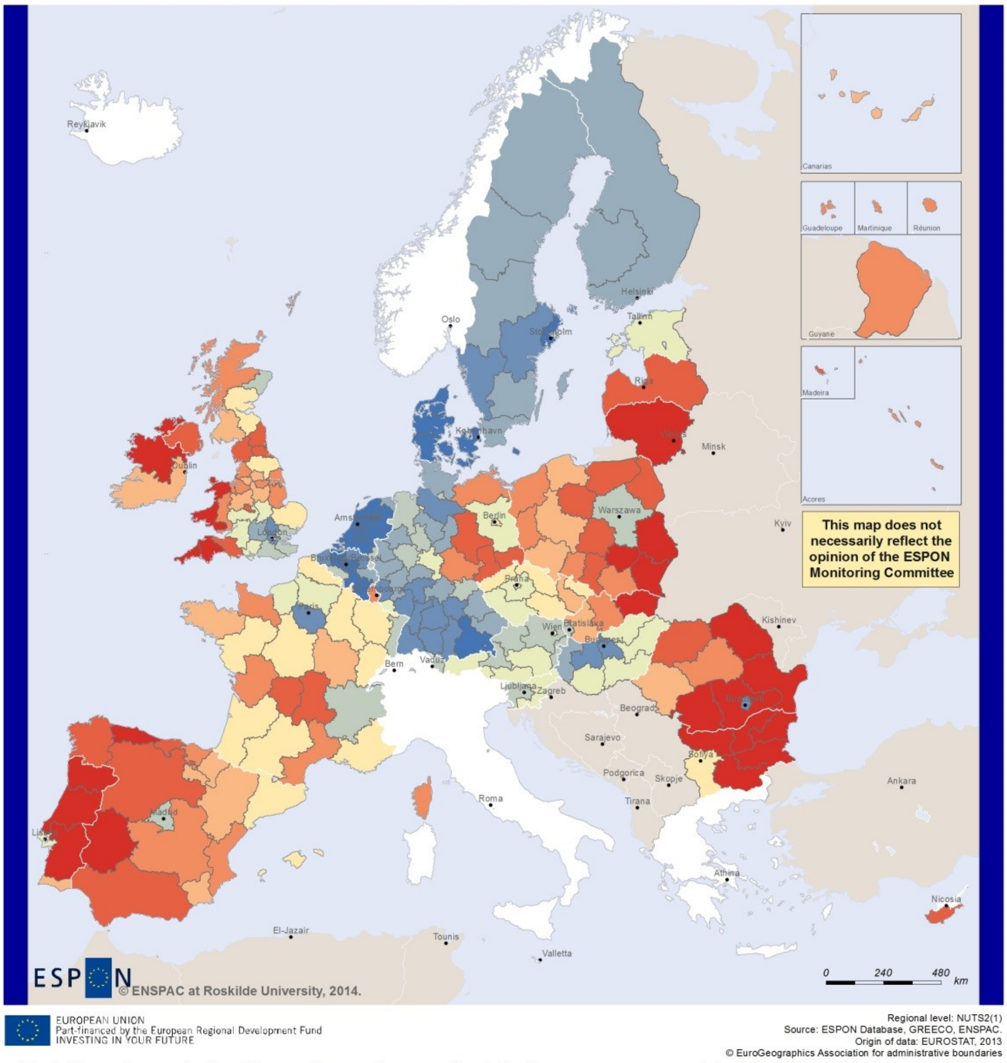


Figure 9. Regional ratios of net fiscal contributions to general government budgets by GDP per capita (in PPS*) of NUTS2 regions. 2000, 2006, 2009.

** Purchasing Power Standards. GDP is measured in PPS to adjust for regional differences in the purchasing power of a EURO or the national currency equivalent.*

The interregional disparities in the ratio of net fiscal contributions to GDP is slightly weaker linked to the regional income level in year 2000, but stronger so in the years 2006 and 2009. In the deep recession year of 2009 the net contribution was even negative in some of Europe's poorest regions.

The regional disparities of NFC reflect regional and national choices between government and private sector expenditures under the specific territorial constraints for mobilising public funds. They do, however, also reflect choices between current and future payment of expenditures. When comparing the regions and countries it should be kept in mind that many of the countries with low NFC ratios contribute less than is financially sustainable to their government budgets (European Commission, 2009, 2006).



Net fiscal contributions from households to government budgets 2009.
= (direct taxes (incl social contributions) - tansfers
+ indirect taxes (net of subsidies)) in per cent of GDP.
NUTS2(1) regions grouped in deciles.

-5,4% - 8,4%
8,5% - 10,2%
10,3% - 12,4%
12,5% - 14,1%
14,2% - 15,6%
15,7% - 18,2%
18,3% - 20,5%
20,6% - 23,2%
23,3% - 26,2%
26,3% - 35,9%
No data

Map 20. Contributions from households to public budgets. Per cent of regional GDP. 2009. Upper map: Direct and indirect tax contributions net of subsidies and transfers. Lower map: Tax-to-GDP ratio (Direct and indirect taxes net of subsidies.

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Annex 11. Wind energy potential (WP)

List of authors

Anders Chr. Hansen

1. Assessing wind energy potentials

Wind energy is expected to replace most of the fossil energy produced and used in Europe today. Far most of the wind resources are located at sea and offshore wind energy is developing fast. There are, however, still considerable wind potentials onshore. They benefit from the low costs of installation, grid connection and maintenance. Thus, they also comprise significant potentials for income generation in the operational phase and employment in the investment phase. These potentials are not evenly distributed across the European regions and the dataset on wind potentials contain a series of indicators of the wind energy that potentially could be produced in each region and the resource rent that potentially could be harvested from this production.

Wind speed data have previously been explored in an ESPON project (ReRisk), but the GREECO dataset takes the analysis further to an assessment of regional patterns of potential wind energy generation and the potential economic value of this energy.

The GREECO assessment of the European onshore wind energy potential is based on an updated and more complete set of wind speed data covering 2000-10 the same meteorological data as the European Environmental Agency (EEA) study of the European wind energy potential ((EEA), 2009).

The estimates take departure in the state-of–the art assessment of the European Environmental Agency (EEA) in 2009. It was a *meso-scale* assessment based on a European dataset of wind speed measurement at stations about 10 m above ground level.

The meso-scale assessment does not capture all of the wind potential because some ”pockets” of ”wind-good” locations only can be identified at the micro-scale level. Micro-scale assessments reveal particularly in mountainous areas additional wind energy resources.

The present study is – like the EEA study – an assessment of the *long term potential* without time constraints. The potential that can be realised within a planning horizon of, e.g. 2020, is only a fraction of the long term potential. This is because the potential that can be realised within a shorter period is constrained by a number of factors such as the extent of the electricity grid, legislative and financial barriers and the availability of balancing options (e.g., back-up capacity, pumped storage and international transmission connections).

The process of computing the wind energy potential involves derivation of the energy potential at the relevant height (depending on wind turbine technology) and relevant area (depending on landscape roughness), identification of areas that are suitable for wind energy and areas that are not, assumption of rated power and density of wind turbines as well as of the cost of wind turbine construction and the socially acceptable cost of wind energy.

2. Wind velocity

The calculations are based on the recent update of the ECMWF wind data set collected at 10 m height at meteorological monitoring stations. The updated dataset includes the monthly means of daily means covering the period 2003-2012 from the ERA-20CM data set ((European Centre for Medium-Range Weather Forecasts (ECMWF), 2013)). The mean of the monthly mean of the daily mean is used as expected future wind speed.

The wind speed data are transformed to expected wind velocity applying the same method and assumptions on roughness height as in the EEA study. The conversions are, however, adjusted to 90 m height - unlike the EEA study assumption of 80m - corresponding to the hub height expected with state-of-the-art onshore wind power technology in 2015-20. The standard transformation procedure used in the EEA study is as follows:

$$(1) \qquad V_H = V_{10}\left(\frac{ln(H/z_0)}{ln(10/z_0)}\right),$$

where *V* is wind velocity, z_0 is the roughness length (the level at which wind velocity is zero due to landscape roughness) and *10* stands for the observation height and *H* for the hub height to which the observed wind velocity should be extrapolated. In the EEA study, the scale factors in the parenthesis have been calculated for each CORINE land cover class.

The scale factor V_{90}/ V_{10} for the 90m hub was achieved by reorganisaing equation (1) to

$$(2) \qquad ln(z_0) = \left(ln(H) - ln(10)\,{}^{V_H}\!/_{V_{10}}\right) \Big/ \left(1 - {}^{V_H}\!/_{V_{10}}\right)$$

from which the roughness length assumptions z_0 for every CLC class can be derived as shown in Table 11.

Table 11. Average hub height conversion ratio used in 15 Corine land cover classes at 80m and 90m hub height.

CLC class number	CLC code and label Level 3		AV ratio 80m	ln(z0)	z0	AV ratio 90m
CL-1	111	Continuous urban fabric	1.91	0.02	1.02	1.96
	112	Discontinuous urban fabric				
	121	Industrial or commercial units				
	141	Green urban areas				
	142	Sport and leisure facilities				
CL-2	122	Road and rail networks and associated land	1.64	-0.95	0.39	1.68
	123	Port areas				
	124	Airports				
CL-3	131	Mineral extraction sites	1.32	-4.20	0.02	1.34
	132	Dump sites				
	133	Construction sites				
CL-4	211	Non-irrigated arable land	1.43	-2.53	0.08	1.45
	212	Permanently irrigated land				
	213	Rice fields				
CL-5	221	Vineyards	1.52	-1.70	0.18	1.55
	222	Fruit trees and berry plantations				
	223	Olive groves				
CL-6	231	Pastures	1.47	-2.12	0.12	1.50
CL-7	241	Annual crops associated with permanent crops	1.51	-1.77	0.17	1.54
	242	Complex cultivation patterns				
	243	Land principally occupied by agriculture with significant areas of natural vegetation				
	244	Agro-forestry areas				
CL-8	311	Broad-leaved forest	1.85	-0.14	0.87	1.90
	312	Coniferous forest				
	313	Mixed forest				
CL-9	321	Natural grasslands	1.33	-4.00	0.02	1.35
	322	Moors and heath land				
	323	Sclerophyllous vegetation				
	324	Transitional woodland-shrub				
CL-10	331	Beaches, dunes, sands	1.3	-4.63	0.01	1.32

CL-11	332	Bare rocks	1.3	-4.63	0.01	1.32
	333	Sparsely vegetated areas				
	334	Burnt areas				
CL-12	335	Glaciers and perpetual snow	1.24	-6.36	0.00	1.25
CL-13	411	Inland marshes	1.34	-3.81	0.02	1.36
	412	Peat bogs				
	421	Salt marshes				
	422	Salines				
	423	Intertidal flats				
CL-14	511	Water courses	1.21	-7.60	0.00	1.22
	521	Coastal lagoons				
	522	Estuaries				
	523	Sea and ocean				
CL-15	512	Water bodies	1.21	-7.60	0.00	1.22

The conversion process uses the CORINE land cover database at a 250m x 250m resolution (European Environmental Agency (EEA), 2012).

Full load hours at 90m are finally calculated with power-velocity curves similar to the EEA study:

For mountainous areas (> 600 m)

(3) $(V_{90} \text{ x } 626.51 - 1\,901) \text{ x } 0.83$

For non-mountainous areas (< 600 m)

(4) $(V_{90} \text{ x } 626.51 - 1\,901) \text{ x } 0.90$

3. Onshore wind turbine technology

The present study also updates the assumptions on the state-of-the-art installed effect per wind turbine from 2MW in the EeA study to 3.5MW. The statistics from wind turbine generation in Denmark, shows that 66% of the wind generation effect installed in Denmark in 2011 was in turbines rated at 3.0-3.6MW. The planning assumptions of The Danish Energy Agency anticipate for 2020 a rated power of 3.5 MW at a hub height of 90 m (Energistyrelsen (Danish Energy Agency), 2012).

4. Wind energy costs and social value

The cost assumptions are based on the International Energy Agency assumptions underlying the World Energy Outlook 2012 (International Energy Agency (IEA), 2012). These assumptions are so called “overnight costs” and do not take into account the variation in local cost of installing, grid-connection, maintenance and the infrastructure costs associated with expansion of the wind energy share. Any interpretation of the data in a specific local context has to take these costs into consideration.

The price assumptions are based on the expected level of market electricity wholesale prices and the financial support schemes for renewable energy provided across the EU. According to a survey conducted by the Council of European Energy Regulators (CEER) the level of financial support in 2011 varies across Europe from €12 to €111 (Council of European Energy Regulators (CEER), 2013). These estimates do, however, comprise support to offshore as well as onshore wind energy generation. Market prices varied in 2011 from 32 to 125 €/MWh.

Wholesale prices as well as financial support differ considerably across Europe, but spot-market prices are expected to converge following a closer integration of European electricity markets. Financial support mechanisms may be raised in countries where the current level is insufficient to realise the wind potential whereas they are set to decline in general as the technology becomes more competitive on its own. 8 and 10 c/kWh are chosen as probable levels of remuneration for onshore wind turbines installed in 2015-20 (i.e. operating in the period 2015-40). In most countries 8 c/kWh is probably the more likely alternative.

5. Land use compatibility and installed power density

The EEA study constrained the area available for onshore wind energy generation by excluding the NATURA 2000 and nationally designated nature areas from the assessment. The GREECO project have updated these constraints with recent data on designated nature areas and has also excluded residential areas, airports, highways and other areas not compatible with wind energy generation. In general, the European area is classified in land cover classes each of which is divided in nature designated and non-nature designated areas.

Forest areas, in particular, represent a difficult case. Tree vegetation is known to cause turbulence to a degree that is incompatible with wind energy generation. On the other hand, new solutions with higher towers and forest clearing around a wind farm have been introduced in recent years. This development could open up a considerable wind power potential in the vast forest areas in some countries. In other countries and regions forest areas are scarcer and the loss of nature values by development of wind power resources would be too high. The dataset thus distinguishes between forest areas and non-forest areas the land use of which is compatible with wind power generation.

The nature designated areas are assigned a potential wind power density of 0 MW/km^2. This is probably not necessarily consistent with spatial planning everywhere since protection of species and ecosystems can be fully compatible with wind energy generation. On the other hand, given the problems with realising the wind energy potential due to concerns for loss of landscape qualities, it is considered more likely that the no wind energy potentials can be realised in nature designated.

The assumed potential density of wind power was 8 MW/km^2 (4 MW/km^2 in mountainous areas) in the EEA study, but experience from Northern Europe indicates that an average power density at this level may be more detrimental to landscape values than generally acceptable. The GREECO estimates take departure in a wind power density that does not establish wind turbines as a dominant element in the landscape. This principle can be transformed to a planning rule of a minimum distance between wind farms of approximately 4 km. With the assumed size of wind farms this rule results in a power density of 1.2 MW/km^2.

Table 12. Potential wind power density in land cover classes.

	Level 1	Level 2	Level 3	Turb/km^2	MW/km^2
1	Artificial surfaces	Urban fabric	Continuous urban fabric	**0**	**0**
2	Artificial surfaces	Urban fabric	Discontinuous urban fabric	**0**	**0**
3	Artificial surfaces	Industrial, commercial and transport units	Industrial or commercial units	**0.2**	**1.2**
4	Artificial surfaces	Industrial, commercial and transport units	Road and rail networks and associated land	**0.2**	**1.2**
5	Artificial surfaces	Industrial, commercial and transport units	Port areas	**0.2**	**1.2**
6	Artificial surfaces	Industrial, commercial and transport units	Airports	**0**	**0**
7	Artificial surfaces	Mine, dump and construction sites	Mineral extraction sites	**0.2**	**1.2**
8	Artificial surfaces	Mine, dump and construction sites	Dump sites	**0.2**	**1.2**
9	Artificial surfaces	Mine, dump and construction sites	Construction sites	**0.2**	**1.2**
10	Artificial surfaces	Artificial, non-agricultural vegetated areas	Green urban areas	**0**	**0**
11	Artificial surfaces	Artificial, non-agricultural vegetated areas	Sport and leisure facilities	**0**	**0**
12	Agricultural areas	Arable land	Non-irrigated arable land	**0.34**	**1.2**
13	Agricultural areas	Arable land	Permanently irrigated land	**0.34**	**1.2**
14	Agricultural areas	Arable land	Rice fields	**0.34**	**1.2**
15	Agricultural areas	Permanent crops	Vineyards	**0.34**	**1.2**
16	Agricultural areas	Permanent crops	Fruit trees and berry plantations	**0.34**	**1.2**

17	Agricultural areas	Permanent crops	Olive groves	**0.34**	**1.2**
18	Agricultural areas	Pastures	Pastures	**0.34**	**1.2**
19	Agricultural areas	Heterogeneous agricultural areas	Annual crops associated with permanent crops	**0.34**	**1.2**
20	Agricultural areas	Heterogeneous agricultural areas	Complex cultivation patterns	**0.34**	**1.2**
21	Agricultural areas	Heterogeneous agricultural areas	Land principally occupied by agriculture, with significant areas of natural vegetation	**0.34**	**1.2**
22	Agricultural areas	Heterogeneous agricultural areas	Agro-forestry areas	**0.34**	**1.2**
23	Forest and semi natural areas	Forests	Broad-leaved forest	**0**	**0**
24	Forest and semi natural areas	Forests	Coniferous forest	**0**	**0**
25	Forest and semi natural areas	Forests	Mixed forest	**0**	**0**
26	Forest and semi natural areas	Scrub and/ or herbaceous vegetation associations	Natural grasslands	**0.34**	**1.2**
27	Forest and semi natural areas	Scrub and/ or herbaceous vegetation associations	Moors and heathland	**0.34**	**1.2**
28	Forest and semi natural areas	Scrub and/ or herbaceous vegetation associations	Sclerophyllous vegetation	**0.34**	**1.2**
29	Forest and semi natural areas	Scrub and/ or herbaceous vegetation associations	Transitional woodland-shrub	**0**	**0**

30	Forest and semi natural areas	Open spaces with little or no vegetation	Beaches, dunes, sands	**0**	**0**
31	Forest and semi natural areas	Open spaces with little or no vegetation	Bare rocks	**0.34**	**1.2**
32	Forest and semi natural areas	Open spaces with little or no vegetation	Sparsely vegetated areas	**0.34**	**1.2**
33	Forest and semi natural areas	Open spaces with little or no vegetation	Burnt areas	**0.34**	**1.2**
34	Forest and semi natural areas	Open spaces with little or no vegetation	Glaciers and perpetual snow	**0**	**0**
35	Wetlands	Inland wetlands	Inland marshes	**0**	**0**
36	Wetlands	Inland wetlands	Peat bogs	**0**	**0**
37	Wetlands	Maritime wetlands	Salt marshes	**0**	**0**
38	Wetlands	Maritime wetlands	Salines	**0**	**0**
39	Wetlands	Maritime wetlands	Intertidal flats	**0**	**0**
40	Water bodies	Inland waters	Water courses	**0**	**0**
41	Water bodies	Inland waters	Water bodies	**0**	**0**
42	Water bodies	Marine waters	Coastal lagoons	**0.2**	**1.2**
43	Water bodies	Marine waters	Estuaries	**0.2**	**1.2**
44	Water bodies	Marine waters	Sea and ocean	**0.2**	**1.2**

The wind power density assumption of 1.2 MW/km^2 is a reference value rather than a recommendation or a prediction. There is no correct value of this parameter as it depends on the regional trade-off between energy production and landscape values.

The computational process leading to the wind resource rent estimates is summarized in Table 13. The model adds GIS-layers consecutively in a way that is algebraically similar to matrix multiplication element by element. Table 13 shows how the value of typical cell is calculated.

Table 13. Steps in calculating the wind energy potential of the typical cell.

Layer	Concept	Parameter	Unit	Value
1	Theoretical	e	m/ s	Observed wind velocity
2	Technology->wind turbine productivity	a	Full load hours	Wind velocity at hub height adjusted for roughness, altitude etc. Converted to full load hours by power-velocity transformation
3	Maximum wind energy density by land cover class	f	MW and turbines / km2	Reference value 1.2MW/ km^2 = 0.2 turbines/ km^2
4	Wind power density without high landscape value loss	g		$g = 1.2MW/km^2$
	Technical, restricted, energy density	D	MWh/ km2/yr	D = B * f * g * 3.5 (Reference size of turbine)
5	Levelised cost including balancing	c	€/ MWh	Annualised generation costs per MW * scaling factor / a*operation factor + 3
	Economic viability filter	v	GWh_i	$v_i = 1$ if $c \leq p_i$, otherwise $v = 0$
	Wind resource class	V	GWh/Region	$V_i = \sum v_i$ by region
	Economic potential by resource class	W	GWh/Region	$Wi = \sum(V_i - V_{i-1})$
	Wind resource rent	R	€/Region	$R = \sum(p_i - c_i)*W_i$

Against this background, the following maps describe the GREECO estimates of the technically and economically realisable wind energy potential

- Onshore wind energy cost contour intervals (with NUTS2 and NUTS3 borders)
- Technically and economically realisable wind energy potential (NUTS2)
- Per capita wind energy potential (NUTS2)
- Potential wind resource rent in per cent of regional GVA (NUTS2)

“Total area” excludes areas designated for nature purposes as well as residential, airport and other areas not compatible with wind energy generation. The total area is divided in the broad categories of “forest” and “non-forest” area as the assumed wind energy density may differ between these two broad land-use classes. Forest areas are increasingly becoming attractive areas for wind resource development as taller wind turbines enter the market. The power density that eventually could be attained in forest areas is likely to be less than that of non-forest areas. Due to lack of better information, however, the wind power density is assumed identical in the two broad area categories.

The resource rent is the net-profit resulting from the difference between the price and the cost (including normal returns and depreciation). It is normalised as a % of gross value added (GVA) 2009.

The results on regional wind energy potential as well as the per capita potential and the rent in per cent of the regional GVA are scalable by the assumed wind power density. Thus, assuming a wind power density of 2.4 MW/km2 rather than 1.2 MW/km2 simply doubles the estimates of these variables. Assuming a wind power density of 0.6 MW/km^2 similarly reduce the estimates by 50%.

6. Results

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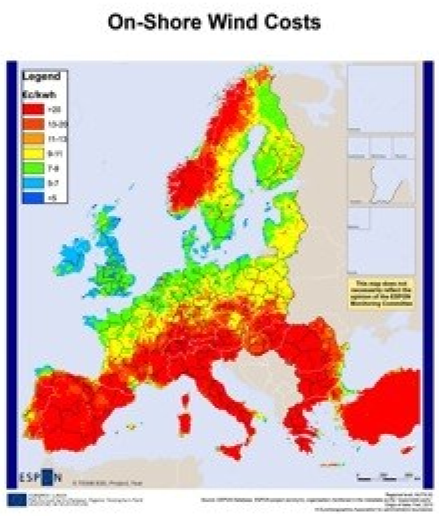
<td>
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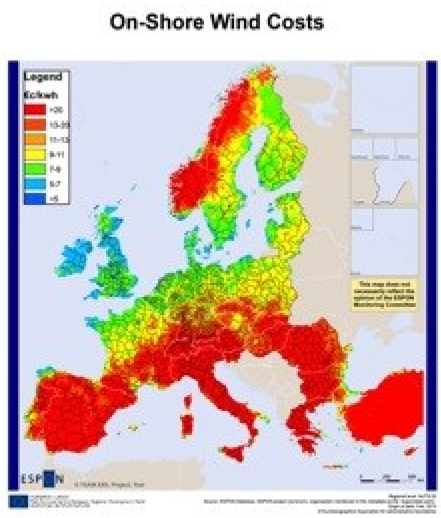
<td>
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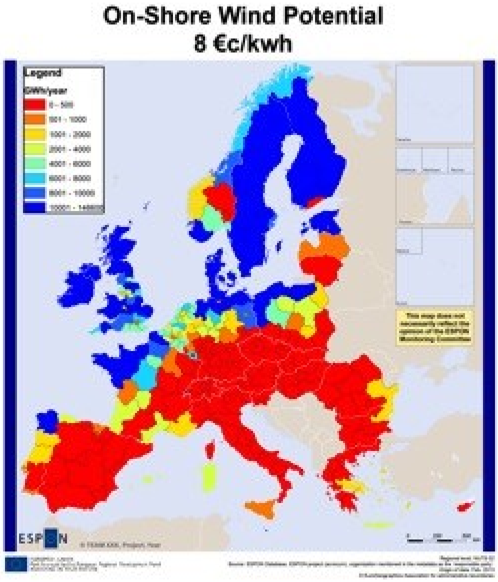
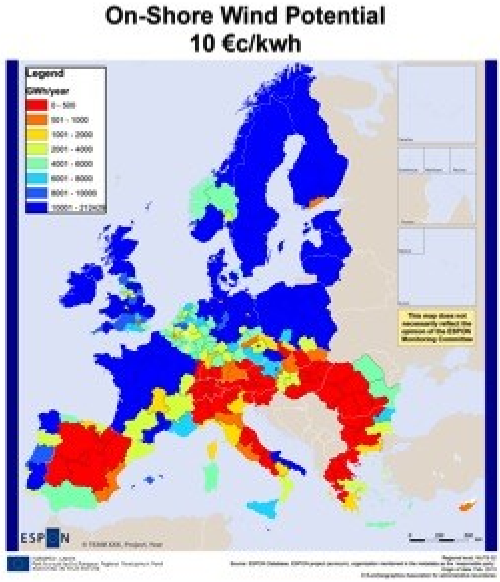
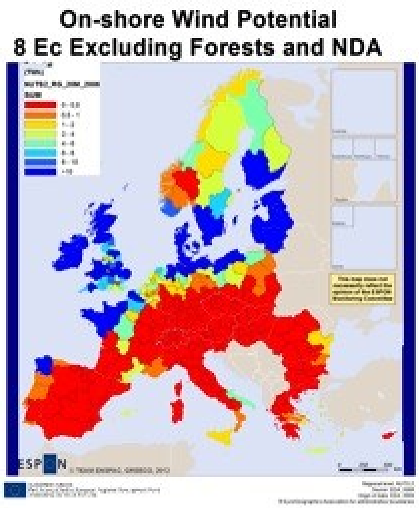
Map 21. Onshore wind energy cost contour intervals (c/kWh).

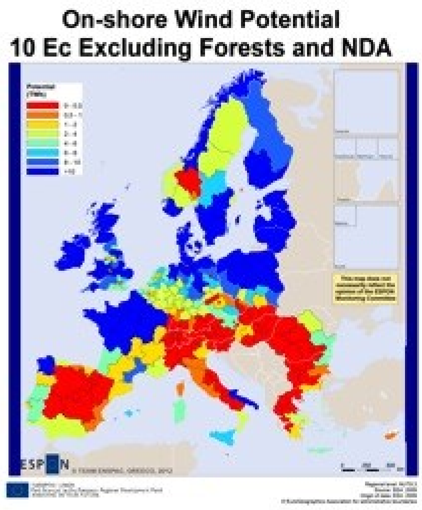




FNF8WP	FNF10WP

Map 22. Technically and economically realisable onshore wind potential at 8 and 10 c/kWh and 1.2 MW/km^2 in total NUTS2 areas (TWh/year).





NF8WP	NF10WP

Map 23. Technically and economically realisable onshore wind potentials at 8 and 10 c/kWh and 1.2 MW/km^2 in non-forest areas (TWh/year).

	
FNF8pc	FNF10pc

Map 24. Per capita wind energy potential in total (forest + non-forest) areas (MWh/person).

F8pc	F10pc

Map 25. Per capita wind energy potential in forest areas (MWh/person).

NF8pc	NF10pc

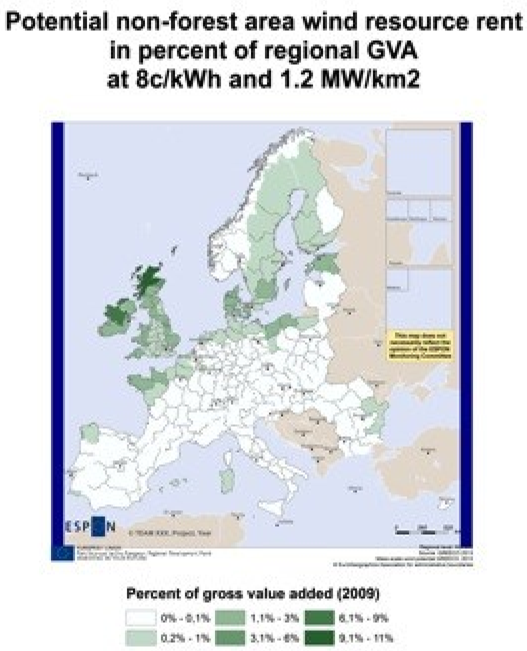
Map 26. Per capita wind energy potential in non-forest areas (MWh/person).

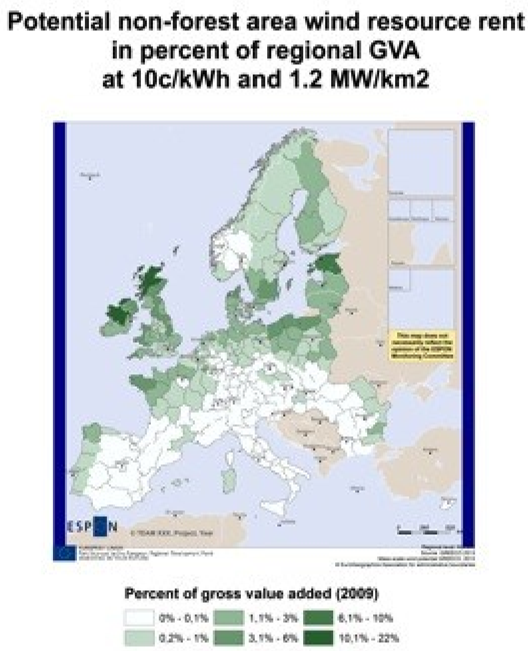
	
FNF8Rg	FNF10Rg

Map 27. Potential wind resource rent in total (forest + non-forest) areas (% of NUTS2 GVA).

F8Rg	F10Rg

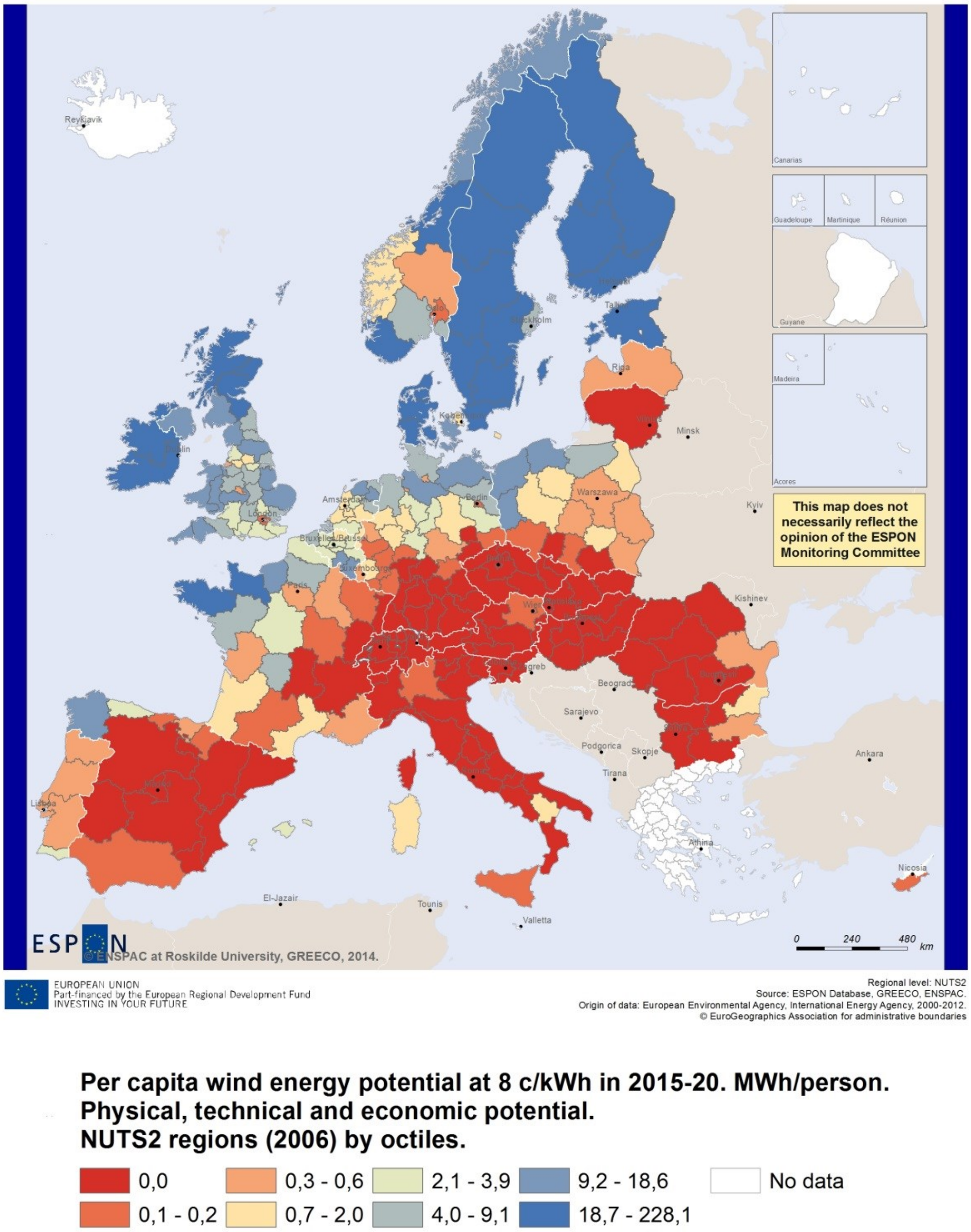
Map 28. Potential wind resource rent in forest areas (% of NUTS2 GVA).



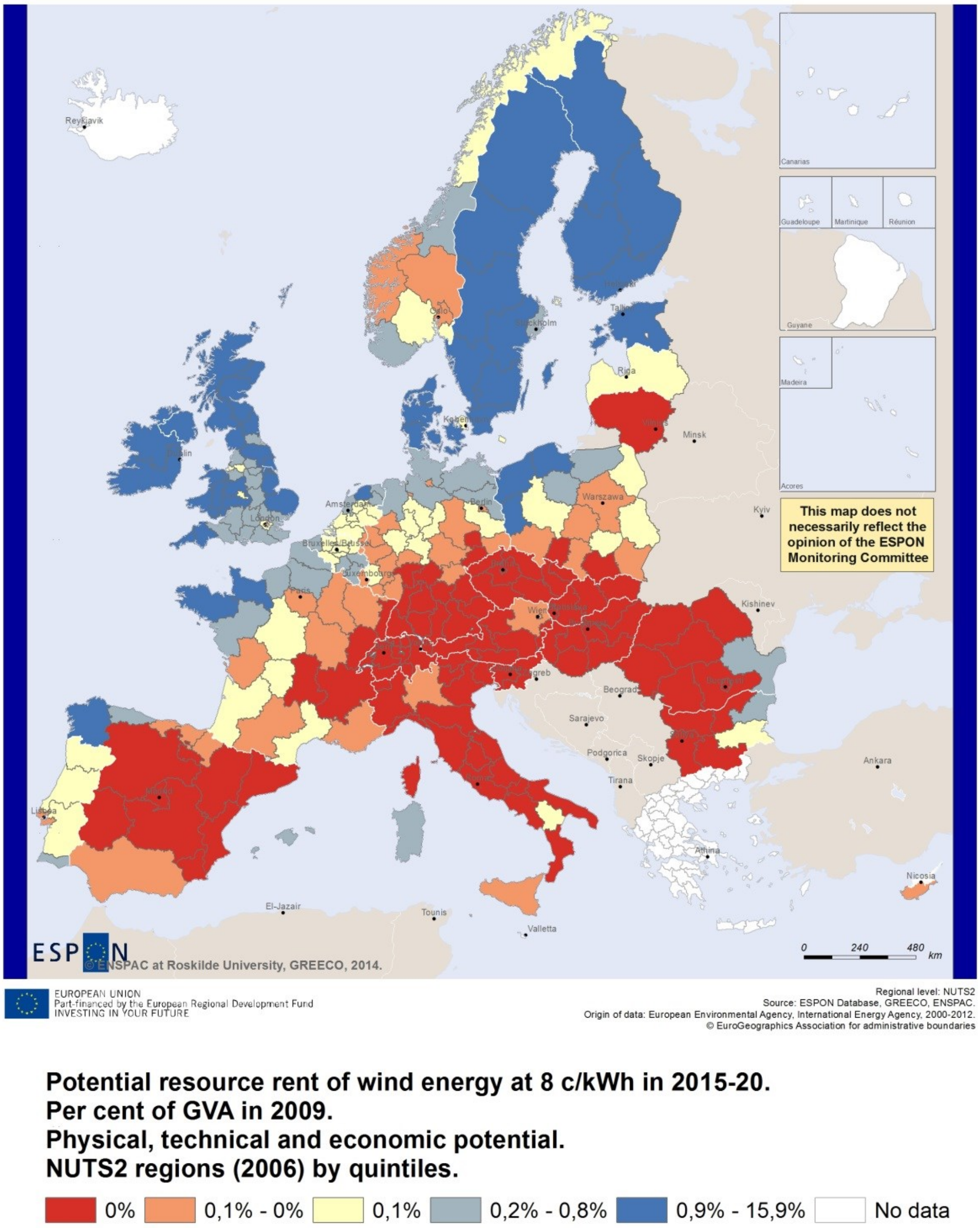


NF8Rg	NF10Rg

Map 29. Potential wind resource rent in non-forest areas (% of NUTS2 GVA).



Map 30. Potential wind resource rent in MW per capita (2009) at 8c/kWh and 1.2 MW/km2.



Map 31. Potential wind resource rent in per cent of regional GVA (2009) at 8c/kWh and 1.2 MW/km2.

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Annex 12. Water Bodies (WQRB)

List of authors

Anders Chr. Hansen

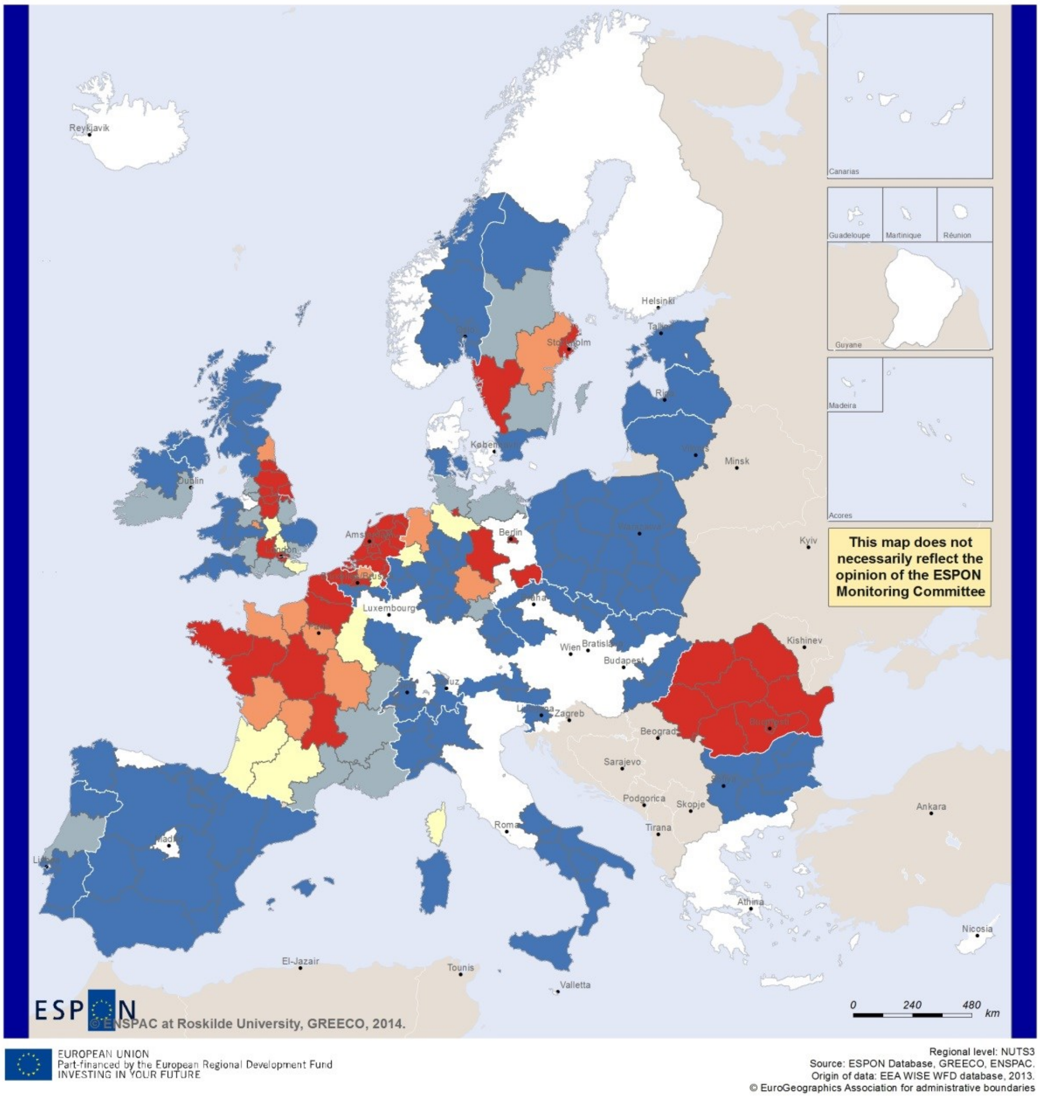
Jacob Byskov

1. Water quality

- **WQLakEcolARN3** Ecological status of lakes in river basins flowing through the region Lakes of less than good ecological status in river basins flowing through the region (Average of percent of total lake area in the river basins flowing through the region weighted by their area in the region)
- **WQRivEcolLtN3** Ecological status of rivers in river basins flowing through the region Rivers of less than good ecological status in river basins flowing through the region (Average of percent of total river length in the river basins flowing through the region weighted by their area in the region)
- **WQTranEcolARN3** Ecological status of transitional waters in river basins flowing through the region Transitional waters of less than good ecological status in river basins flowing through the region (Average of percent of total transitional water area in the river basins flowing through the region weighted by their area in the region)
- **WQCoastEcolARN3** Ecological status of coastal waters in river basins flowing through the region Coastal waters of less than good ecological status in river basins flowing through the region (Average of percent of total coastal waters area in the river basins flowing through the region weighted by their area in the region)
- **WQLakChemARN3** Chemical status of lakes in river basins flowing through the region Lakes of less than good chemical status in river basins flowing through the region (Average of percent of total lake area in the river basins flowing through the region weighted by their area in the region)

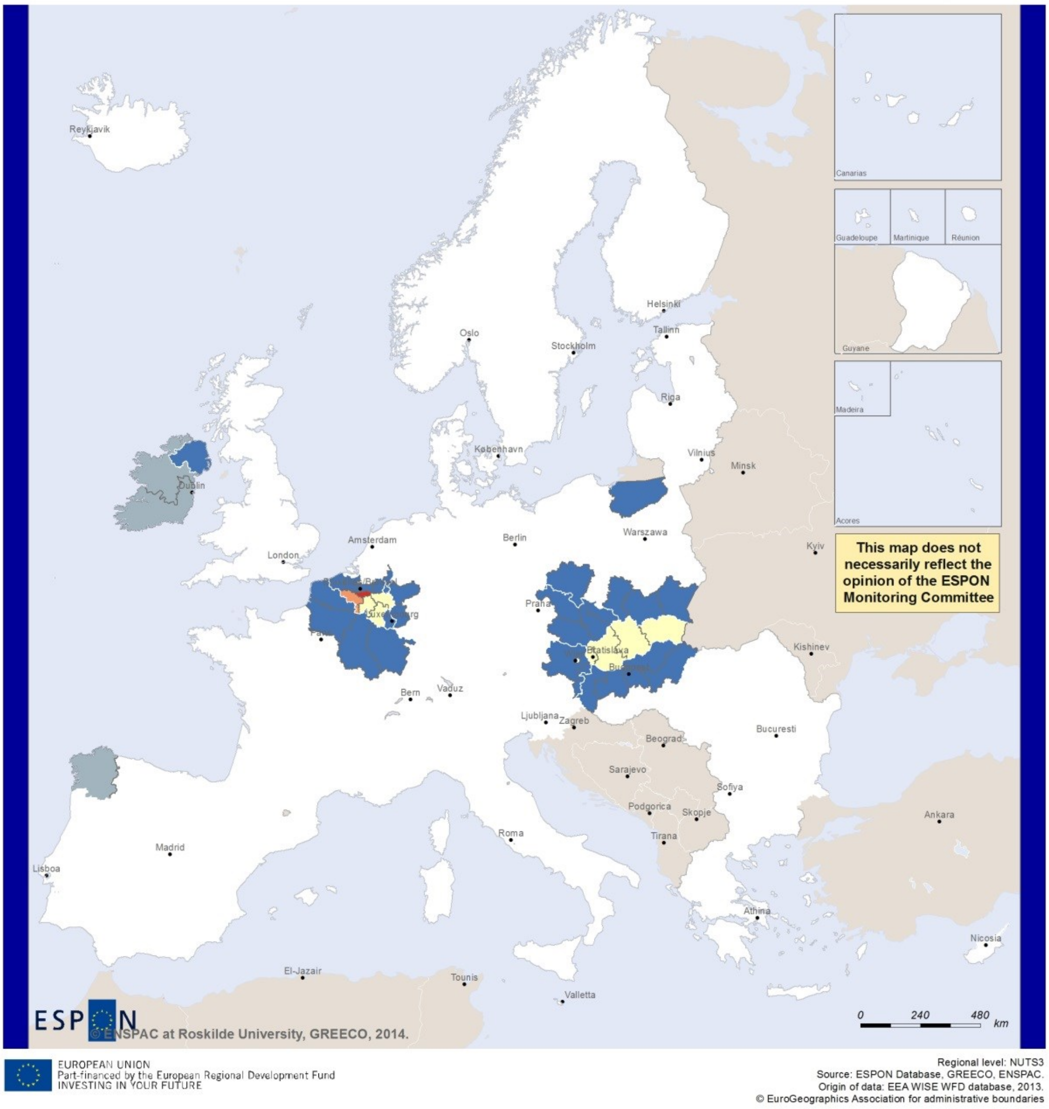
- **WQRivChemLtN3** Chemical status of rivers in river basins flowing through the region Rivers of less than good chemical status in river basins flowing through the region (Average of percent of total river length in the river basins flowing through the region weighted by their area in the region)
- **WQTranChemARN3** Chemical status of transitional waters in river basins flowing through the region Transitional waters of less than good chemical status in river basins flowing through the region (Average of percent of total transitional water area in the river basins flowing through the region weighted by their area in the region)
- **WQCoastChemARN3** Chemical status of coastal waters in river basins flowing through the region Coastal waters of less than good chemical status in river basins flowing through the region (Average of per cent of total coastal waters area in the river basins flowing through the region weighted by their area in the region)

2. Regional patterns



Transitional water area of less than good chemical status, 2011.
Per cent of river basin transitional water area.
Weighted average of river basins running through the NUTS2 territory.

0% - 20%
21% - 40%
41% - 60%
61% - 80%
81% - 100%
No data



River length of less than good ecological status, 2011.
Per cent of river basin river length.
Weighted average of rivers running through the NUTS2 territory.

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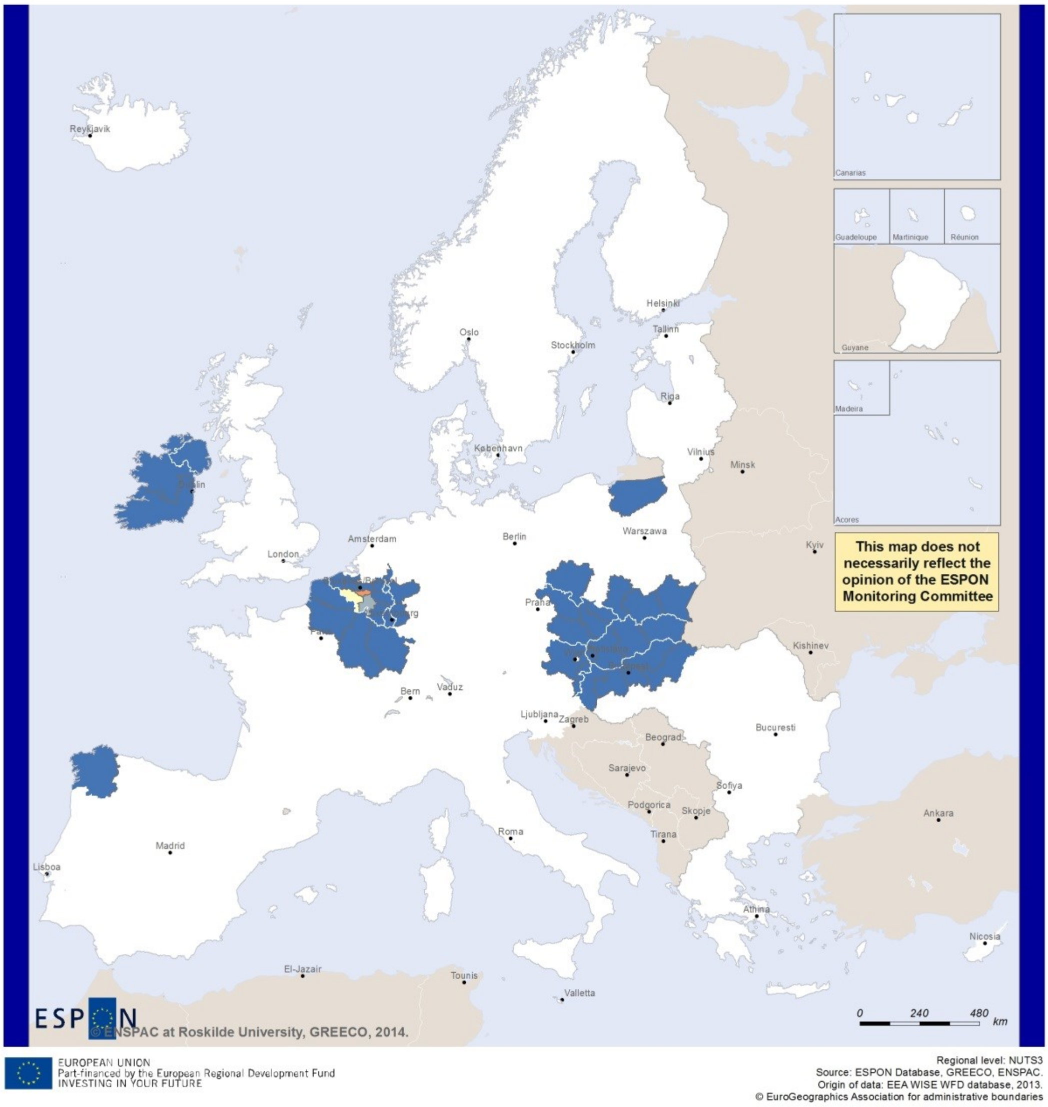
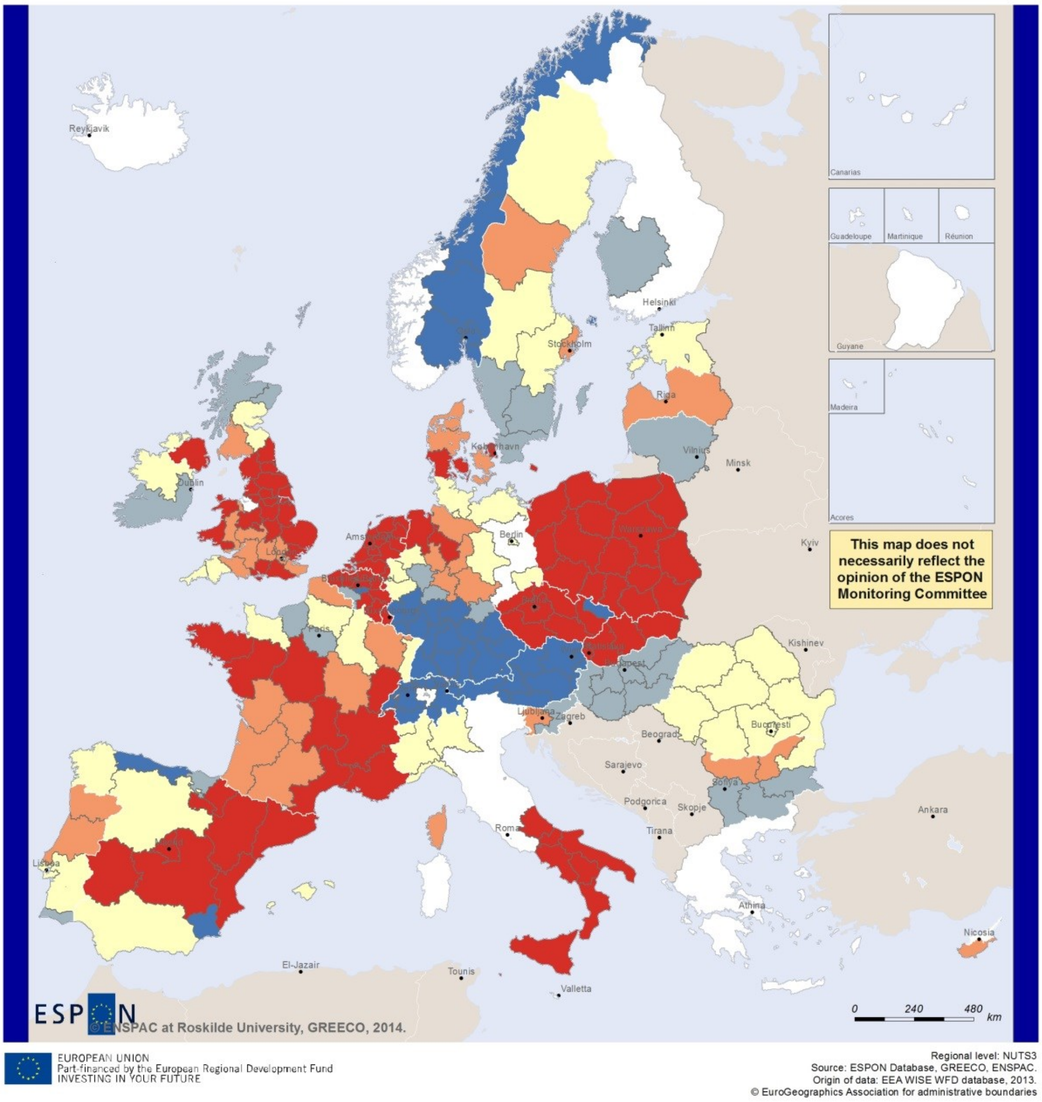
21% - 40%	61% - 80%	No data



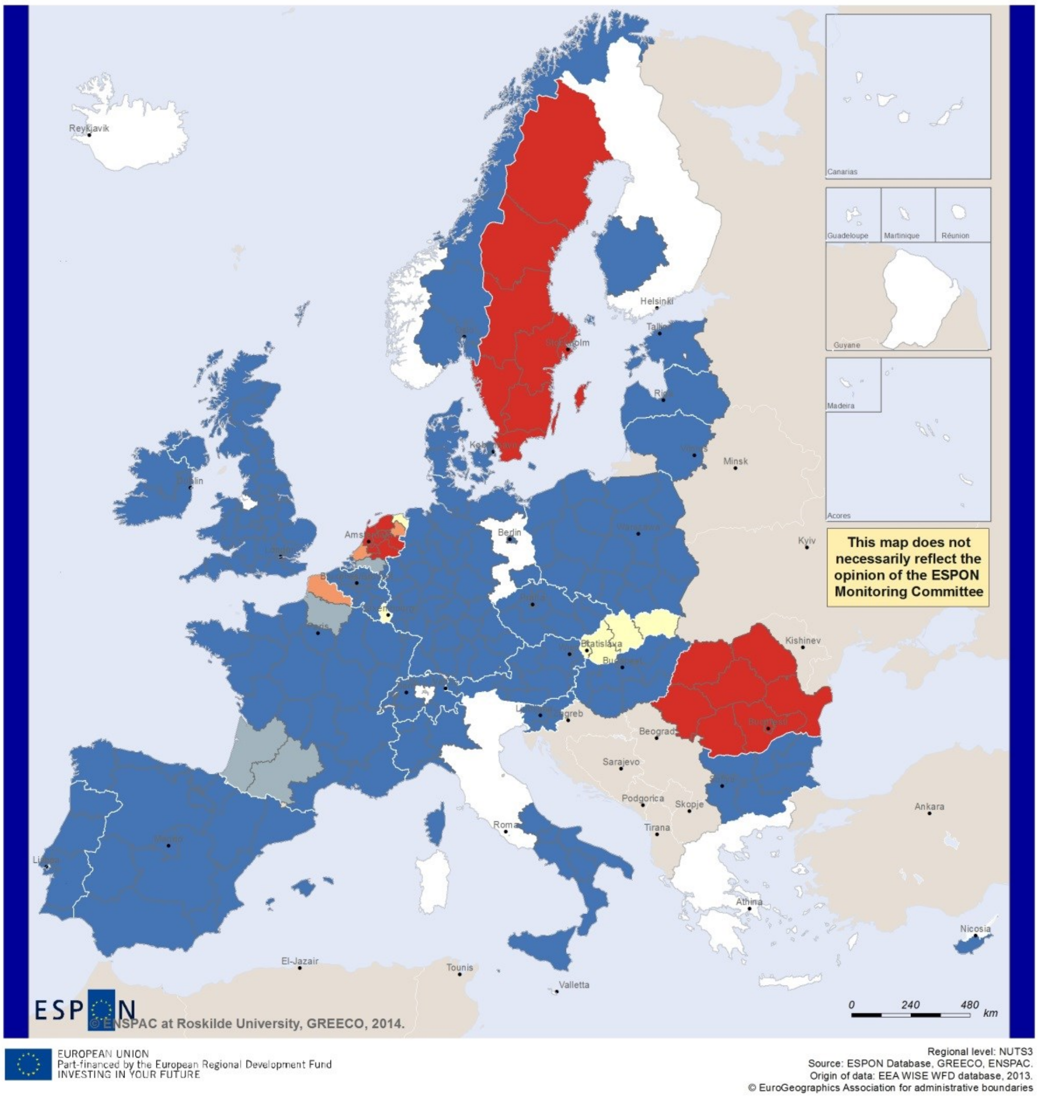
River length of less than good chemical status, 2011.
Per cent of river basin river length.
Weighted average of river basins running through the NUTS2 territory.

0% - 20%
21% - 40%
41% - 60%
61% - 80%
81% - 100%
No data



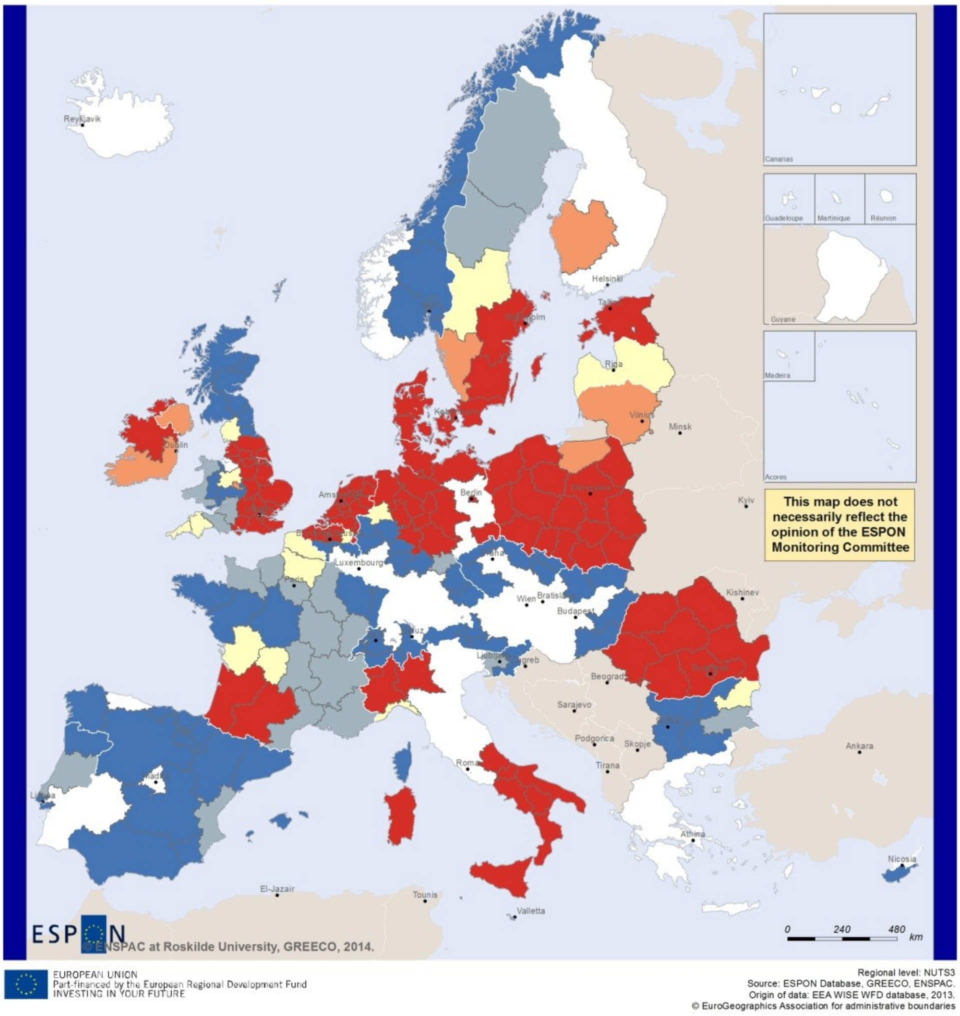
Lake area of less than good ecological status, 2011.
Per cent of river basin lake area.
Weighted average of lakes running through the NUTS2 territory.

0% - 20%
41% - 60%
81% - 100%
21% - 40%
61% - 80%
No data



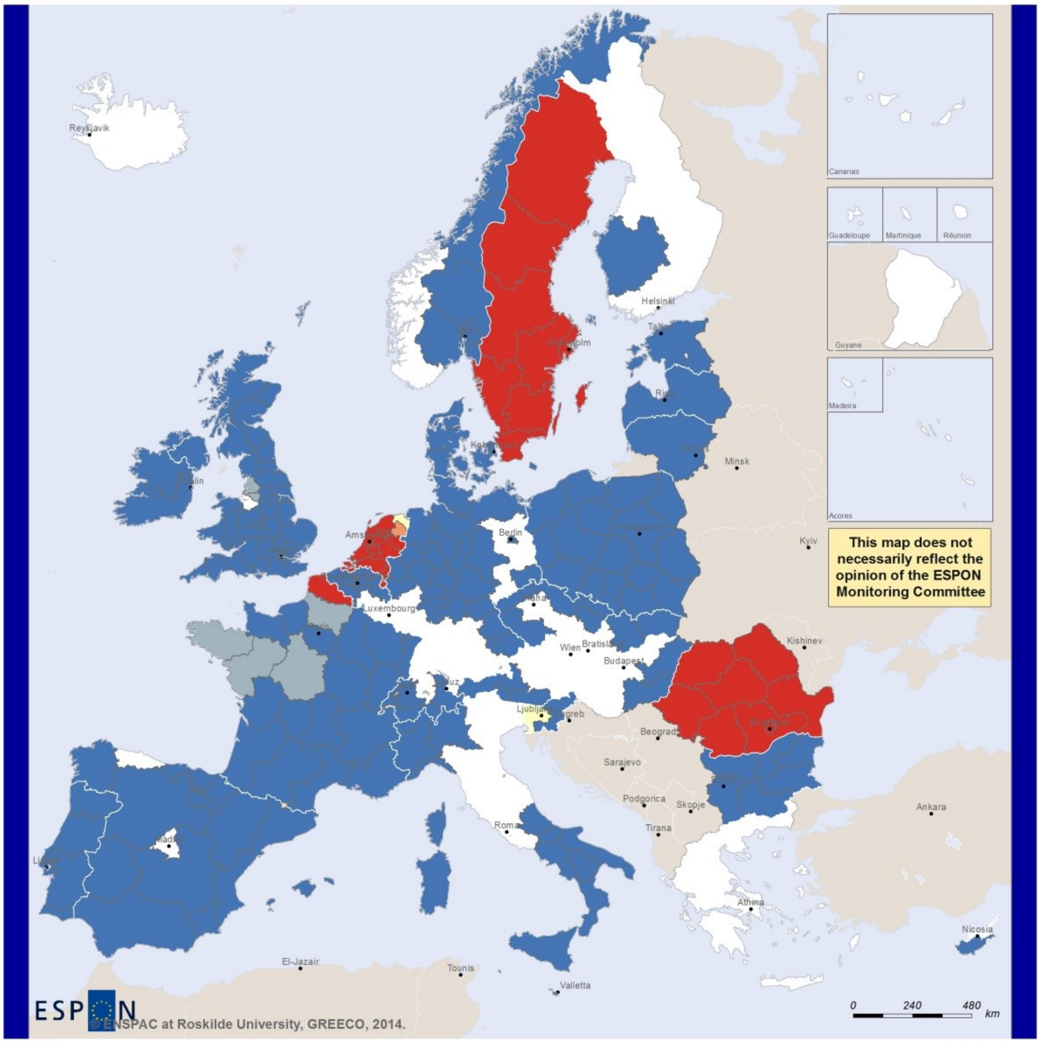
Lake areas of less than good chemical status, 2011.
Per cent of river basin lake area.
Weighted average of river basins running through the NUTS2 territory.

0% - 20%　41% - 60%　81% - 100%
21% - 40%　61% - 80%　No data



Coastal water areas of less than good ecological status, 2011.
Per cent of river basin coastal water area.
Weighted average of coastal waters running through the NUTS2 territory.

0% - 20%	41% - 60%	81% - 100%
21% - 40%	61% - 80%	No data



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Regional level: NUTS3
Source: ESPON Database, GREECO, ENSPAC.
Origin of data: EEA WISE WFD database, 2013.
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Coastal water area of less than good chemical status, 2011.
Per cent of river basin coastal water area.
Weighted average of river basins running through the NUTS2 territory.

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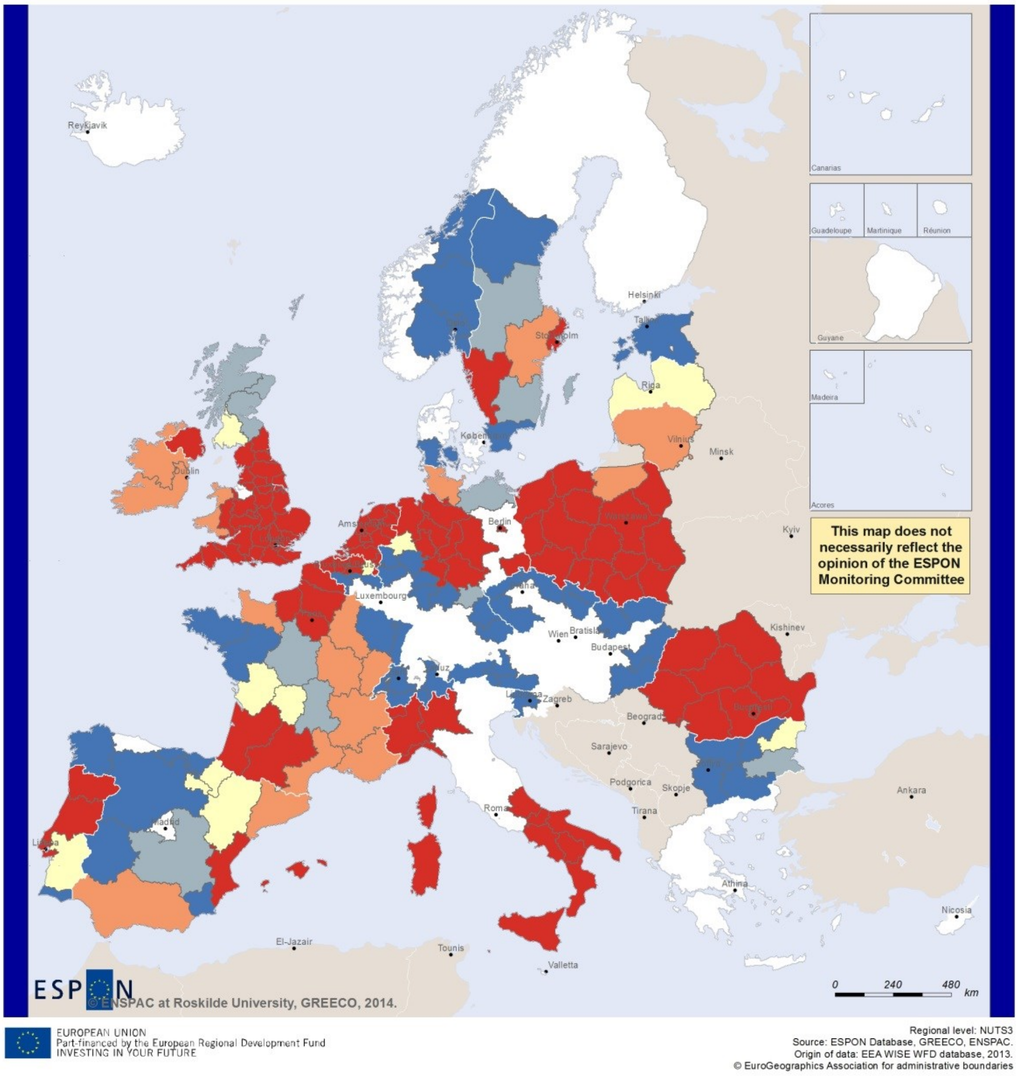
21% - 40%
41% - 60%
61% - 80%
81% - 100%
No data



Transitional water areas of less than good ecological status, 2011.
Per cent of river basin transitional water area.
Weighted average of transitional waters running through the NUTS2 territory.

0% - 20% | 41% - 60% | 81% - 100%
21% - 40% | 61% - 80% | No data

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