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The green economy

The concept of the *green economy* reflects the *operationalization* of the sustainability principles. These principles include balances between the present and the future generations, between social, ecological and economic concerns and between global interests and national self-interest. It is *inclusive* and its physical structures enable society to *prosper without over-consuming* the sink, resource and space budgets provided by nature. This is only possible if its system of fixed capital and supply chains (the econosphere) is designed for minimizing the consumption of the resources, sinks and spaces of nature.

Consequently, indicators of sustainable development including the social and ecological dimensions are better indicators of social progress. Composite indices attempting to reduce all dimensions to a one-dimensional indicator are, however, not recommendable. Composite indices by definition assume substitutability between their sub-indices. Instead a multidimensional indicator framework is recommended.

Measuring progress towards a green economy should take account of the potentials of the economy that differ widely.

Like economic balances the ecological balances be measured in terms of a budget. Economic balance is achieved if the economy does not consume more than the consumable budget. By the same token ecological balance is achieved by avoiding over-consumption of nature in its capacities of resources, sinks and areas.

Ecological balances

Exceeding limit values for air pollutants implies over-consumption of the sink capacity of the troposphere. There are national emission ceilings in Europe, but they are generally much higher than the ecological budget constrained by the limit values. EU targets for emission reductions by country represent emission budgets, but local and regional budgets for the severely exposed areas could facilitate the green transformation in these regions.

The point source emissions of major pollutants are often concentrated in a few regions. This is one of the reasons for the different exposure in different regions. Many of these regions face challenges of restructuring the economy as the large point sources are retired or downscaled.

The use of fossil fuels is an integrated part of the European story of economic growth in the 20th century. It linked CO_2-emissions closely to economic growth. The prospects of reducing CO_2 emissions to sustainable levels are formulated in carbon-budgets for the ETS sector as well for the non-ETS sector in the individual member-states.

The patterns of GHG emission reduction shows that the new member-states (NMS10) reduced their GHG-emissions in the 1990s along with Germany and the UK. In 2000-08, however, this trend was reversed. The CO_2-emissions increased in most regions as they experienced high rates of economic growth. This trend is set to continue in the 2013-2020 period. These higher emissions will then have to be reduced again in the 2020s or later.

The non-ETS sector carbon-budgets can be regionalised if statistical information on energy production and use is available at the regional level. An example of annual regional non-ETS sector reduction rates by NUTS2 regions is provided based on the pattern of annual carbon-budget reduction rates to GDP per capita.

Economic balances

Progress in the economic dimension can be measured by GDP or GNI per capita growth although this indicator is not perfect even just to measure progress in the economic dimension. Two indicators are important in assessing whether the economic growth is financially sustainable. First, only a part of GDP can be spent on consumption – some of it has to be reinvested to make up for the capital consumed. This is the constant total capital approach. Second, the government can run deficits to stabilise the economy, but not infinitely.

The adjusted net savings indicator includes consumption of natural resources in the constant capital stock principle. The European economies, however, have comfortable margins for spending on green investments within this criterion.

Social balances

It is important to be aware of the adverse distributional impacts of higher energy costs associated with the transformation of the production and use of energy. The methods developed for neutralising such adverse impacts shows that it is possible to use high energy prices to give incentive to changes without causing energy poverty.

The ecological-economic nexus

The simultaneous progress in the economic and the ecological dimension is not possible when the physical structures of the economy links flows of fossil energy to energy services and similarly flows of materials to other necessary services and products. Thus, the green economy requires different sets of materials and energy flows and fixed capital stocks designed to handle them. These sets are called the econosphere. The green econosphere is characterised by a larger amount of capital relative to the flows of materials and energy.

Energy delinking and decarbonisation

The emissions of CO_2 can be decomposed in a number of factors and a model was developed to study the impact of the individual factors. A higher rate of employment ("growth") had a positive impact on emissions in almost all countries. This was offset by a lower intensity of emissions ("decarbonisation") in the energy used. The energy used per employee also had a negative impact on emissions ("delinking") in most European countries.

The linking of carbonised energy to economic growth has during the 2000s resulted in an increasing share of GDP to be reserved for imports of mineral fuels. The economies of many of the member-states with the lowest per capita GDP are severely drained by this property of their econosphere.

Decarbonisation

The European onshore wind energy potentials have been estimated at the NUTS2 level. The estimates identify the physical, technical and economic potential at different levels of the social value of wind power and the wind power density. The estimates show that onshore wind could contribute considerably to regional income generation in many regions.

A similar study was carried through for PV-energy. The two studies show that these two renewable energy technologies complement each other. The European wind resources are primarily located in the North European wind belt from Bretagne to Finland. The PV energy potential is primarily located in Southern Europe. This points to a new dividsion of labour as energy producers and consumers and new energy-trade patterns between regions. It makes both local smart-grids and European scale super-grids necessary, both with new technologies for energy storage.

Energy dependency and delinking

Statistics on final energy consumption was collected and used for analysis of energy dependency rates, catch-up potentials and delinking.

Through the 2000s most of the EU15 economies managed to have lower final energy consumption while they had higher employment. In many of the NMS10 the energy consumption increased more than the employment in that period. Both need, however to delink much more in the 2010-20 period to reach the targets for 2020.

The final energy consumption by region increases with income level. It does so, however, at different rates. Transport energy demand is much more elastic to income level than residential energy use and production energy use is in between.

Ecosystem restoration

Two fundamental shifts are important to reverse the trend of declining biodiversity and increasing risks to natural ecosystems. First, the land allocation between economic (urban and agricultural) and nature purposes. Second, the use of the natural ecosystems and in particular the water bodies as sinks.

A merged dataset with updated CLC and designated nature area allows the analysis of spatial patterns of designated nature areas per capita. The regions with low rates of nature areas to population seem to cluster and thus being adjacent to each other. Thus there are quite large regions with homogenous levels nature areas per capita.

The limited data reported on the state of the aquatic environment under the Water Framework Directive indicates that measured by area, a less than good ecological state is more widespread than a less than good chemical state.

Green innovation and employment

The statistics on environmental goods and services describes the environmental protection and resource conservation expenditures in the private and public sectors. The employment effect of these expenditures can be estimated, but the definition of environmental expenditures limit the expenditures to only a couple of per cent of GDP. Transformations such as individual to public transport are for instance not included. Maybe half of the expenditure relates to the waste and wastewater sector. A large waste and wastewater sector can be environmentally beneficial but can also reflect a large flow of waste. Thus, this indicator should be interpreted with caution.

The green product innovations measured by patent applications show a traditional east-west and north-south pattern. Low rates of patent applications per employed are found in the east and the south of Europe. The share of green innovations is, however more mixed. In particular in the NMS10.

Some academic and political debates

A number of academic and political debates have questioned whether it is possible to achieve progress in the economic and the ecological dimension at the same time. Some of the questions are taken up here. They include

- delinking and rebound effects?
- economic progress without ecological decline?
- ecological progress without economic decline?
- green growth without green economy?

1. Introduction

1.1. The transformation to a green economy

Local government and administrative bodies as well as civil society and business networks and regional policy authorities are increasingly engaged in the transformation of the regional economies to a "green economies". In some regions the greening of the economy is even seen as the way out of an obsolete industrial structure and as the backbone of the regional development strategy.

This change in policy gives rise to a series of questions that are addressed in this report. First of all the question is how a green economy *differs* from the existing economy and what it means to regional policies. What is the difference between the typical 20th century European economy and the future green 21st century economy in *principle* and *praxis*? How does the *statistical indicator framework* needed for governing the transition towards a green economy differs from that needed for the 20th century economy?

Statistical indicator frameworks are important when operationalizing policy principles into executable programmes. They enable decision makers and the public to define exact objectives to be reached in defined time frames and they allow the continuous monitoring of progress towards the objectives.

This report thus focuses on the statistical indicator framework available, how well it reflects the underlying changes in the economy and how it could be improved to meet the needs of the 21st century. It takes up new data on the regional level to analyse regional level challenges of and progress towards the green economy and discusses the strengths and weaknesses of the indicators.

The above questions are addressed from several angles. The green economy is not a scientific concept, but formed as a political vision emerging from a policy debate. Thus, the study attempts to integrate definitions from political consensus documents with definitions from the scientific literature and attempts to empirically quantify the "greenness" of the economy. This approach is chosen with the aim of getting closer to an operational understanding of the concept of a green economy at various territorial levels.

The concept of a region is closely linked to the territorial level of government. EU government provides the institutional framework for transformations to a green economy in all of Europe. National government remains the backbone of the European government structure, but in federal states sub-state governments has powers that are in the hands of national government in other states. Authority is delegated to local government (including municipal as well as regional government) in varying degrees.

This structure of government means that the powers of local governments for changing "their" economies in a green direction are limited and varying. Most of the institutional frameworks are decided at the EU and national levels. On the other hand, they can exert influence on national and EU policies with regional impacts. Thus, the present study also attempts to see the sub-national level changes of the economy in their coherence with EU and national level changes.

For national and local government alike the statistical indicator framework offers the opportunity of identifying and describing challenges and potentials of green transformations. Further, it enables the formulation of policy objectives as quantitative targets to be achieved within specified time frames. It also enables the monitoring of progress towards - or steps backwards - the targets. The study discusses all three dimensions of the statistical indicator framework for transition to a green economy.

The ambition of report is not to provide a complete blueprint for how to orchestrate the transition to the green economy at the various levels of government. The ambition is rather to approach a concept of a green economy that is useful in identifying and quantifying what to change and how to change it. The statistical data frameworks are discussed.

The report is organised as follows. It takes departure in political consensus on the concept of sustainable development and its three dimensions: economic, ecological and social. Section 3 discusses attempts to measure the overall sustainability and greenness of economies and section 4 the sustainability indicator framework in the EU. The criteria for sustainability are discussed in each of the three dimensions in sections 5-8. Section 9 describes the physical interface between nature and the economy, the econosphere and sections 10-12 analyses changes towards a low carbon econosphere. Section 13 is about delinking of other flows ("dematerialisation") and section 14 restoration of natural ecosystems. These changes require innovation – development, production and use – of new green technical solutions. Indicators on these are reviewed in the sections 15-17.

The relevant policy issues are addressed in each of the sections. Policies and institutions in specific sectors are addressed in other reports of GREECO project.

2. Sustainability and the green economy

2.1. Defining the green economy

The vision of a green economy reflects a future where economic prosperity goes hand in hand with conservation of ecological values and a society in social balance. Beyond this understanding, however, there is little consensus on what a "green economy" really is.

The concept has been used in scholarly publications, but there is no scientific consensus on an unambiguous and concise definition. The meaning of the concept has primarily evolved from the international political discourse on sustainable development. It is, however, supported by science-based studies underlying the strategic decisions and orientation of international and national policies.

2.2. The emerging consensus on a green economy

The green economy was literally put on the agenda of the world community by the decision of the United Nations general assembly on organising in 2012 the United Nations Conference on Sustainable Development "Rio+20". The conference agenda contained two themes: a) "a green economy in the context of sustainable development and poverty eradication" and b) "the institutional framework for sustainable development" (UN, 2010).

The United Nations Environmental Programme (UNEP) provided a range of important analyses and strategy papers in the years leading up to the conference. The green economy concept as such a framework for development was defined by UNEP as

"*a green economy as one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. In its simplest expression, a green economy can be thought of as one which is low carbon, resource efficient and socially inclusive. In a green economy, growth in income and employment should be driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services. These investments need to be catalysed and supported by targeted public expenditure, policy reforms and regulation changes. The development path should maintain, enhance and, where necessary, rebuild natural capital as a critical economic asset and as a source of public benefits, especially for poor people whose livelihoods and security depend on nature*" (UNEP, 2011, p. 9).

This definition is not in any important respect different from the definition of sustainable development provided by The Brundtland Commission (World Commission on Environment and Development (WCED), 1987) and the documents agreed upon at the Rio summit in 1992, the Rio Declaration and the Agenda 21 (United Nations (UN), 1993).

The WCED definition states that "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs…, in particular the essential needs of the world's poor, to which overriding priority should be given; … Development involves a progressive transformation of economy and society." (World Commission on Environment and Development (WCED), 1987).

The Rio Declaration (United Nations (UN), 1993) similarly states that "The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations." "Environmental protection shall constitute an integral part" of and "eradicating poverty" is "an indispensable requirement for sustainable development" (Principles 3-6).

This "3 dimensional" concept of sustainable development is unfolded in more detail in the Agenda 21 document of the Rio Summit (United Nations (UN), 1993). It contains details on the *social, economic and ecological*[1] dimensions. It is evident from the documents that social progress is *sustainable development* in its three dimensions rather than simply *economic growth.*

The consensus documents emphasise that poverty eradication and the ecological values that the present generation share with future generations are essential components of sustainable development. Thus, it can be inferred that the consensus excludes the principle of economic growth as an overriding priority to which ecological and social concerns necessarily must give way. Practically all governments have adopted the concept of sustainable development as the overarching ambition for society and understanding of social progress. The broad definition of what sustainable development is and what it is not, however, leaves the concept open to varying national interpretations.

Since the 1992 Rio summit the EU, its member states and regional authorities have attempted to implement the principles of sustainable development as have governments around the world. The 2002 UN summit in Johannesburg confirmed the principles of sustainable development and adopted the Johannesburg Plan of Implementation (United Nations (UN), 2002). The green economy can be seen as way to generalise this experience with technologies and ecological responses and institutional frameworks for related information and innovation as well as technical and economic regulation of ecological-economic patterns. In this sense the green economy is the *operationalization* of the principles of sustainable development.

The Rio+20 conference in 2012 recognised the importance of advancing the consensus on the principles of sustainable development towards more operational *goals* for sustainable development (United Nations (UN), 2012). In its final document "The future we want" it defined the "green economy in the context of poverty eradication and sustainable development" as an economy that "should contribute to eradicating poverty as well as sustained economic growth, enhancing social inclusion, improving human welfare and creating opportunities for employment and decent work for all, while maintaining the healthy functioning of the Earth's ecosystems" (United Nations (UN), 2012, p. 9). Moreover, the final document emphasises "that fundamental changes in the way societies consume and produce are indispensable for achieving global sustainable development" (United Nations (UN), 2012, p. 39).

The operational setting of goals, objectives and targets is left to the subsequent series of conferences. They will relieve and build upon the results of the Millennium Development Goals (MDG) and are insofar primarily concerned with the developing and emerging economies. They are also concerned with the transformation of the developed economies. For the EU they are described in the

[1] Called "environmental" and "Conservation and management of resources for development" in the document, but called "ecological" to represent "source" and "area" as well as "sink".

EU Strategy for Sustainable Development and the Europe 2020 strategy for smart, inclusive and sustainable growth. The EU Commission provides an overview of Rio+20 implementation actions in the EU and internationally and includes them in the proposal for the 7th environmental action programme (EC, 2013a, 2012a).

The European Commission and UNEP characterize the green economy as "patterns of consumption and production (that) are sustainable and enable all citizens to have access to resources while conserving the quality and quantity of the world's shared resources. This implies primarily the decoupling of economic growth and well-being from energy and resource consumption" (EC, 2011a). As elaborated in more detail below, the coupling of energy and resource consumption is built-in in the fixed capital stock of infrastructure, buildings, plants, machines, means of transport. Thus, in economic terms, sustainable or delinked patterns of consumption and production is to a high degree a matter of investment.

The transformation of the economies towards a green economy involves investment in new production capacity and new technologies across a broad range of industrial sectors. As a response to the 2008 financial crisis and the ensuing investment crisis and recession, the UNEP and others advocated for a *green new deal*, advancing such investments to break the negative spiral of the crisis and hasten the recovery (Edward B. Barbier, 2009; United Nations Environmental Programme (UNEP), 2009). The EU Commission shared some of these views in its recovery plan from 2008 (EC, 2008a), but it is, of course, the member states that control the government budgets required for realising the green new deal. The fiscal consolidation strategy from 2011, however, pulled in the opposite direction.

At a ministerial level meeting in 2009, the OECD countries reached a consensus on developing a common response to the dual challenge of their ecologically unsustainable economies and the collapse of the economically unsustainable growth in the preceding years. The following year an interim report was presented (Organisation for Economic Co-operation and Development (OECD), 2010) and in 2011 the strategy "Towards Green Growth" was published opening with the following explanation of the need of a green growth strategy: "The world faces twin challenges: expanding economic opportunities for a growing global population, and addressing environmental pressures that, if left unaddressed, could undermine our ability to seize these opportunities" (OECD, 2011a).

According to the accompanying report on green growth indicators "green growth is about fostering economic growth and development while ensuring that the natural assets continue to provide the resources and environmental services on which our well-being relies. To do this it must catalyse investment and innovation which will underpin sustained growth and give rise to new economic opportunities" (OECD, 2011b).

The United Nations Division on Sustainable Development (UNDESA) has reviewed 50 similar publications and 32 national strategies on the green economy, green growth and a low-carbon economy. The definitions on a green economy differ considerably, but they share some common elements:

"Social: Human well- being; social equity; socially inclusive; reduced inequalities; better quality of life; social development; equitable access; addressing needs of women and youth.
Economic: Growth in income and employment; public and private investments; resilient economy; economic growth; new economic activity.

Environmental: Reducing environmental risks and ecological scarcities; low carbon; resource efficient; reduce carbon emissions and pollution; enhance energy and resource efficiency; prevent loss of biodiversity and ecosystem services; within ecological limits of the planet; environmental responsibility; finite carrying capacity" (Division for Sustainable Development (UNDESA), 2012, p. 60).

It is important to note that in all definitions of "sustainable development" and "green economy" the economy should "contribute to" or "ensure" progress in a range of dimensions *simultaneously* or at least in parallel in the long run. None of the definitions use the word "or" when listing the functions that a green economy should be able to deliver. Thus, the concept of a green economy underlines that even with best of intentions, it is not enough to strike the right balance between economic and ecological values given the technically and economically feasible options offered by the economy. A green economy also means an economy that provides a different set of options for achieving economic prosperity and ecological balance at the same time.

There are more institutional frameworks and societal conditions that are often brought into the discourse on a green economy. They include broader goals such as peaceful international relations and a highly developed democracy with comprehensive citizen participation. These aspects are, however, beyond the scope of this report that focuses more on the economy, the material relations between people in a society sharing production, consumption and investment.

The above definitions depict a shared vision of a 21st century green economy. It can be inferred that unlike the typical industrial economy of the 20th century, the green economy is *inclusive* and able to *prosper without over-consuming* the sink, resource and space budgets provided by nature. This is only possible if its system of fixed capital and supply chains (the econosphere) is designed for minimizing the consumption of the resources, sinks and spaces of nature.

This does not in any important respect differ from the principles of sustainable development agreed upon in the documents of the Rio Summit in 1992. On the contrary, the concept of the *green economy* reflects the *operationalization* of the sustainability principles. These principles include balances between the present and the future generations, between social, ecological and economic concerns and between global interests and national self-interest.

3. Analysing social progress

3.1. GDP as a measure of well-being

One of the rising concerns in the 60s was the rising social costs which was associated with the economic growth, but not accounted for. As many economists pointed out in, GDP is poor measure of economic progress because these costs are unaccounted for and their growth may even outpace economic growth (E.g., Mishan, 1971).

One of the first and most comprehensive attempts to quantify these costs and adjust the GDP to a more informative measure of economic progress was the study by Nordhaus and Tobin on the question of whether growth had become obsolete (Nordhaus and Tobin, 1972). Recognising that GDP is a poor indicator of general well-being and even of economic well-being, they decomposed it into components, which were directly related to human well-being and components that were not. The positive impact of household activities was added to the former and the negative impact of urbanisation was subtracted. The result was a Measure of Economic Well-being (MEW), which, however, could not confirm the suspicion that the social costs of economic growth outweighed the benefits. It turned out to develop in parallel with GDP.

Daly (Daly et al., 1994) explained the parallel development by the missing social dimension of the index. Including a measure of inequality in an "Index of Sustainable Economic Well-being" with a weight of 50% produced a much different development. Whereas there is no doubt that social balance is an important component of social progress, it is difficult to find a scientific basis for the weight and the index.

Another observation that questioned the use of GDP as an overall measure of social progress was the *Easterlin paradox* (Easterlin, 1973). Easterlin found that the average feeling of happiness as revealed by regular happiness surveys did not follow GDP. Surveys studying such broad questions such as the respondents' feeling of happiness can be subject to serious framing bias, but the Easterlin paradox was confirmed by several studies in the following decades.

Such considerations provided the background for the consensus on sustainable development as a strategy for economic development and as a conceptual framework for indices of social progress. The most extreme versions of the alternative frameworks for social progress that were propagated in the growth and environment debate of the 1970s and 1980s can be characterised as "maximum economic growth at all costs" and "zero growth for conserving ecological values". They represent a dilemma in the choice of strategy that is rejected by the sustainable development concept. The national accounts framework with its income and production aggregates is clearly insufficient to reflect social progress or sustainable development as defined above.

3.2. Adjusting and synthesizing indices

Against this backdrop several attempts have been made to develop better measures of social progress. The EU Commission has engaged in this work with a comprehensive set of initiatives (EC, 2013b, 2013c, 2013d, 2009a) and has commissioned the Stiglitz-Sen-Fitoussi-report on the issue (Stiglitz et al., 2009).

The Commission provides a compilation of indices developed to satisfy this need for better measures of social progress. The indices comprise indicator frameworks on the three dimensions – economic, ecological and social – and attempts to integrate the three dimensions in aggregate well-being measures. The well-being indicators can be categorised in four groups.

Indicators of *well-being relevant consumption opportunities of the present* take departure in the gross national income and adjust it for fixed and natural capital consumption, defensive expenditure etc much along the lines set out for the MEW and ISEW above (Daly et al., 1994; Nordhaus and Tobin, 1972).

Indicators of changes in the *productive capacity of the future* involve the balance between savings, investments in human capital and the use of man-made and natural capital. These indicators follow the capital stock approach operationalizing the sustainability concept in a way similar to portfolio management. The adjusted net savings approach below belongs to this group of indicators (The World Bank, 2011).

Indicators of *poverty and exclusion* of groups of society from the private consumption opportunities, public services and ecosystem services are important for assessing the actual well-being impact of larger consumption opportunities. The shares of the population at-risk-of-poverty, severely materially deprived citizens, long-term unemployed and low educated citizens indicate the result of marginalisation mechanisms. Income and wealth inequality measures can indicate the share of the population that is included in the economic growth.

Indicators of *subjective well-being* are derived from surveys of happiness and satisfaction. Time-use studies with values of well-being assigned to the various categories of time use also represent an approach to quantify subjective well-being.

Composite well-being indices attempt to combine the above indicators in a single dimension measure of economic or overall well-being. The Human Development Index (HDI) and the Human Poverty Index (HPI) discussed below are prominent representatives of this class of indicators.

3.3. Human development index and Human Poverty Index

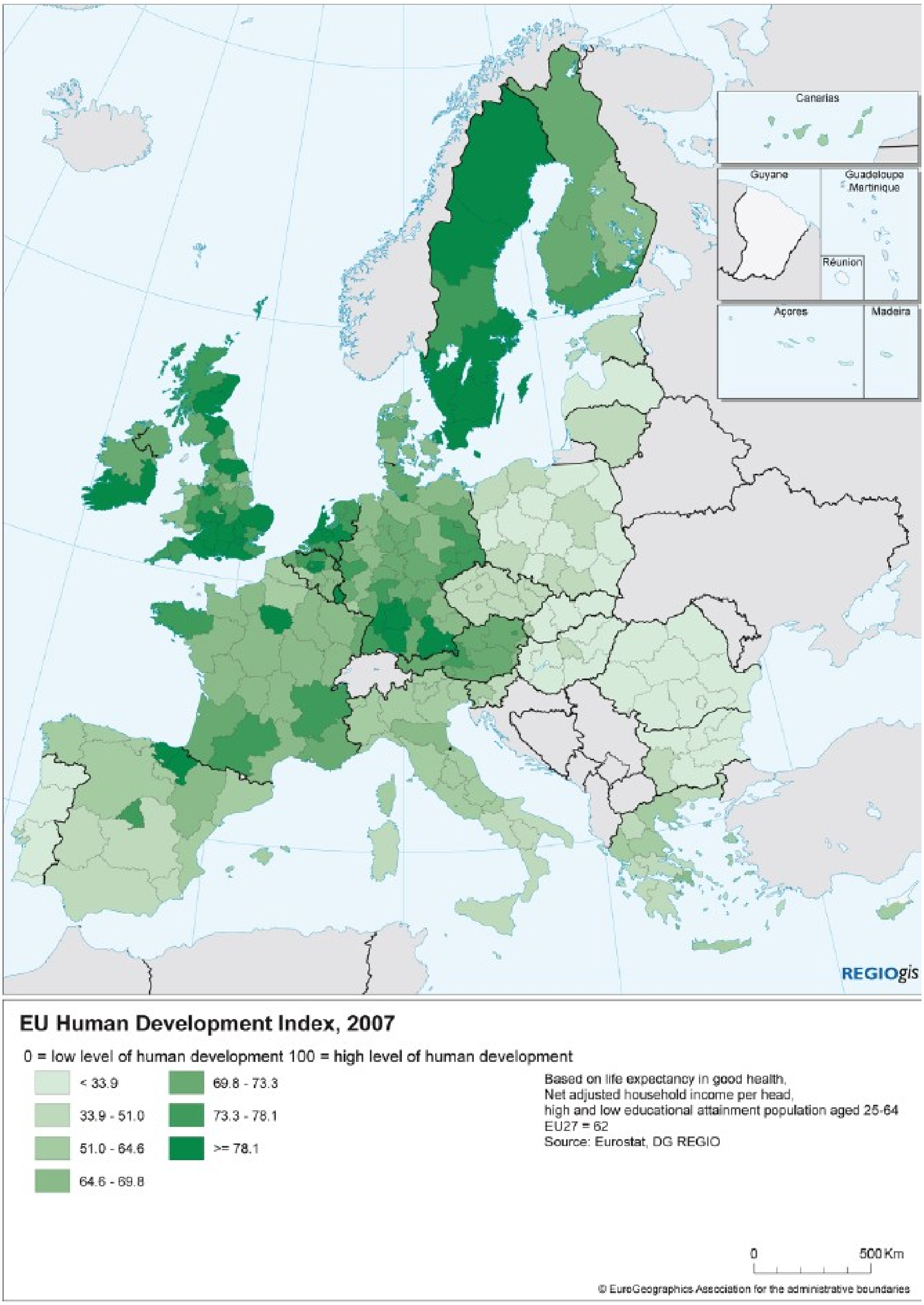
The United Nations Development Programme (UNDP) has published a series of human development indices on health, education and income levels of almost all countries since 1990 (United Nations Development Programme (UNDP), 1990). The annual publications also ranks countries according to an aggregate Human Development Index in which the three sub-indices for health, education and income enter with equal weights.

The HDI is computed as the geometrical mean of the three indices with equal weights, that is,

(1) $$\text{HDI} = \text{Longevity index}^{(1/3)} * \text{Education index}^{(1/3)} * \text{GNI per capita index}^{(1/3)}$$

From 2010 onwards the formulas for calculation of these sub-indices have been revised. In particular, the education index was formerly composed by indices of literacy and enrolment, but from 2010 by years of schooling.

The index has been calculated for European NUTS2 regions with indices of low and high education. The result is shown in map 1.

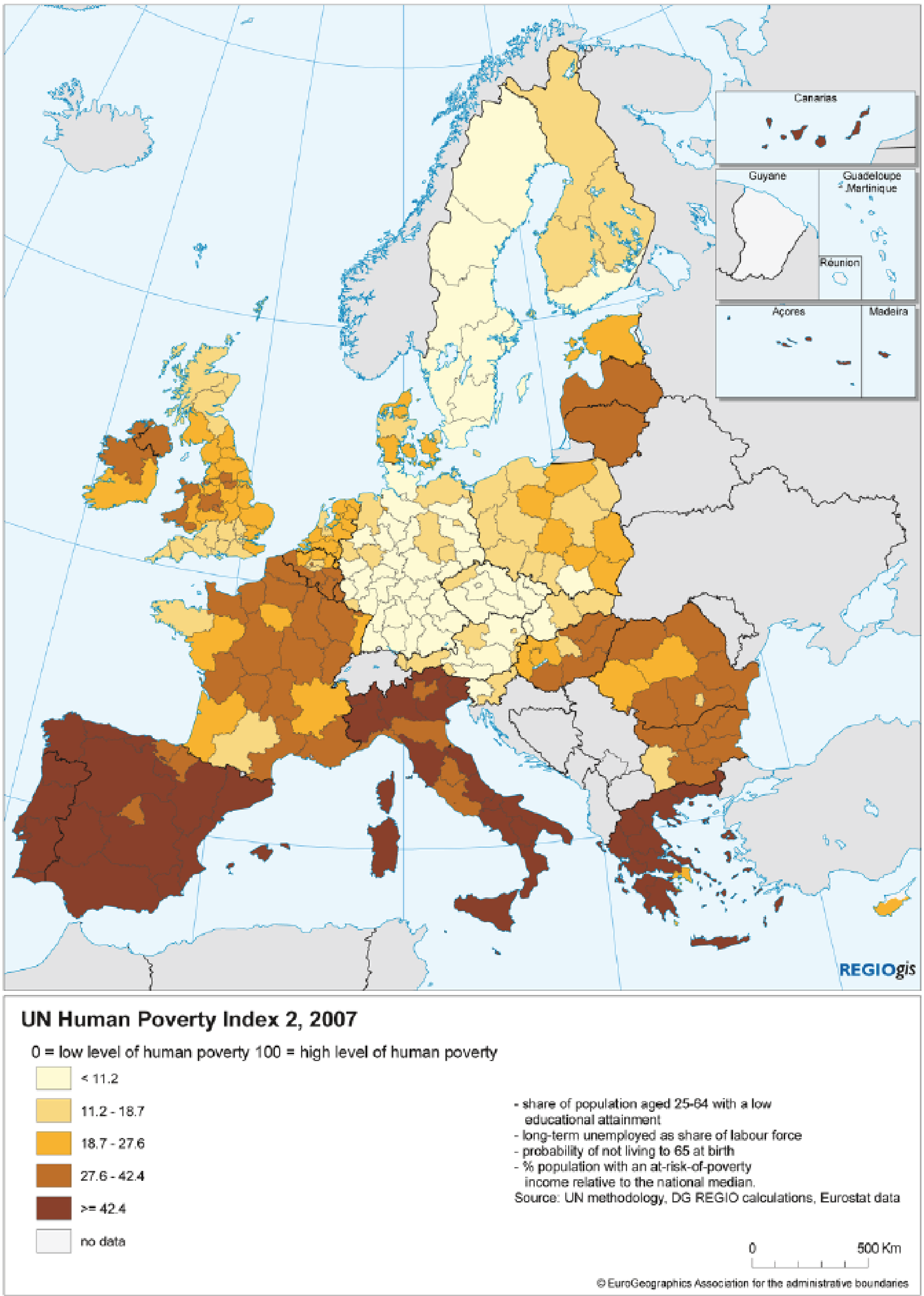


Map 1. Human Development Index (HDI) by NUTS2-regions, 2007.
Source: (Bubbico and Dijkstra, 2011, p4)

The regional patterns of the HDI share similarities with the regional patterns of GDP or GVA per capita and derived indicators. This is because the HDI is composed by a GNI per capita index and indices of education and life expectancy that are closely correlated with GDP per capita.

It is important to note that different regions of an economy have different potentials for achieving a high HDI. Metropolitan regions host universities, head quarter functions of corporations and similar government functions and all kinds of specialised services that require highly educated staff. This is not the case for rural and peripheral regions. Thus, it is neither expectable nor socially desirable that rural and peripheral regions should score as high as metropolitan regions in education and income level. Thus, for providing information of how a region performs, the HDI index of a region should be related to its potentials and the it should be compared to peers as to the individual sub-indices.

The HDI does not reflect economies with strong social exclusion processes. The UNDP has developed a Human Poverty Index (HPI) for this purpose and it has also been calculated for European NUTS2-regions. The result is shown in map 2.



Map 2. Human Poverty Index 2 (HPI2) of NUTS2 regions, 2007.
Source: (Bubbico and Dijkstra, 2011, p5).

The HPI2 for NUTS2-regions is composed by indices of longevity, low education, share of population with income less than 60% of the median and the long-term unemployment. All of these four sub-indices are assigned the same 25% weight. Map 2 reveals patterns that are to some degree similar to those of map 1. This is not surprising as the two indices share two sub-indices and as the other two sub-indices are correlated with GDP per capita. However, the pattern of "trade-off" between the HDI and the HPI2 differs between the new member states (NMS10) and the EU15. At a given HDI value, the NMS10-regions have much lower HPI2 values than the EU15 regions (Bubbico and Dijkstra, 2011).

3.4. Composite indices

The HDI and HPI2 indices do not include sub-indices reflecting the ecological dimension, but they highlight the problem of weighting in composite indices.

The mathematics of composite indices inevitably involves weights assigned to the individual indices. In some cases the sub-indices are assigned equal weights because there is no empirical basis for assigning a specific weight. In these cases, however, a specific weight is assigned like 1/3 in equation (1) above. Thus, assigning equal weights is not the same as assigning no weights, but assigning random weights, depending on the number of sub-indices in the calculation.

This has important consequences for the impact of changes in the sub-index on the composite index. This is because the weights are relative prices, terms of trades for changes in the sub-indices. In the case of equation (1) a one-point change in one sub-index like longevity can be offset by a one-point change in the education index.

There are two problems with this method. First, it assumes that decline in one index can be offset by progress in one or more of the other indices. In equation (1) any decline in the health and education indicators can be offset by a higher GNI and still show a higher level of human development. Second, even if such substitutability is warranted the "exchange rate" between the indices is arbitrary. If nothing else is known about the importance of progress in health vs education vs income, it is most likely not constant, but changes over time and by region and country. A more in depth analysis of the implicit price on health and educational standards is provided by (Ravallion, 2010).

The concept of sustainable development reflects a consensus on progress in all three dimensions – not in one dimension at the cost of decline in another dimension cf. section 2.2. Economic growth at the cost of important ecological values that we share with future generations would not meet this criterion for sustainable development or social progress. Economic growth without poverty eradication would not be social progress either. A composite index can reflect developments where progress in one dimension can offset decline in another, but not sustainable development.

In cases where different sub-indices reflect the same development and run in parallel, they can be combined to composite indicators. This is, for instance the case for indicators of consumer confidence and for innovative activity. This is particularly useful if there are data gaps or delays in some of the sub-indices.

In cases where substitution between the sub-indices is warranted, the appropriate weights must reflect the values and the importance of progress in the sub-indices as assessed by the users. The OECD has developed a "Better Life Index" where the each user has to set her own weights to 11 sub-indices (Organisation for Economic Co-operation and Development (OECD), 2013a). Operationalising such a solutions for policy decisions in a regional context would require continuous collection of poll data from a representative sample of the citizens of the region on the relative importance of the sub-indices. This would probably involve difficulties as many citizens may lack the mathematical skills required for assigning weights to a set of indices.

3.5. Composite environmental index

Another attempt to contribute to a broader understanding of social progress is a measure of environmental quality developed in the framework of an EEA project (EEA, 2011). It includes 5 sub-indices:

(1) FARO — EU Rural typologies
(2) High Nature Value farmlands;
(3) proximity to natural areas (CLC semi-natural classes, N2000, CLC water);
(4) PM10 (air quality);
(5) degree of soil sealing

Based on these indices, a map of a composite index on environmental assets is produced.

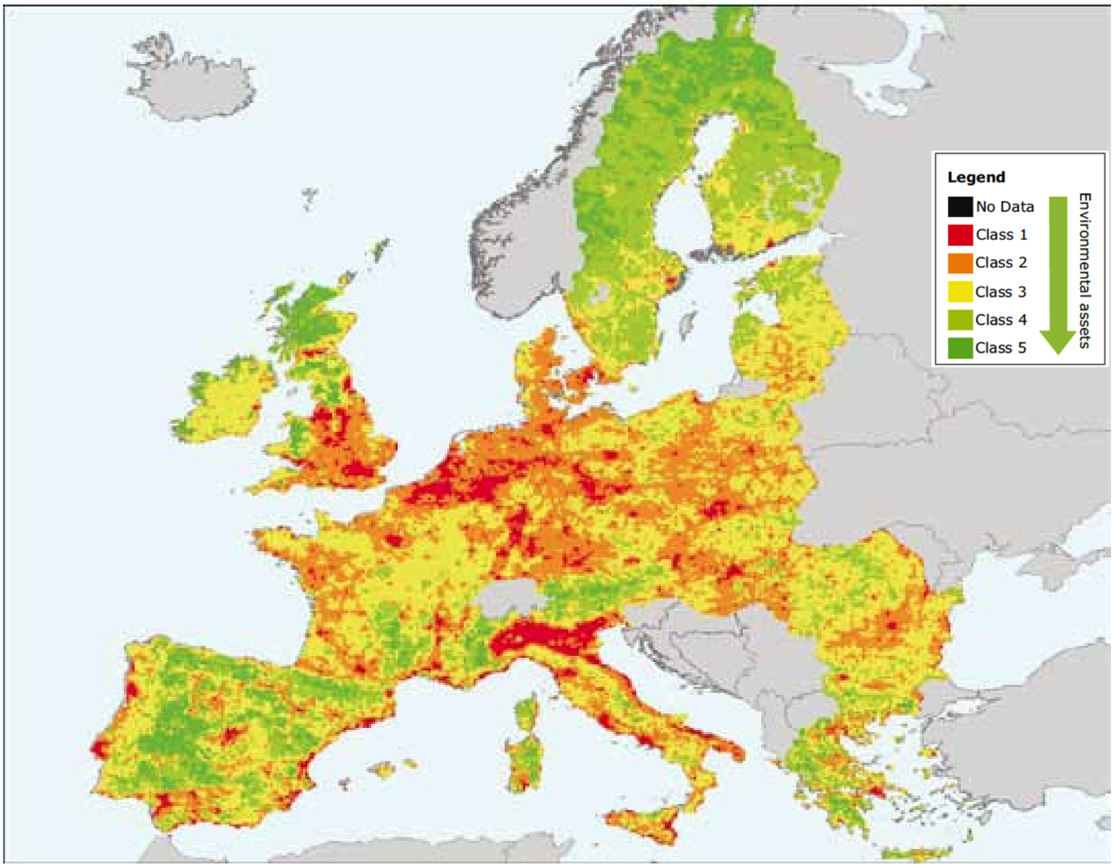


Figure 1. Composite environmental asset index.

Source: (EEA, 2011).

The map in figure 1 shows a spatial pattern similar to the pattern of population density. This is because air pollution and the degree of soil sealing are positively correlated and nature and farmland negatively correlated with population density.

If such an index was used operationally by assigning targets to the composite index, then a region would show progress towards a green economy even if the number of premature deaths due to air pollution was increasing as long as the share of farmland classified as "high nature value" was also increasing. This would be in conflict with the fundamental policy principle of EU environmental policy that rejects not accept "significant negative impacts on and risks to human health and the environment" (EC, 2002) regardless of the landscape qualities in other parts of the region or country.

3.6. A multidimensional indicator framework

Compared to a composite index, a multidimensional indicator framework provides a more informative framework for policy decisions on the transformation of economies to green economies. Some statistical material is available at the regional level and is reviewed in the following. There is, however, not any scientific basis for assigning constant weights to the individual indicators. If weights are derived from running opinion polls, they must be expected to change according to the shifting challenges of to the economy and the corresponding shifts in political priorities. That would, however, complicate the interpretation of changes in the index over time.

With the above definitions on a green economy it means social progress means achieving progress simultaneously in all three dimensions – economic, social and ecological. It is not about progress in one dimension at the cost of decline in another dimension. This is challenging - in particular in the ecological-economic nexus where the 20th century economies were characterised by trade-offs between environmental qualities and economic growth.

In the social-economic nexus, it is not as challenging to achieve synergies because economic growth often provides opportunities for the poor to work themselves out poverty and leave the "vicious circles" of poverty. This is, however, not automatically ensured if growth is not inclusive. In the social-ecological nexus, synergies are also more easily achieved because environmental risks often are more severe in areas populated by poorer segments of the population whereas well earning segments are able to pay the higher price of locating in greener areas. These aspects will be covered in the treatment of the social dimension below.

The primary focus in the following is on the ecological-economic nexus to which we return after the review of the three dimensions below. The trade-offs or synergies between environmental and economic values depends on the physical system of materials and energy flows and fixed capital stocks designed to handle them. This system can be called the *econosphere* to distinguish it from other aspects of the economy. This is important for being able to identify the properties that have to be changed and those that are of less importance for the ecological-economic sustainability of an economy.

The multidimensional framework has also been the preferred framework for statistical indicators on sustainable development used by the EU Commission (EC, 2013e), the EEA (EEA, 2012) and the green growth indicators used by the OECD (OECD, 2011b). The EU indicator framework further differentiates between "headline" and other indicators.

4. Sustainability indicators in the EU

Progress towards a green economy is to some extent mainstreamed into the programmes for economic development at the various territorial levels. At the EU level a comprehensive set of sustainable development indicators have been developed. More than 100 indicators are used to monitor whether the development is sustainable and progressing towards a green economy. 11 of these indicators have been selected as headline indicators. They are shown in Table 1.

Table 1. EU Sustainable Development headline indicators

Theme	Headline indicator
Socio-economic development	Growth rate of real GDP per capita
Sustainable consumption and production	Resource productivity
Social inclusion	People at-risk-of-poverty or social exclusion
Demographic changes	Employment rate of older workers
Public health	Healthy life years and life expectancy at birth, by sex
Climate change and energy	Greenhouse gas emissions Share of renewable energy in gross final energy consumption
Sustainable transport	Energy consumption of transport relative to GDP
Natural resources	Common bird index Fish catches taken from stocks outside safe biological limits: Status of fish stocks managed by the EU in the North-East Atlantic
Global partnership	Official development assistance as share of gross national income
Good governance	No headline indicator

Source: (EC, 2013e).

The *headline* indicators shown in Table 1 reflect some of the high priority aspects of sustainable development, but beneath each of them a large body of sub-indices are calculated for monitoring the field.

The 10 broader fields for action are encompassing the economic, social and ecological dimensions of social development. The dataset enables a policy process informed about whether progress takes place in all three dimensions, which is required for the development to be sustainable. Moreover it allows monitoring and analysis of the physical flows and production machinery in the material part of the economy as well as the impact of environmental and social living conditions on our quality of life.

Individual governments as well as the United Nations, the OECD and other organisations have developed similar datasets with the same intentions under the headline of "sustainable development" or "green economy". These datasets are highly overlapping, but they have also inspired the GREECO project.

This orientation has been further sharpened in the set of targets of the Europe 2020 strategy. It pursues growth that is smart, sustainable and inclusive and supported by reforms of economic governance. A leaner set of *headline targets* quantify these overall priorities:

1. **Employment:** 75% of the 20-64 year-olds to be employed
2. **R&D / innovation:** 3% of the EU's GDP (public and private combined) to be invested in R&D/innovation
3. **Climate change / energy:** greenhouse gas emissions 20% (or even 30%, if the conditions are right) lower than 1990, 20% of energy from renewables and 20% increase in energy efficiency
4. **Education:** Reducing school drop-out rates below 10%, at least 40% of 30-34–year-olds completing third level education
5. **Poverty / social exclusion:** at least 20 million fewer people in or at risk of poverty and social exclusion

The instruments and targets relating to **economic governance** are mainly laid down in agreements such as the stability and growth pact and the recent fiscal compact.

It is worth noting that the smart, sustainable and inclusive growth is not measured in euros. This must be seen as the logical inference from the broad consensus about replacing *GDP growth* by *sustainable development* as the overarching societal goal. As in all government programmes, the exact targets and goals can be debated as well as the adequacy of the instruments engaged to reach the targets.

The roadmap for the flagship initiative Resource Efficient Europe points to Resource Productivity as a provisional lead indicator. It is, however, recognised that it is a very crude indicator measuring flows in tons rather than by their ecologically harmful potential. Thus, it must be supplemented with a host of other indicators.

The Europe2020 headline targets are an important starting point for regional indicators on the green transformations of the economy. They are differentiated across member-states according to their national level priorities and would be even more differentiated at the regional level. The intention of the GREECO project, however, is not to develop exact targets for regional development.

The goals and priorities at sub-national territorial levels are formulated in the Territorial Agenda 2020 (TA2020) and the Common Strategic Framework (CSF) for the structural funds.

The TA2020 objectives include

1. Promoting **polycentric** and balanced territorial development
2. Encouraging **integrated** development in cities, rural and specific regions
3. Territorial integration in **cross-border** and transnational functional regions
4. Ensuring global **competitiveness** of the regions based on strong local economies
5. Improving territorial **connectivity** for individuals, communities and enterprises
6. Managing and connecting **ecological, landscape and cultural values** of regions

These objectives are not operationalized in specific targets, but they add territorial dimensions to the economic development pursued in the Europe 2020 strategy.

The development of cross-border cooperation around the Baltic Sea and the river Danube for instance are for instance highly focused on coordinating investments in the natural capital of these regions and safeguarding the environmental qualities shared by them.

The Common Strategic Framework (CSF) for the EU structural funds was developed through 2012 (amended version sept 2012). It aims at concentrating the investment efforts of the structural funds in the following fields:

1. Strengthening research, technological development and innovation;
2. Enhancing access to, and use and quality of, information and communication technologies:
3. Enhancing the competitiveness of small and medium-sized enterprises, the agricultural sector (for the EAFRD) and the fisheries and aquaculture sector (for the EMFF);
4. Supporting the shift towards a low-carbon economy in all sectors;
5. Promoting climate change adaptation, risk prevention and management;
6. Protecting the environment and promoting resource efficiency;
7. Promoting sustainable transport and removing bottlenecks in key network infrastructures;
8. Promoting employment and supporting labour mobility;
9. Promoting social inclusion and combating poverty;
10. Investing in education, skills and lifelong learning;
11. Enhancing institutional capacity and an efficient public administration

The Common Strategic Framework aims at aligning the allocation of structural funds with the overall Europe 2020 objectives. Allocating investments following such priorities is likely to generate progress along the headline targets of Europe 2020. The role of the structural funds and the Cohesion funds in the green transformations could be further strengthened if the future budget includes the proposed earmarking of 20% of the budget for climate action.

The allocation of funds along these lines is followed up by a set of monitoring prescriptions. The member states are to establish performance frameworks for each priority for the years 2016 and 2018 and targets established for 2022.

"Milestones are intermediate targets for the achievement of the specific objective of a priority, expressing the intended progress towards the targets set for the end of the period. Milestones established for 2016 shall include financial indicators and output indicators. Milestones established for 2018 shall include financial indicators, output indicators and where appropriate, result indicators. Milestones may also be established for key implementation steps." They must be

- "relevant, capturing essential information on the progress of a priority;
- transparent, with objectively verifiable targets and the source data identified and publicly available;
- verifiable, without imposing a disproportionate administrative burden; and
- consistent across operational programmes, where appropriate."

Based on the above indicators, the EU Commission has developed a selection of performance indicators for monitoring the performance of member-states compared to the EU average and the lowest and highest value of the indicator in the EU (EC, 2013f).

A similar set of indicators could be developed for regions, but it is important to recognise the fundamentals of regional economics. Whereas, national economies typically embrace all or most of the spectrum of products and services, skills and organisations, natural resources and infrastructures, this is is not the case for NUTS2 regions and definitely not for NUTS3 regions. Regional economies are typically more specialised than national economies. They are even organised in hierarchies where the highest earning specialists tend to locate in and around metropolitan agglomerations.

Thus, far from all regions have the potentials of being among the top performers in all “disciplines” and it would not even be socially desirable. Achievements in resource efficiencies, renewable energy production etc should thus always be seen in relation to what it is possible to achieve. This point will be elaborated in the review of various indices below.

5. Economic, ecological and social balances

5.1. Budgets and overconsumption

The notion of "balance" in all three dimensions is key to measuring the "state of sustainability" or how "green" an economy is. Lending from the vocabulary of economic accounting, keeping a long-term balanced *budget* is the indispensable condition for an economic activity to be viable. That is, the resource use must be financed. If there is a deficit in one year, it must be balanced by a surplus in another year. Otherwise the deficits can only go on until the wealth or capital is gone or as long as some outside donor wants to finance the activity. This is the basic condition for the economic viability or financial sustainability of firms and projects as well as households and governments.

A household *over-consumes* when it spends more than its budget and thus generates a deficit. This goes for firms and governments as well. It is the core of the economic perception and measurement of sustainability and it is the approach used to define the fiscal sustainability of government and the robustness of financial institutions in the attempts to restructure the financial circuits in Europe after the financial crisis.

This simple kind of metric is useful in analysing ecological sustainability as well.

Resource budgets are well-known in renewable resource management. A fish resource is not sustainably managed if more fish is harvested than the fish population can regenerate. The source budget depends on the natural regeneration. In the case of non-renewable resources, the consumption of natural assets is mirrored in a compensating budget for investment in man-made assets.

The sink-function of nature is over-consumed or over-used if the impacts on human and ecosystem health lead to losses of ecological qualities that are unacceptable. In any case, nature provides a potential or "budget" for its economic use as source, sink or area. Using nature beyond the potential use means that natural assets are ultimately lost. It compromises the ability of future generations to meet their needs.

In defining the sink budget, a key challenge for regional as well as national government is to distinguish between acceptable trade-offs and unacceptable ecological losses. The budget unacceptable ecological losses are politically defined as, e.g., depleted ozone layer, global warming more than 2°C and exposure to pollution in excess of the adopted limit values. A number of scenarios are possible within such budgets limits. E.g., the installation of technical plants in a natural landscape often makes the landscape less attractive. This includes wind-turbines and high voltage transmission lines. In some cases the loss of landscape values would be unacceptable whereas in other cases the loss of landscape qualities in one location can be offset by other land-use changes making the landscape more attractive and by restoration of landscape qualities in other locations. In these other cases, ecological losses are acceptable if adequately compensated by investment in other assets.

In the United Kingdom the Climate Change Act of 2008 provides the stable long-term framework for a transformation of the economy by providing 4 year CO_2-emission budgets. It has also been suggested as a framework for a global climate agreement (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (WBGU), 2009).

A land resource is not sustainably managed if it allocates more land to economic purposes - and thus less to the natural ecosystems - than required to maintain the desired level of biodiversity. The land budget is limited by the area requirements from sustaining healthy populations of species and ecosystems.

Renewable energy potentials are also budgets of are that As individuals we unfold our productive potentials by developing our talents through education and work experience. If we don't, we under-invest in our human capital. Firms similarly unfold their economic potentials by developing and producing the services and solutions in which they have a particularly good chance of being competitive. Economies do the same. Otherwise they underinvest.

Similarly, underinvestment in sustainable use of ecosystem services and non-biotic natural resources similarly refers to a potential for investing in the production of ecologically low-impact services and solutions. Good potentials for wind energy, for instance, is an investment potential and leaving it undeveloped can be characterised as under-investment.

The social dimension is more about distribution of the production and income generated than allocation of the specific resources used to generate it. Thus, social balance is in many respects concerned with a zero sum game where gains to some equal losses to others. Both aspects are, however, involved. The use of national income for investing in human capital – education, health, welfare – also affects the rate of participation of the population in the economy and the productive potential of participating population. Under-investment in human capital is then the flip-side of overconsumption of consumption goods.

Zero sum changes are not necessarily socially desirable, but they may be. The societal value of increasing national income, for instance, depends on the share of the population that are included in the generation and consumption of it. €10 billion earned and consumed by the middle-class in healthy and ecologically sound activities has a higher social value than €10 billion earned from diamond mining and exclusively enjoyed by a small elite. In that sense there can be over-consumption by some and under-consumption by others.

Sometimes excessive income differences can work in tandem with other social mechanisms to cause systematic marginalisation of groups of society. Ultimately, the marginalisation can lead entire groups into vicious circles of poverty and resource erosion reproduced generation by generation. It has been the top priority of the European welfare-states in the 20th century to break these vicious cycles and it has been successful. The collapse of financial balances and labour markets in parts of Europe in the recent years, however, has shown that sustaining a decline in the occurrence of poverty is not automatic.

The social balance constituting the green economy can thus be characterised by indicators on the inclusion of groups that otherwise would have been under-consuming, under-producing and under-investing. It is difficult to device hard criteria as to when the social imbalances are unsustainable although some, like a 50% youth unemployment rate, self-evidently are. A range of indicators, however, may help to encircle the direction of the changes in the social balance.

Key balances important for the green economy include:

- *Ecological balance*: Potential (sustainable) vs. actual use of nature as source, sink and area for economic activities.
- *Economic balance*: Consumption opportunities vs consumption (=savings requirements vs savings) of the economy and public budget balance

- *Social balance*: Marginalisation vs inclusion of population groups and investment in future inclusion

It is important to note that the balance requirements concern relevant time scales. Public budget deficits are for instance necessary for stabilising economic development during recessions, but not infinitely. Ecosystems are resilient and able to absorb and recover from temporary shocks, but not necessarily from a perpetual environmental pressure.

Thus, relating the actual use of nature to the potential use can indicate the potentials for transformation to a green economy. In policy formation and planning, this approach can generate indicators of ecological as well as economic over- or underuse. Just like over- or underspending or financial budgets.

For practical political and planning purposes, it is necessary to decide upon a time scale for the transition from the present unsustainable state to a sustainable state. This timescale typically represents a trade-off between economic well-being of the present and the chain of future generations that can live under the sustainable conditions. If, for instance, the time-scale for achieving the sustainable level of greenhouse gas emissions is shortened from 2050 to 2040, more people will enjoy living in an economy that is sustainable in this respect, but at a higher cost for the generations living until 2040.

The pace of transformation is, however, not totally up to the decision of the present. The response from natural ecosystems – including the climate system – may be irreversible as a consequence of cumulated pressure. Thus, there is an upper limit to the time-scale of transition to sustainable environmental pressure as well.

Within these budgets for future use of nature as source, sink and space, there is a wide range of sustainable development scenarios.

6. Ecological balances

6.1. Tropospheric air pollution budgets

The environmental living conditions are important to a broader concept of well-being than the consumption opportunities measured by, e.g., GDP per capita. Among these are concentration rates of particulate matter, ozone, heavy metals, acidification and eutrophication.

Pollutants often have more than one adverse effect and often work together in causing environmental damage. Important air quality pollutants include ozone (O_3) and particulate matter (PM) (respiratory disease) and ozone also has negative effects on vegetation and on the durability of some materials. Nitrogen oxides (NO_x) from fossil fuel combustion as well as from agriculture cause eutrophication and acidification – terrestrial as well as aquatic - along with SO_2 pollution. Acidification causes materials erosion as well.

The EU has introduced limits for tropospheric air pollution. They are based on the long term ecological balance of the EU economies with the atmospheric environment expressed in the environmental action programme objective of "achieving levels of air quality that do not give rise to significant negative impacts on and risks to human health and the environment" (EC, 2002). This ecological balance principle is measured by the distance of the air quality to certain limit values (EC, 2008b). They are maximum values for significant negative impacts that are considered safe or intermediate maximum values in a longer-term transition to safe limit values. They are often higher than the limit values recommended by the WHO.

Based on the considerations of the distance to these values and the time span over which ecological balance is to be achieved, it is possible to set national emission ceilings for SO_2, NO_X, NMVOC and NH_3 that are compatible with the limit values. For most countries, notably some the new member states, there is a wide margin from the emission levels to the ceiling. This follows two decades of dramatic reductions of emissions of these pollutants in the EU15 countries and is partly explained by the economic recessions since 2008.

Table 2. Deviation of emissions in 2011 from national emission ceilings 2010. Per cent (negative = ceiling above emission).

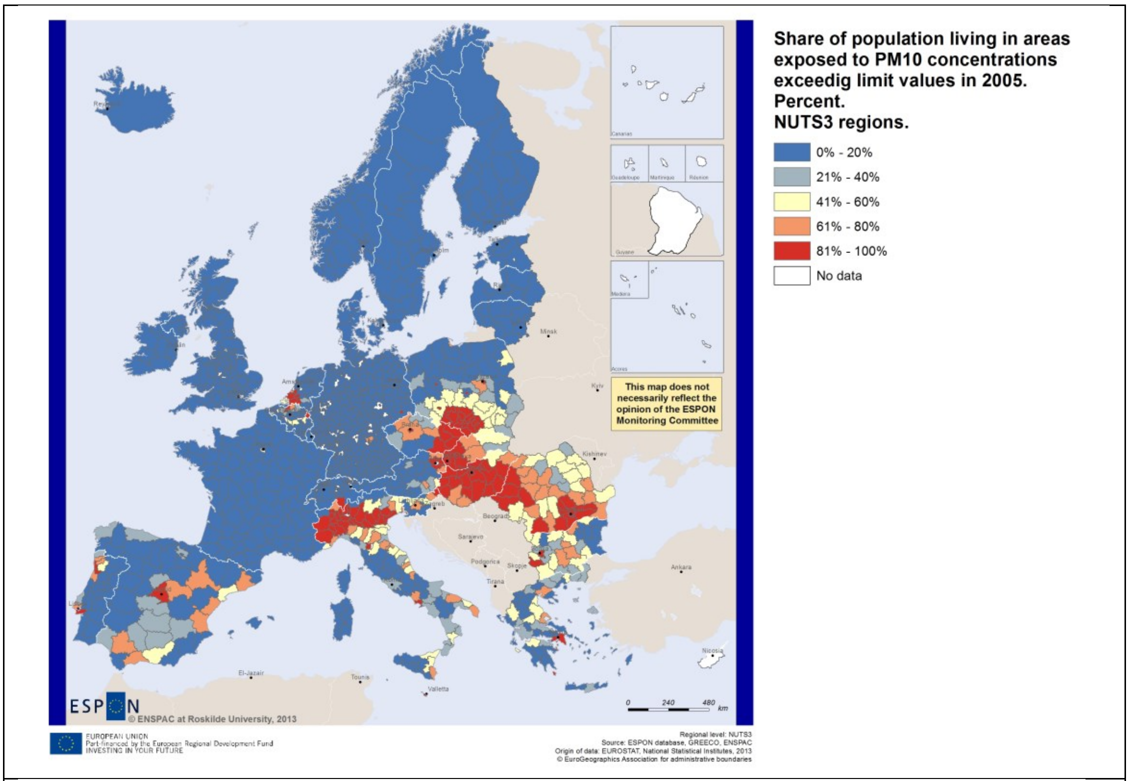
	NH3	NMVOC	NOX	SO2
Austria	-6%	-21%	40%	-53%
Belgium	-9%	-28%	19%	-44%
Bulgaria	-55%	-46%	-53%	-54%
Cyprus	-43%	-31%	-9%	-46%
Czech Republic	-18%	-34%	-21%	-36%
Denmark	-1%	-6%	-1%	-75%
Estonia	-64%	-32%	-41%	-27%
Finland	20%	-16%	-9%	-48%
France	-14%	-30%	24%	-32%
Germany	2%	1%	23%	-14%
Greece	-16%	-39%	-14%	-50%
Hungary	-28%	-27%	-35%	-93%
Ireland	-6%	-21%	9%	-44%
Italy	-7%	-11%	-5%	-56%
Latvia	-71%	-49%	-48%	-97%
Lithuania	-65%	-25%	-54%	-75%
Luxembourg	-31%	4%	338%	-56%
Malta	-48%	-75%	-2%	-12%
Netherlands	-7%	-22%	0%	-33%
Poland	-42%	-19%	-3%	-35%
Portugal	-48%	-2%	-30%	-71%
Romania	-24%	-32%	-49%	-64%
Slovakia	-38%	-51%	-35%	-38%
Slovenia	-16%	-25%	-1%	-60%
Spain	8%	-10%	10%	-33%
Sweden	-9%	-26%	-2%	-56%
United Kingdom	-2%	-37%	-11%	-35%

Source: Author's calculations based on the EEA emission data viewer (European Environment Agency (EEA), 2013a).

Despite dramatic reductions of emissions through the recent decades, the pollution problems generated by these emissions persist in parts of Europe.

The European environmental policy has particular focus on the pollution with particles and ozone. The GREECO project processed the data from the monitoring network by the European Environmental Agency (EEA) in cooperation with the Dutch institute NERI. Based on these results it was possible to estimate the share of inhabitants in NUTS3 regions that have been exposed to pollution beyond safe levels in 2005, 2009 and 2010.

The spatial patterns of the problem with PM10 pollution (concentration of particulate matter with a diameter of less than 10μ) seems to be linked to more to geography than to GDP, but following fluctuations of GDP.


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
This map does not necessarily reflect the opinion of the ESPON Monitoring Committee
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INVESTING IN YOUR FUTURE
Regional level: NUTS3
Source: ESPON database, GREECO, ENSPAC
Origin of data: EUROSTAT, National Statistical Institutes, 2013
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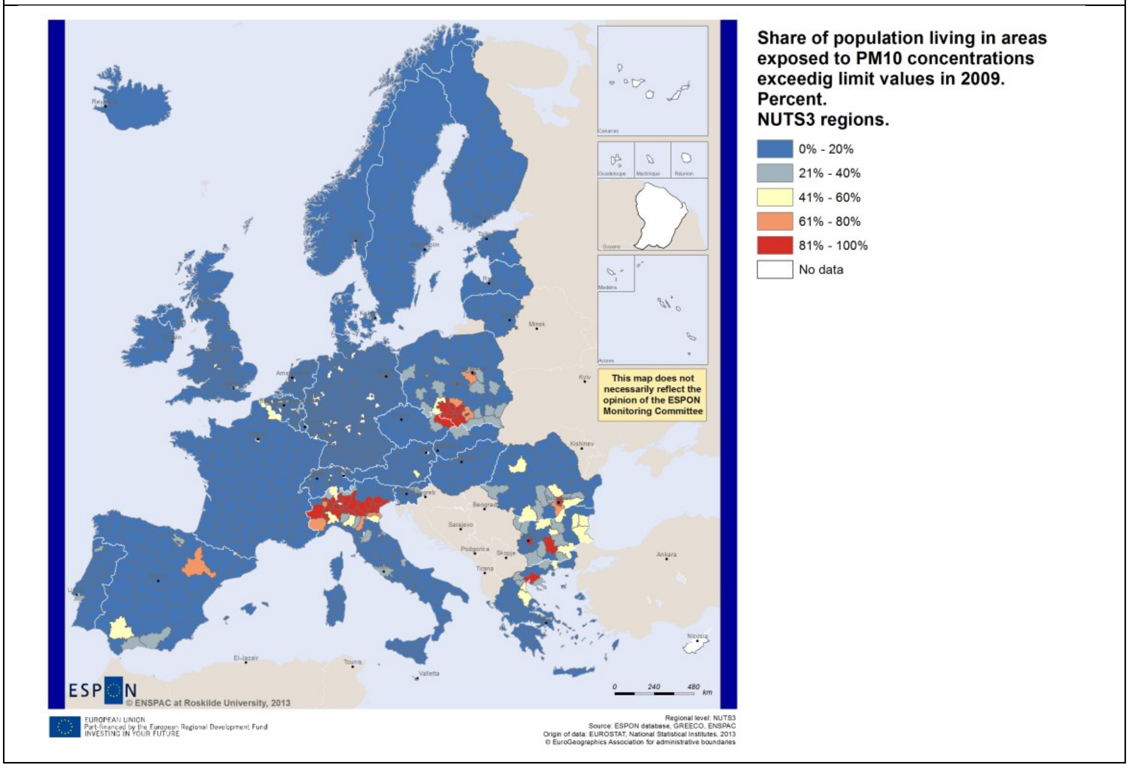
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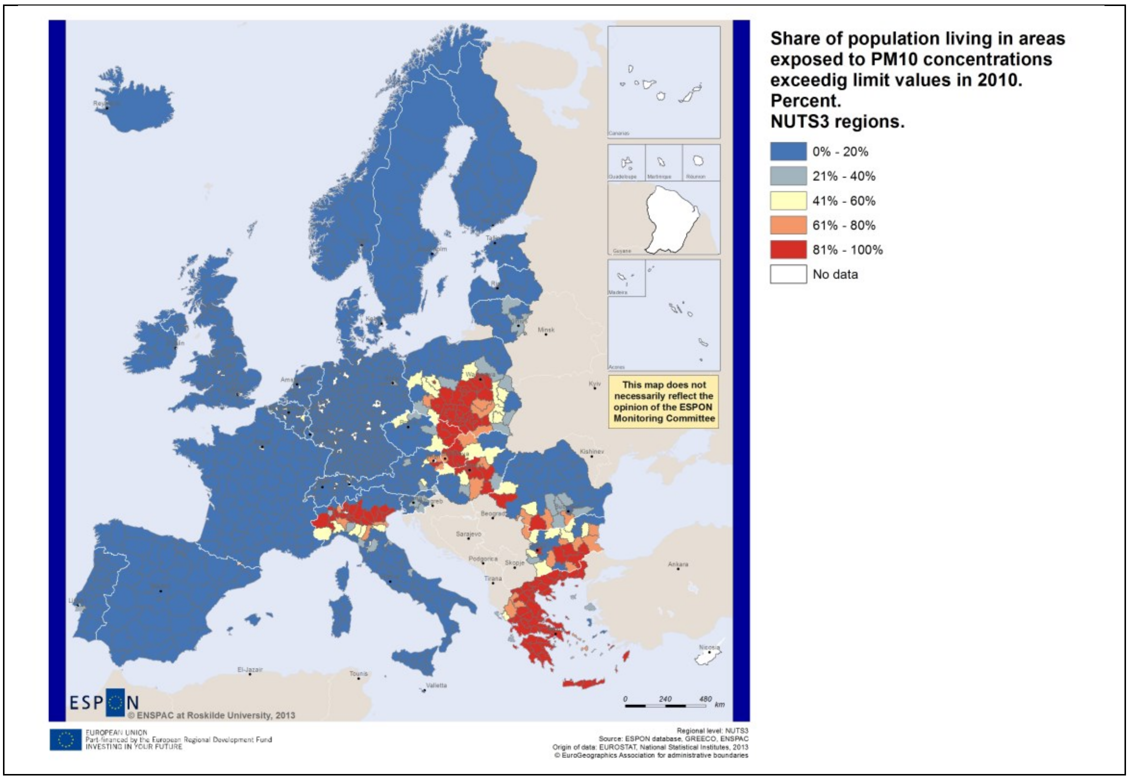
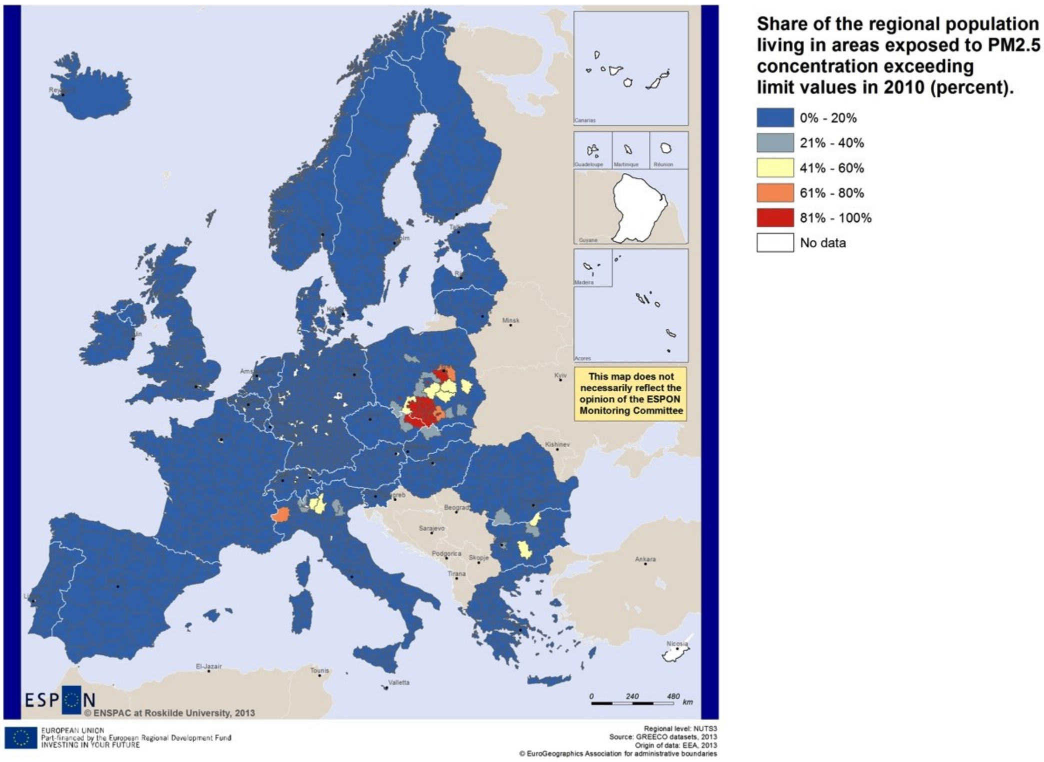


Map 3. Share of population living in areas with PM10 concentration exceeding limit values in NUTS3 regions. 2005, 2009 and 2010. Per cent.
Source: Author's calculations based on GREECO datasets (Hansen, 2013a).

Some of the PM10 pollution shown in map 3 is transported from other regions, but in the regions with high risk, such as northern Italy and south of Poland, most of the emissions are of local origin. There is not a clear link between the level of environmental risk and the level of GDP at the European scale. A number of factors contribute to explaining the geographical location of the high-risk regions. The regions mentioned as well as the scattered pattern of urban regions are characterised by a concentration of energy intensive production plants and transport. Many of these locations are also located in valleys with air-sheds that are locked or only replaced at a slow rate.

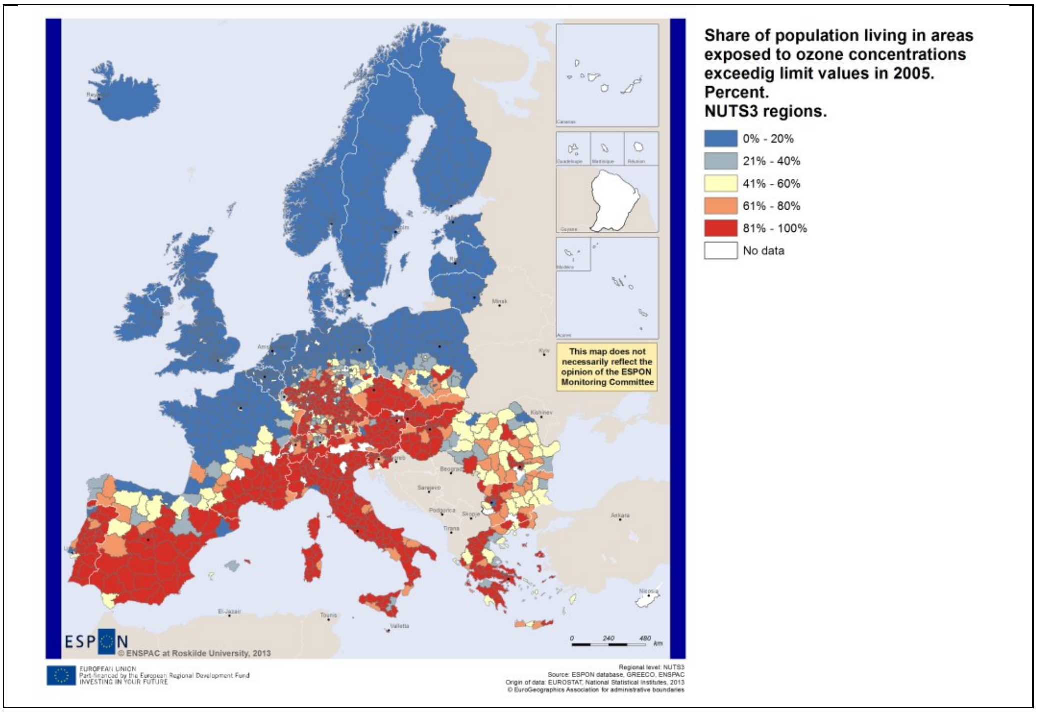
The changes from high-risk levels in 2005 to lower risk levels in 2009 and again higher risk in 2010 could indicate that the risk levels pulsates around these regions in parallel with the economic cycle. Even in the deep recession of 2009, however, the pollution problem was still severe in these regions.

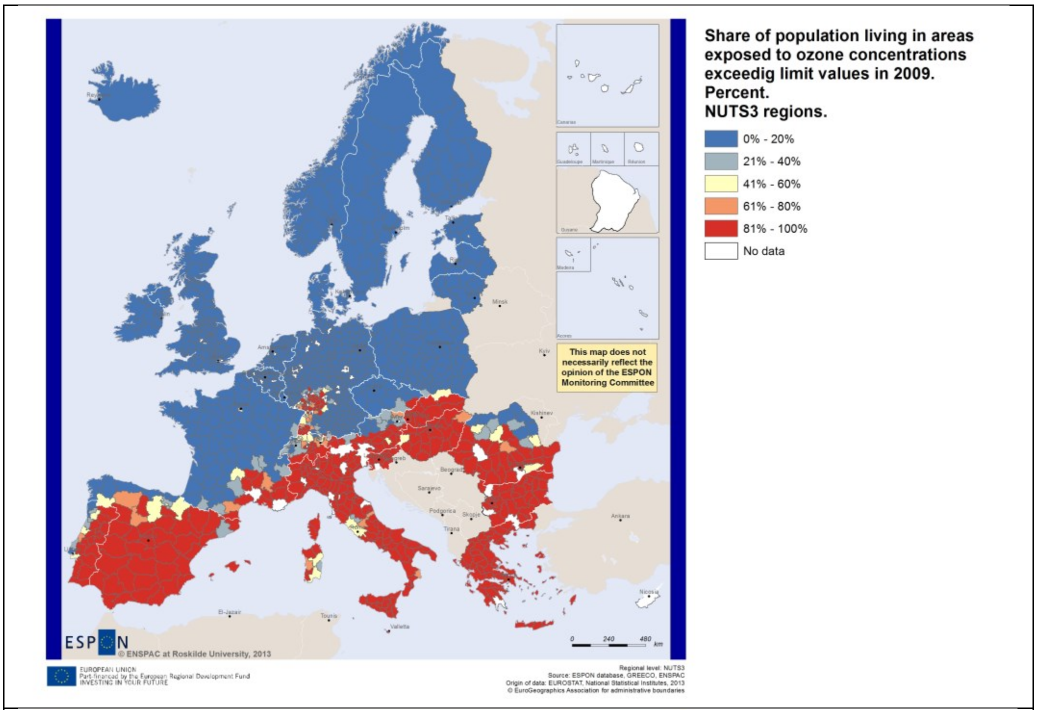
From 2010, limit values have been introduced for the concentration of the very fine particulate matter called PM25 (diameter less the n 2.5μ). Map 4 shows the exposure rates in NUTS3 regions.

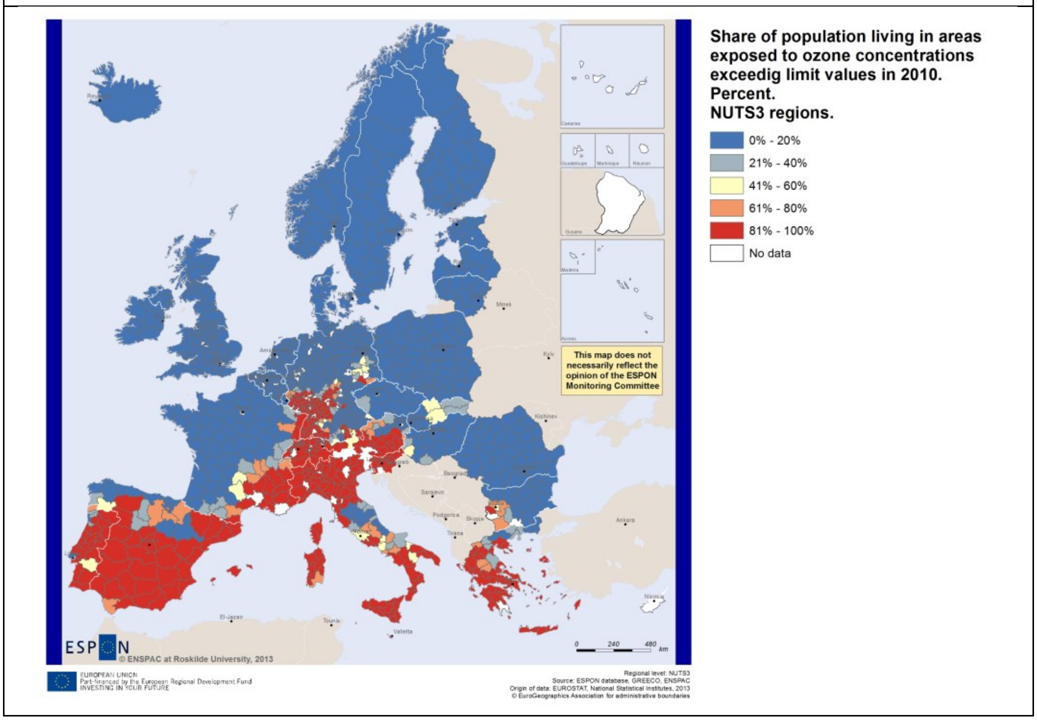


Map 4. Share of the regional population living in areas exposed to PM2.5 concentration exceeding limit values in 2010. NUTS3 regions. Per cent.
Source: Author's calculations based on GREECO datasets (Hansen, 2013a).

Another problem is the ozone problem. Sunlight is a decisive factor for ozone formation and the risk of exposure to elevated level is mainly a problem for the south of Europe.







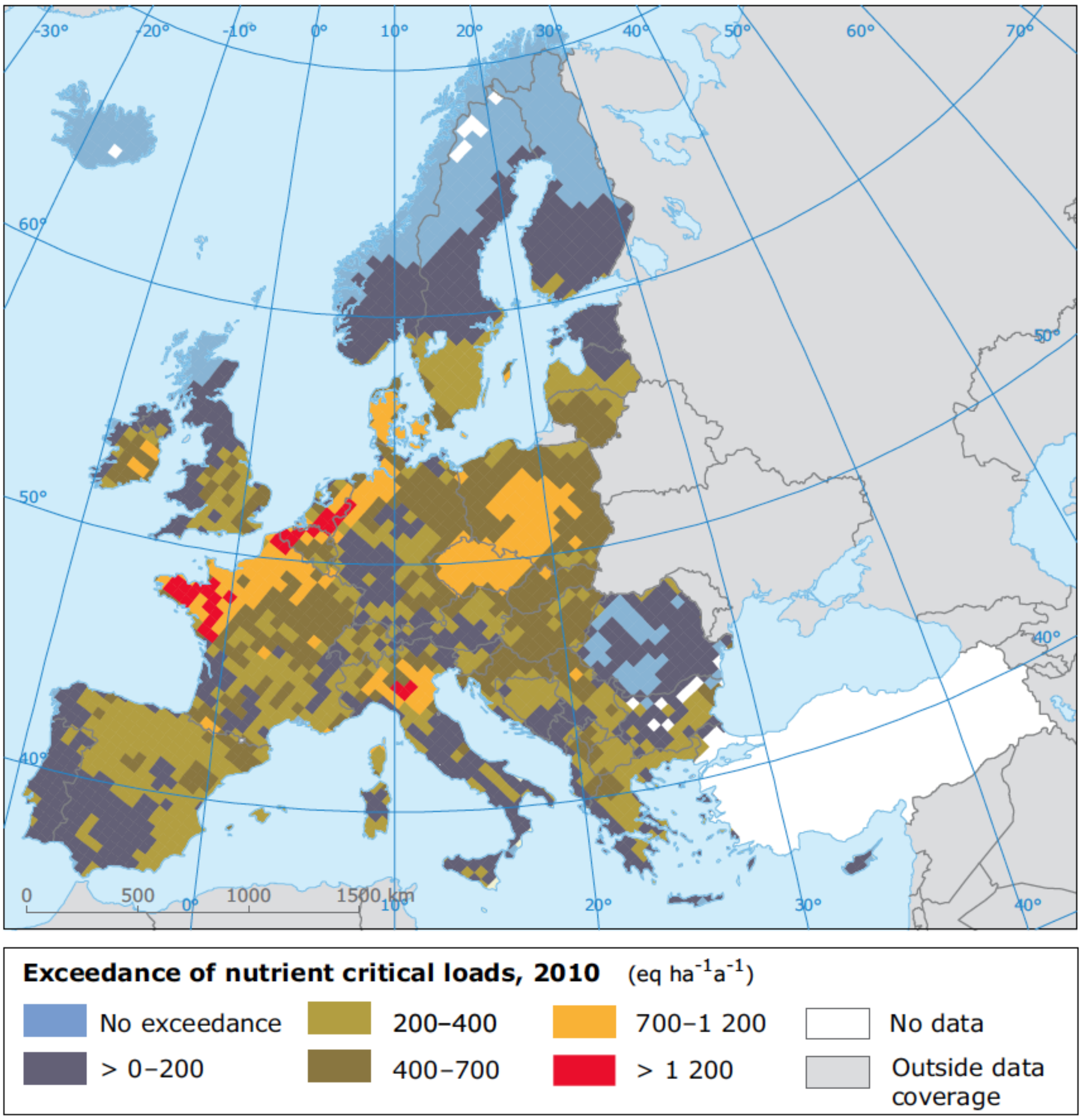
Map 5. Share of population living in areas with ozone concentrations exceeding threshold values in NUTS3 regions. 2005, 2009 and 2010. Per cent.
Source: Author's calculations based on GREECO datasets (Hansen, 2013a).

The geographic pattern of the risks of being exposed to elevated levels of ozone is not only related to the geographical patterns of emissions levels. As shown in Map 5 they are as much linked to solar irradiation.

The common EU goal of eliminating significant health risks is obviously more distant in some regions than in others. Reinforced efforts that could advance the implementation of green solutions in these areas are thus justified. Local and regional level emission budgets could facilitate the development of effective strategies at the regional level.

6.2. Exposure of nature and crops beyond critical loads

One the important achievements of European environmental policy is the reduction of areas exposed to acidification by 80% from 1990 to 2010 (European Environmental Agency (EEA), 2012). Despite the reduction 10% of the natural ecosystems areas was subject to acidification in 2010, mainly from agricultural emissions of nitrogen(European Environment Agency (EEA), 2010). These emissions are also responsible for eutrophication of terrestrial and aquatic environments. Map 5 shows the spatial patterns of deposition exceeding the critical load.



Map 6. Exceedance of critical loads for eutrophication due to the deposition of nutrient nitrogen, 2010 (Neq /ha/year).
Source: (European Environment Agency (EEA), 2010 p63).

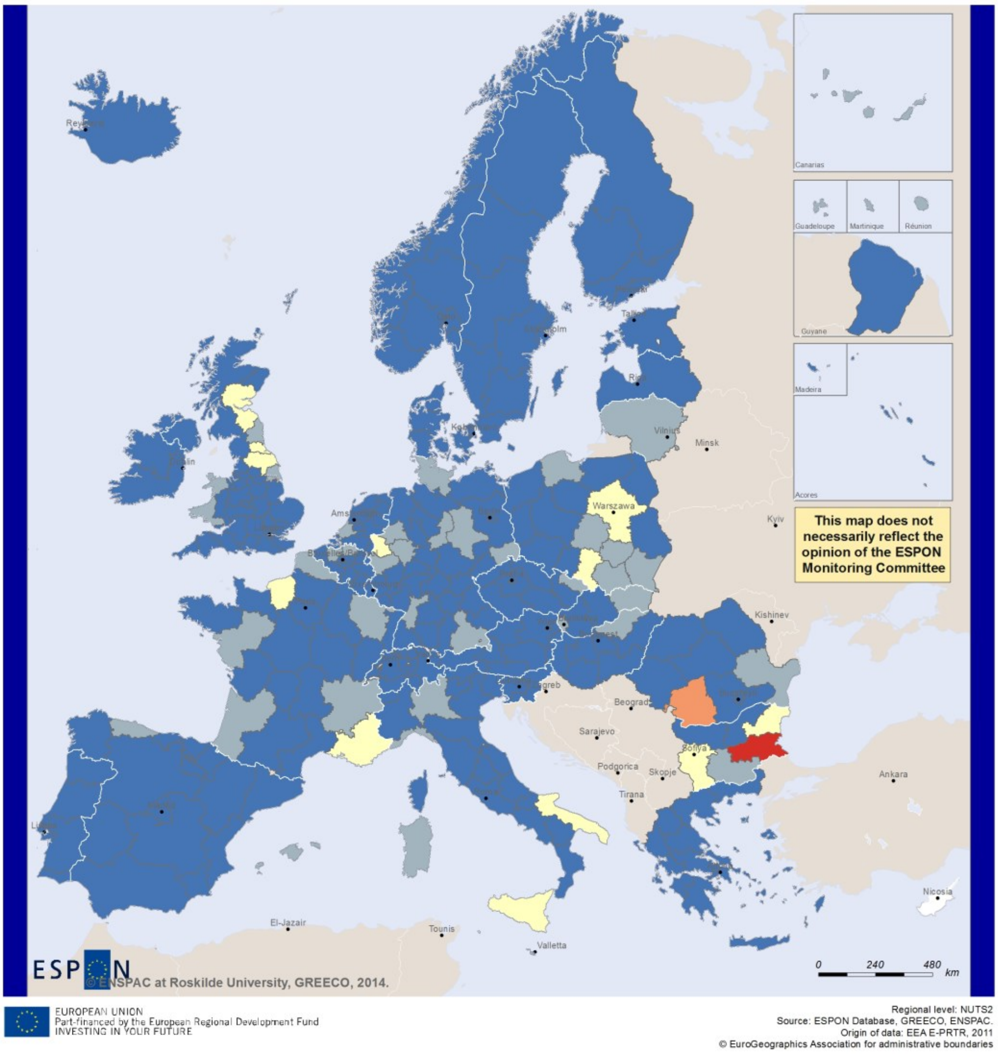
Map 6 shows that the critical loads are exceeded in most of Europe by deposition of nutrients. Important polluting activities causing these emissions include NO_X from combustion and NH_3 from agriculture. The same conclusions as to the above air pollutants apply to the indicators for conforming agricultural activities and activities involving combustion to these boundaries.

6.3. Emission to air of main tropospheric pollutants

The unsustainable air pollution in many regions identified above is the result of a combination of a geographical concentration of emissions and a limited absorption dilution capacity of the local wind shed. The following section addresses the geographical concentration of emissions.

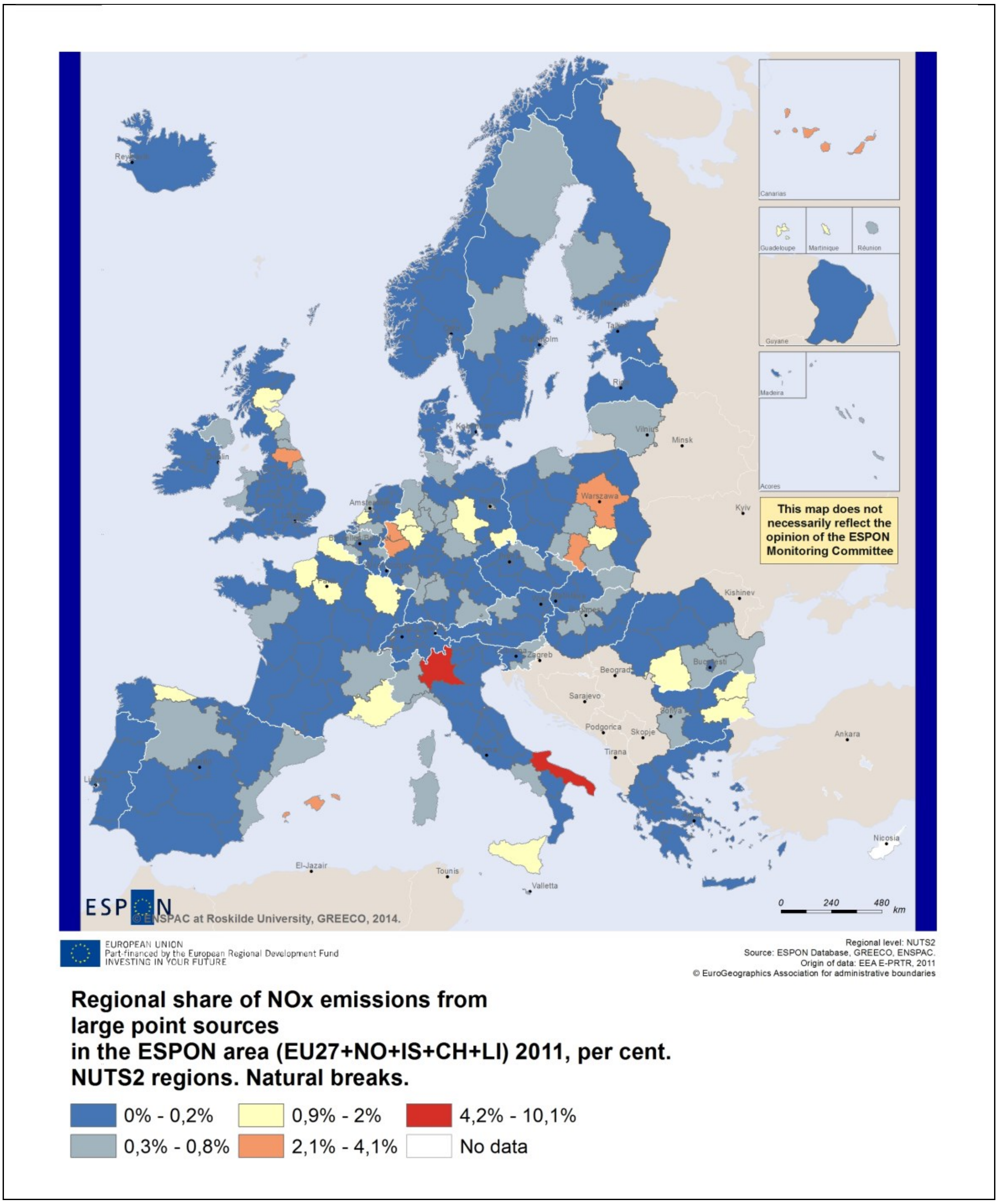
The emissions of SO_2 and NO_X have been dramatically reduced in Europe through the recent decades, but are still imposing severe environmental risks on populations in many regions of Europe. The pollutants are transboundary and contributions to the pollution problem come from all countries and even other continents. The hotspot regions with populations exposed to high levels of environmental risk from PM10 and ozone pollution are, however, also regions with strong local sources of emissions.

The emissions from which the particulate matter and ozone are formed are not evenly distributed among the European regions. They come from diffuse as well as from point sources. The emissions from large point sources are reported to the authorities and recorded in the E-PRTR database of the European Environmental Agency (EEA). Primary data on emissions from diffuse sources are not systematically collected.



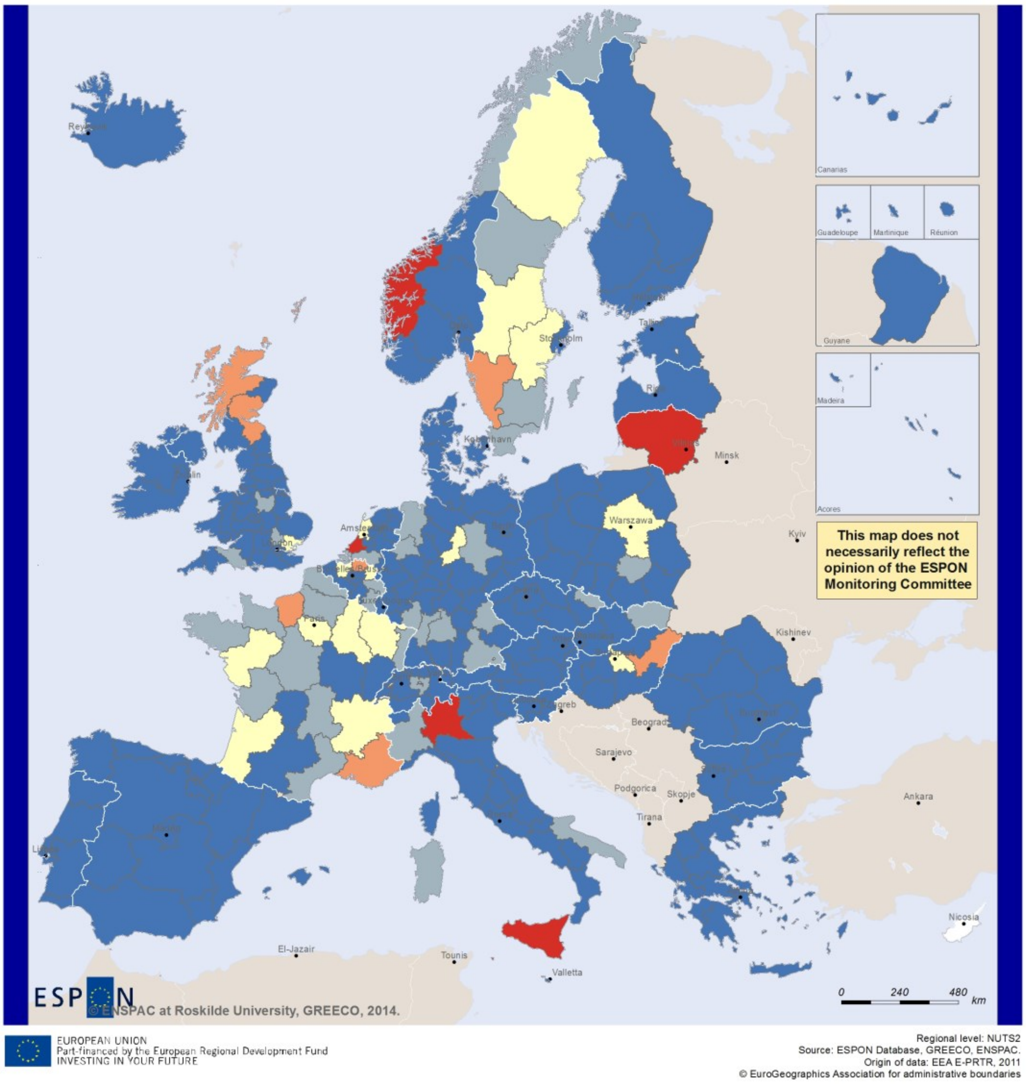
Regional share of SO2 emissions from large point sources in the ESPON area (EU27+NO+IS+CH+LI) 2011, per cent. NUTS2 regions. Natural breaks.

0% - 0,4% | 1,7% - 4,4% | 8,6% - 19,7%
0,5% - 1,6% | 4,5% - 8,5% | No data



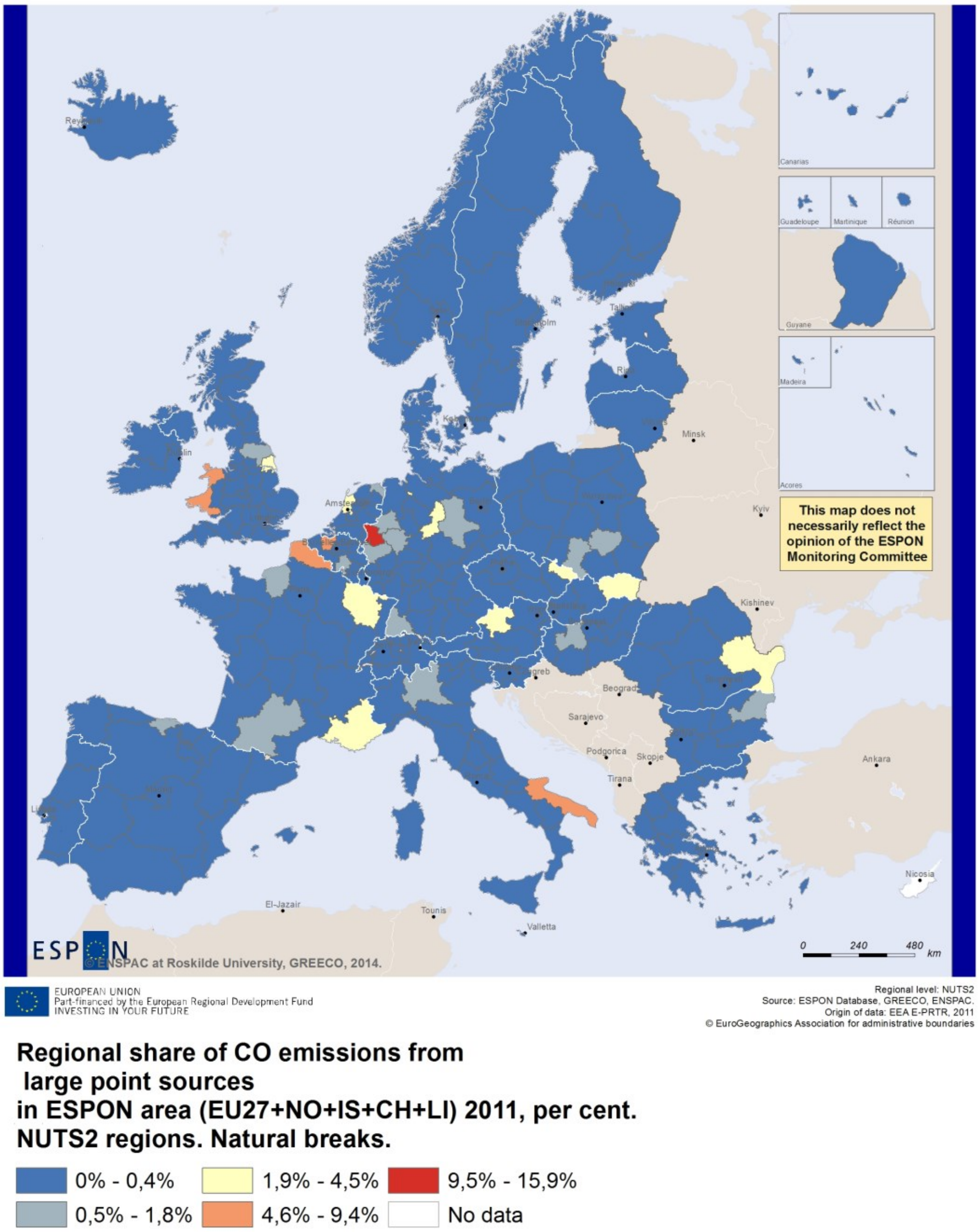
Map 7. Regional shares of European point source emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_X) in 2011. Per cent.
Source: Author's calculations based on the EEA E-PRTR database (European Environment Agency (EEA), 2013b).

Map 7 shows that although the emissions of SO_2 and NO_X have been dramatically reduced in Europe through the recent decades, there are still regions with very large emissions of these pollutants. Lombardia and Puglia in Italy alone stands for 20% of the European point source NO_X-emissions. Yugoiztochen in Bulgaria and Sud-Vest Oltenia in Romania delivers 28% of the European point source sulphur dioxide emissions. Another 15% comes from the three regions of Mazowieckie and Yugozapaden (BG) and Slaskie (PL).



Regional share of NMVOC emissions from large point sources in the ESPON area (EU27+NO+IS+CH+LI) 2011, per cent. NUTS2 regions. Natural breaks.

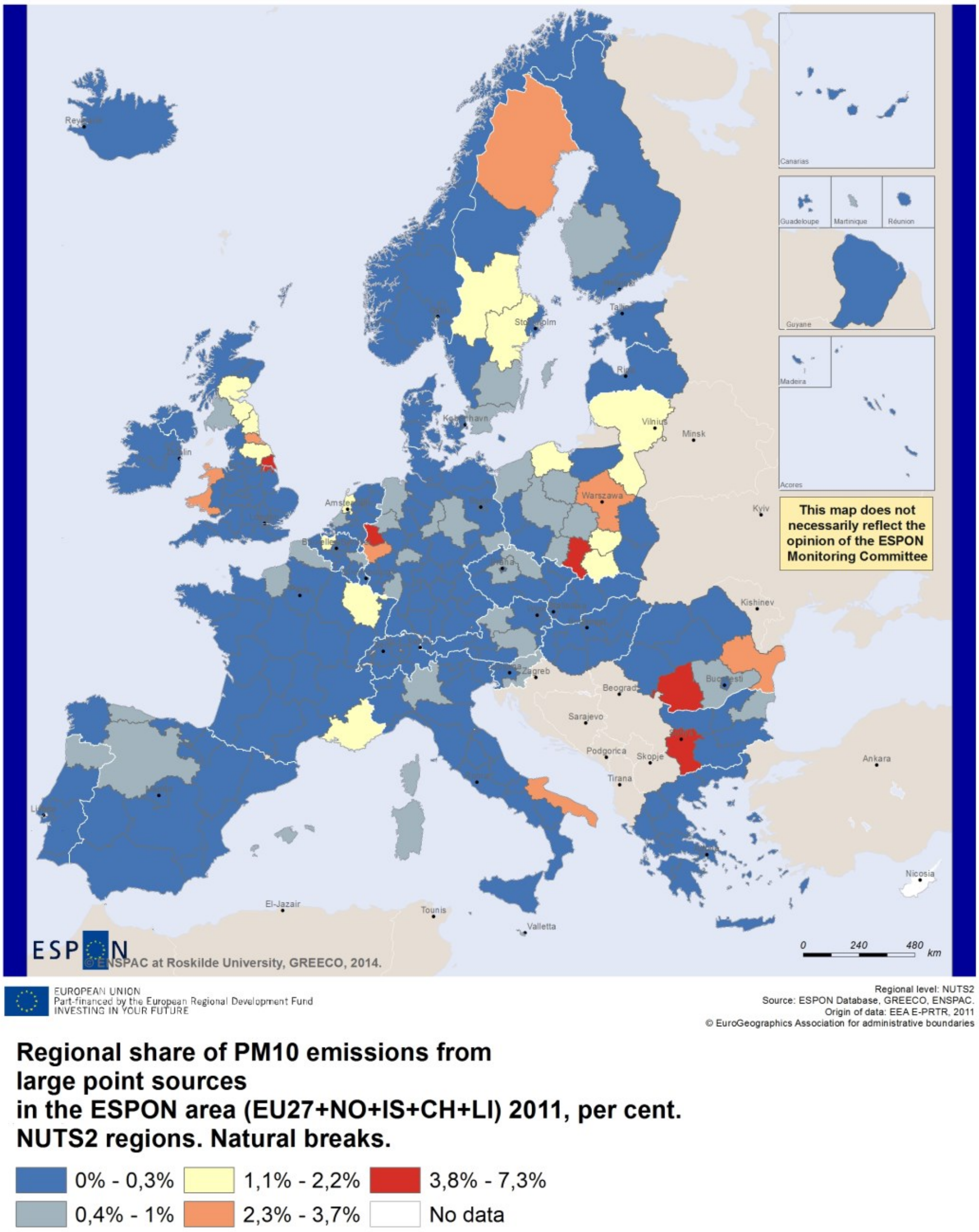
0% - 0,3%
1,1% - 2,2%
4,1% - 6,8%
0,4% - 1%
2,3% - 4%
No data



Map 8. Regional shares of European point source emissions of non-methane volatile organic compounds (NMVOC) and carbon oxide (CO) in 2011. Per cent.

Source: Author’s calculations based on the EEA E-PRTR database (European Environment Agency (EEA), 2013b).

Map 8 shows that the point source emissions of NMVOC that are emitted by evaporation as well are distributed among regions slightly differently than the other pollutants.



Map 9. Regional shares of European point source emissions of particulate matter with diameter less than 10µ (PM10) in 2011. Per cent.
Source: Author's calculations based on the EEA E-PRTR database (European Environment Agency (EEA), 2013b).

The emissions of PM10 from point sources are also highly concentrated with the 5 regions of Sud-Vest Oltenia (RO), Düsseldorf (DE), Yugozapaden (BG), East Yorkshire and Northern Lincolnshire (UK) and Slaskie (PL) providing 30% of the emissions.

The concentration of point source emissions in a few regions makes it easier to identify the sources and thus the solutions, but it makes it also more difficult to implement them if they involve downscaling of the polluting activities. Such plants often play a major role in the local or regional economy. In any case, however, it poses the challenges of transformation to a green economy totally different for regions with such emission sources compared to regions without.

6.4. Carbon budgets

6.5. 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 20th 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.

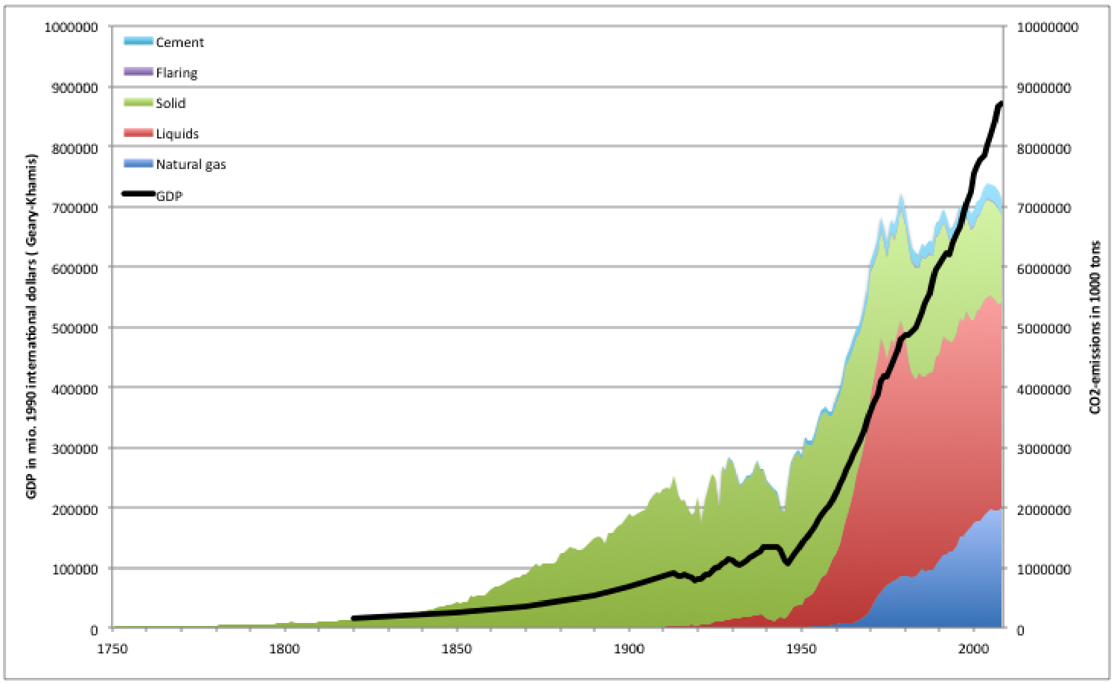


Figure 2. GDP and CO2 emissions (by source) of Western Europe. 1751-2008.
Authors calculations based on historical data (Andres et al., 2011; Maddison, 2006).

Figure 2 shows the *carbonisation* of the European economy in particular through the first three quarters of the 20th century. The access to cheap fossil energy enabled the growth of not only value creation, but also heavy flows of other materials through the economy.

Energy access as a competitiveness factor contributed to the formation of the European map of industrial topography. 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. A key process of the industrialisation was that the primary movers converting biomass to horsepower were relieved by steam engine driven vehicles, pumps etc. (E.g., Rifkin, 2011; Smil, 1994) instead.

The period following the WW2 period during which the oil economy was built up has been called the oil era or another industrial revolution were new prime mover technologies driven by oil and electricity were taken massively into use (Smil, 1994).

The combination of investments in energy resource extraction, infrastructures and conversion plants and final use capital such as cars and ships provided with the continuous flows of energy through it the fundamental physical condition for moving and processing the immense flows of materials through the 20th century economies and feeding, accommodating and moving the increasing world population. 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 to these historically exceptional growth rates. Economic growth is in the long run a matter of specialisation and cooperation, 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 has been found to follow from the shift from coal with a high content of carbon to energy to oil, natural gas, nuclear and hydro power and, eventually, electricity. These shifts to more convenient fuels also implied an overall decarbonisation, a trend of lower CO_2-emissions per energy unit consumed (Grübler and Nakićenović, 1996). This unplanned and spontaneous decarbonisation was much to weak to curb the CO_2-emissions from fossil fuel combustion to sustainable levels, but they nevertheless represent historic changes towards cleaner fuels and, eventually, electricity. Trends that can be amplified.

Part of this weakening of the carbon link could, however, 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).

The green economy must also be seen in such a historic perspective. Its physical basis must be as different from the physical basis of the fossil energy fuelled economy as the oil economy was from the steam economy and the steam economy from the preindustrial "muscle and sail economy". Otherwise it will link increasing fossil energy use to economic growth.

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.

The transformation to the green economy a *decarbonisation growth model* and the growth effects of that are different than those of the 20th century model, whereas some properties of it has been developed in the last decades of the century.

6.6. Allocating the European carbon budget

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.

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 with 80-95% of the 1990 carbon emissions within this timeframe. 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, 2011b).

The IPCC assesses in its Fifth Assessment Report the remaining global budget (2012-2100) to be 140-210 GTC with a mean value of 170 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).

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.

Based on the IPCC assessments the carbon budget of Europe can be translates to a greenhouse gas emission path leading to emission levels of 5-20% of the 1990 level in 2050. This is the sustainable GHG emission path of Europe and it is shown in figure 3.

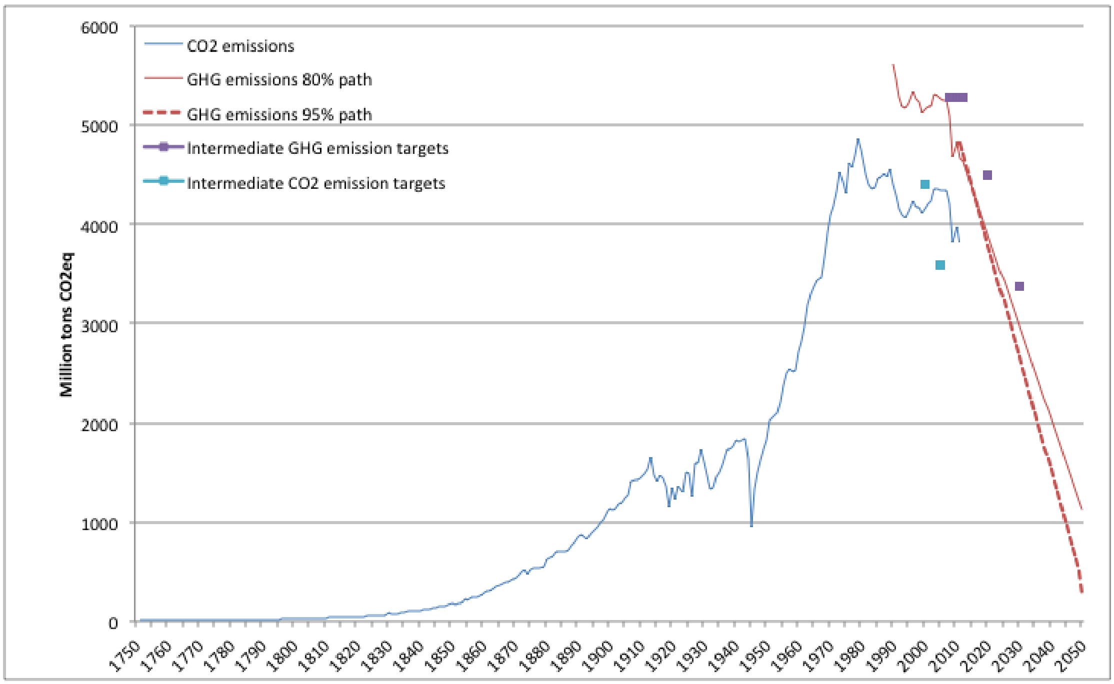


Figure 3. CO_2 emissions 1750-1989, GHG and CO_2 emissions 1990-2011 and sustainable GHG emission paths 2010-2050 for EU27+NO+IS+CH+LI. Million tons (Tg) CO_2 equivalents.

Note: 1990-11 figures are the officially reported emission inventories. 2010-2050 emission reduction paths are linear reductions towards the 5-20% of 1990-levels. The emissions include emission removals by land-use change and international bunkers attributed to the country of refuelling.

international bunkers are fully included in accounts of the country of refuelling.

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.

As milestones towards this end, the EU has adopted the target of reducing emissions by 20% of the 1990 emissions in 2020 (EC, 2010a). The EU Commission has proposed a 40% emission reduction target for 2030 (EC, 2013g). 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, 2011b). These decisions sum up to what can be characterised as a “20-40-80 carbon budget”.

Table 3 shows the annual changes in GHG emissions from EU27 in the sub-periods 1990-2011 and the future changes consistent with the 20-40-80 GHG emission reduction budget or an 80-60-20 GHG emission budget.

Table 3. 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, 2013g, 2011b, 2010a; European Environment Agency (EEA), 2013c)

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 moderate reduction rates in 2000-08 and in 2011-20 imply more dramatic rates of reduction in the 2020-2050 period. The emission reductions are postponed to the future. The higher reduction rates in 2030-50 are also due to the reductions being imposed on a still smaller budget.

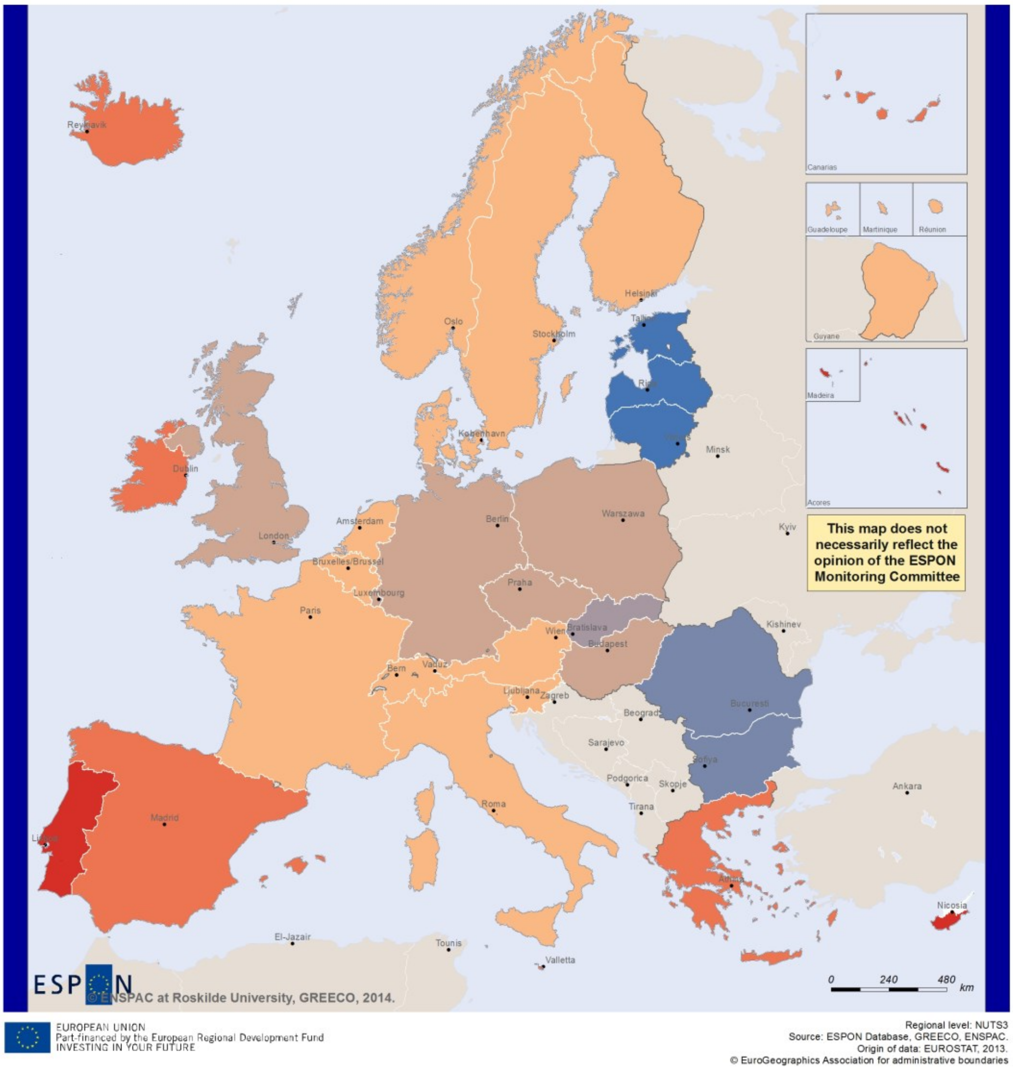
6.7. Historic changes in CO_2-emissions by regions

The average annual rate of reduction of greenhouse gas emissions in 1990-2000 and 2000-2008 is known for the EU as a whole and for the individual member-states.

The GREECO project has used the "gridded" emission data from the EDGAR database to predict the regional CO_2-emissions from the national emission data just like future developments are "predicted" from past experience. The gridded emissions in the EDGAR database are estimated by distributing the national emission figures according to known spatial distributions of production, population and other economic variables that are known to be associated with the spatial distribution of energy combustion.

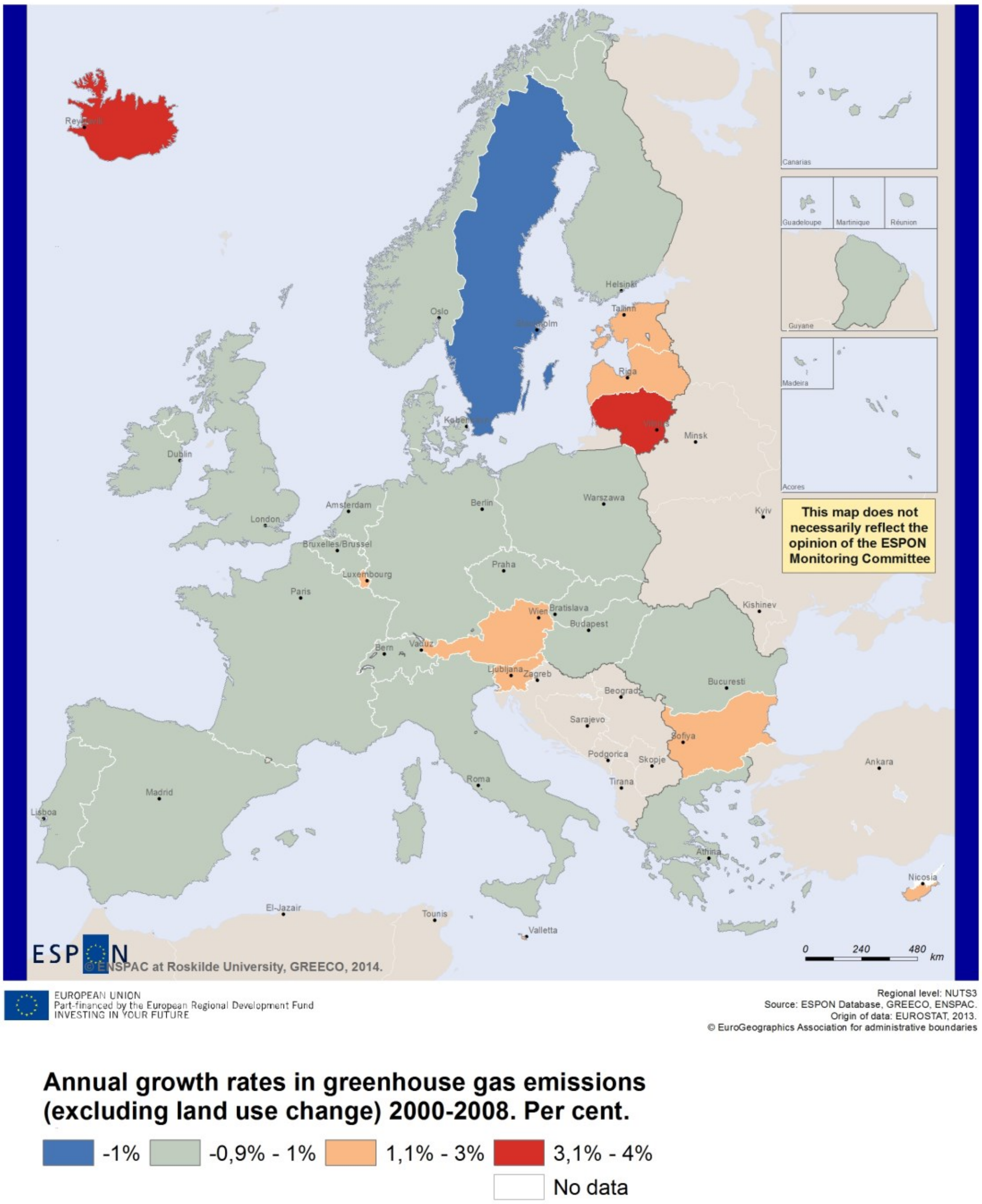
Map 10 shows the compound annual growth rates of expected GHG emissions in European countries in the 1990s and in the 2000s until 2008.

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.

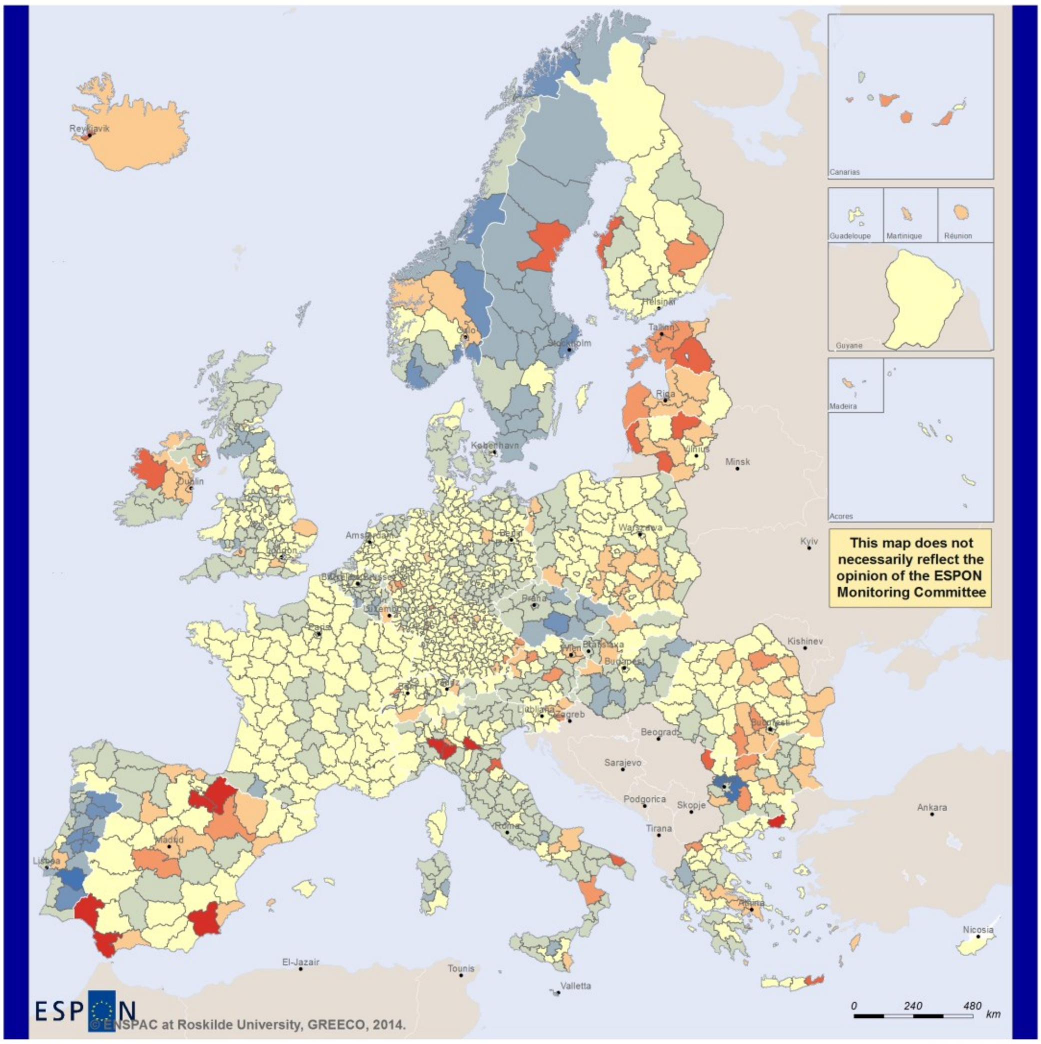
-9,2% - -7%	-4,9% - -3%	-0,9% - 1%	3,1% - 5%
-6,9% - -5%	-2,9% - -1%	1,1% - 3%	No data



Map 10. Greenhouse gas emission growth in EEA countries. Reported change 1990-2000 and 2000-2008. Percent per year.

Map 10 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 spatial predictions from the EDGAR database are regionalised to the NUTS3 level. Based on these estimates the predicted change in the 1990s and the 2000s are shown in map 11.



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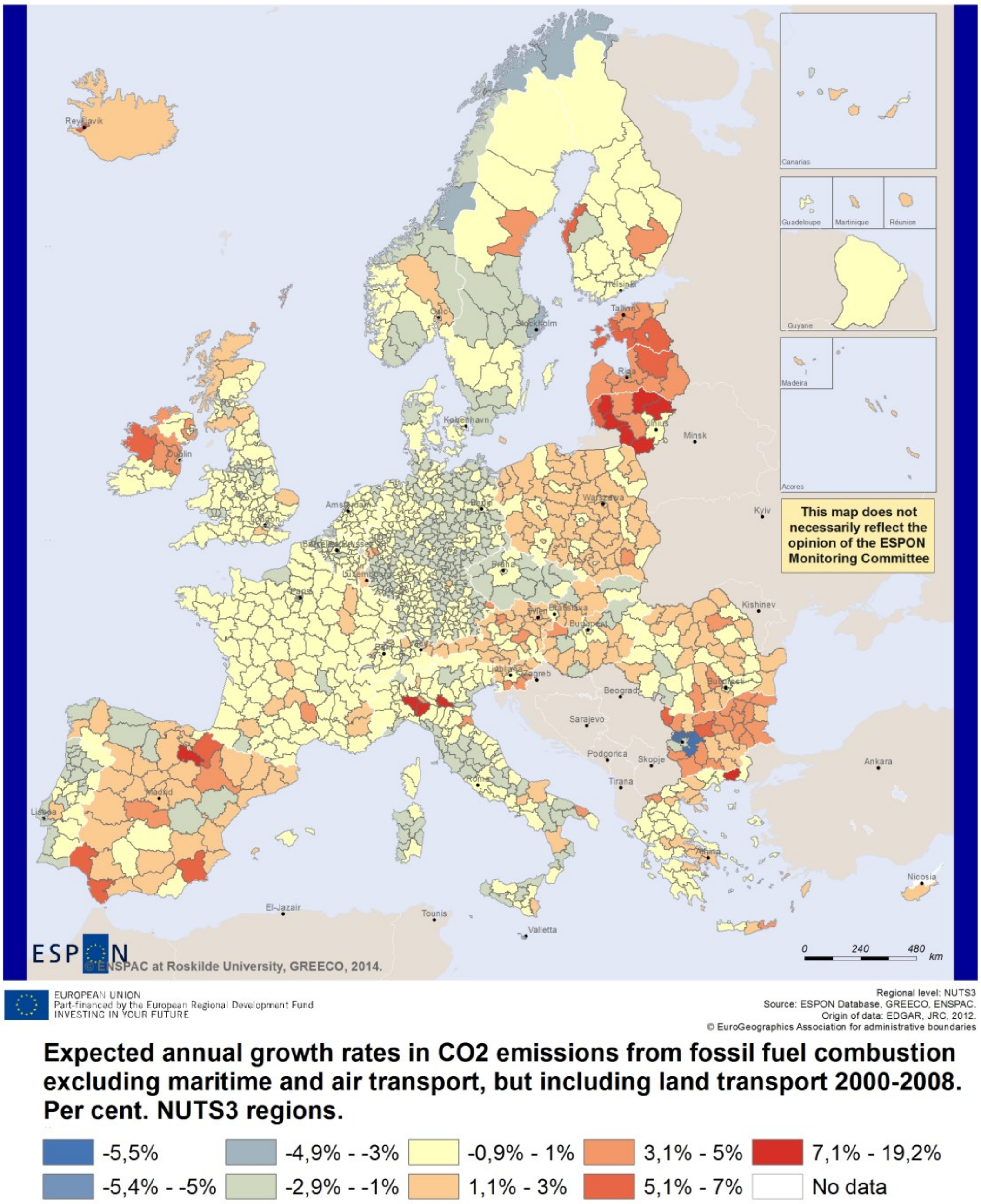
Regional level: NUTS3
Source: ESPON Database, GREECO, ENSPAC.
Origin of data: EDGAR, JRC, 2012.

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

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



Map 11. 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).

Map 11 shows how the emission reductions in NUTS3 regions can be expected – based on the EDGAR-project distribution keys - to be distributed over regions.

In the 1990s GHG emissions were reduced in Germany and the United Kingdom and what became the new member-states. In Spain, Portugal, Greece, Ireland, Iceland, Cyprus and Malta they wer increasing, whereas in the rest of the countries the rate of change were between 1% and -1% cf map 10. In 2000-08 the changes were less significant in either direction.

As shown in map 11, however, different regions within the same country must be expected to differ by changes in emissions. It is because some regions are growth regions and some are in regions in decline. In some regions energy intensive plants are retired whereas in other regions they are established. Reducing emissions is preferable, but it is not equally preferable whether the reduction happens in a growth region or in a region in decline. Solutions to this problem are suggested in section 12.2 below.

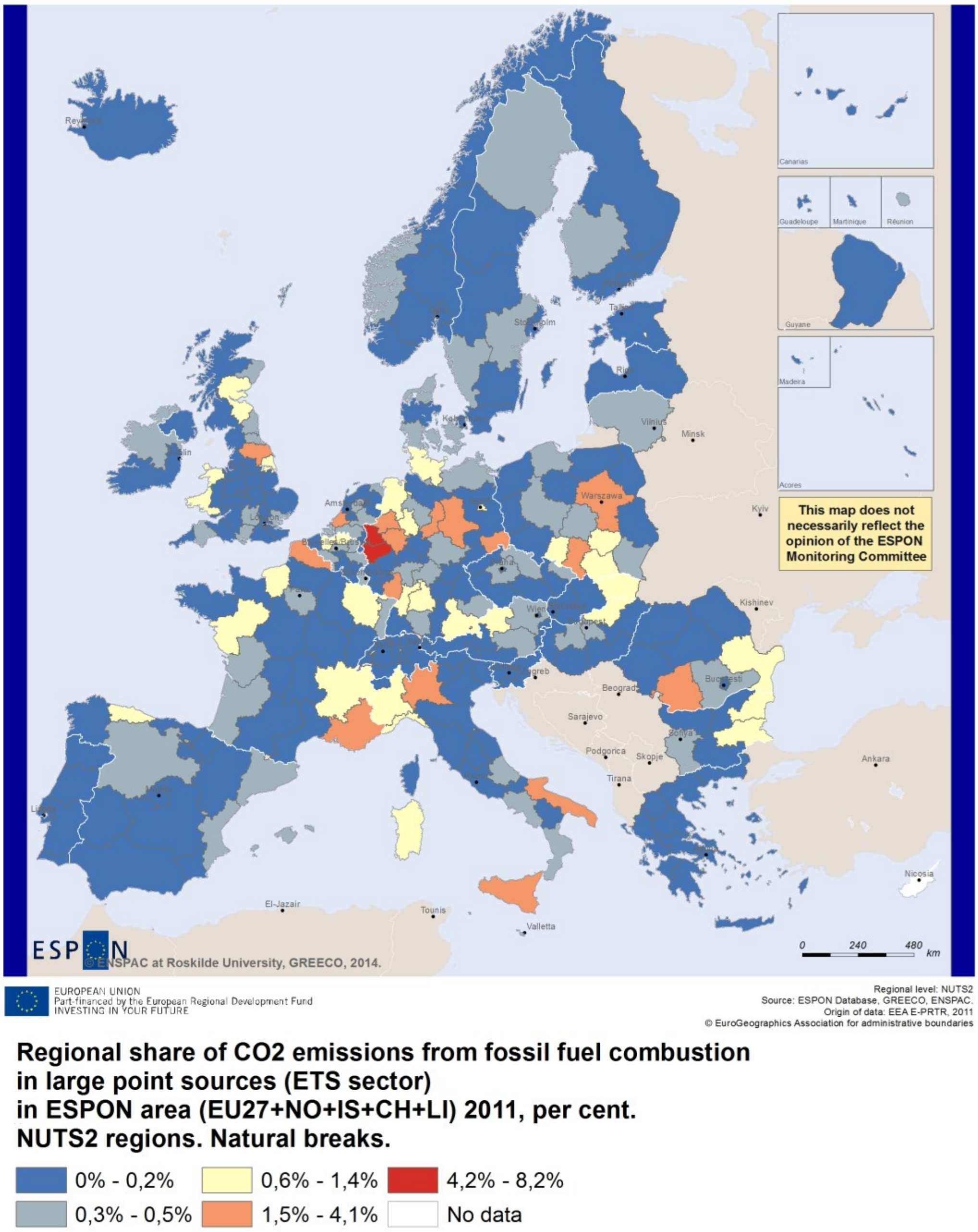
It is important to note that the regional emission figures are not observed emissions or based on observed fossil energy combustion but just the emissions one would expect to find if these data were collected. Consequently, the data are of no use for monitoring, performance measuring or even target setting. A region can only reduce these emission data relative to those at the national level by inducing its citizens and firms to migrate to other regions.

The E-PRTR data-base of the European Environmental Agency (EEA) now collects

6.8. Regionalised ETS CO_2-emissions

The large point source emissions of CO_2 are regulated by the EU emission trading system (ETS). In principle, it includes all plants with a fossil fuel boiler with a capacity of more than 20MW in. The emissions are reported to the E-PRTR data-base of the European Environmental Agency (EEA).

Based on these data, it is possible to study the regional distribution of these large point source emissions.



Map 12. Share of ETS CO_2-emissions by NUTS2 region, 2011. Per cent.
Source: Author's calculations based on the EEA E-PRTR database (European Environment Agency (EEA), 2013b).

The emissions of CO_2 from the large point sources regulated by the ETS are not evenly distributed across the European map. Some regions have the potentials of becoming global leaders of the transformation of large point source econosphere whereas other regions only have diffuse sources. 18.5% of the reported point source emissions in 2011 came from the three regions, Düsseldorf (DE), Cologne (DE) and Puglia (IT) (the darkest blue on map 12). Another 16.6% were emitted from the 7 regions Münster and Arnsberg (DE), Slaskie and Mazowieckie (PL), Zuid-Holland (NL), Lombardia (IT) and North Yorkshire (UK) (the slightly lighter shade of blue on map 12). Another 13.6% were reported from the 8 regions of Sicily (IT), Dresden, Braunschweig, Rheinhessen-Pfalz and Sachsen-Anhalt (DE), Nord - Pas-de-Calais and

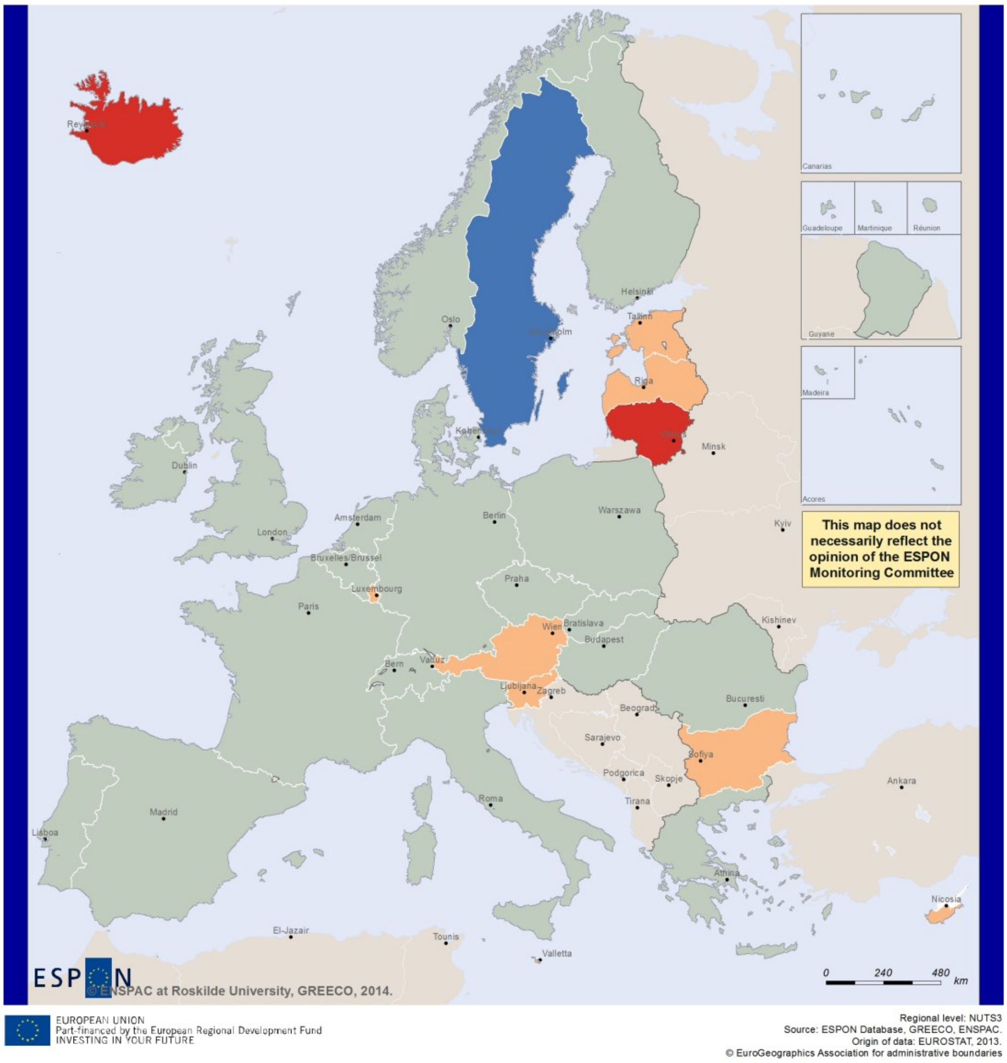
Provence-Alpes-Côte d'Azur (FR) and Sud-Vest Oltenia (RO) (the still lighter shade of blue on map 12).

Almost half of the point source emissions from the ETS area in 2011 came from fossil fuel combustion in these 18 regions. The local governments of the 18 regions do not control the solutions to the problem of transformation. They are mainly controlled by the EU and national governments. The challenge of transformation to a green economy, however, is markedly different to these regions than to regions with no point sources.

6.9. Regionalised non-ETS carbon budgets

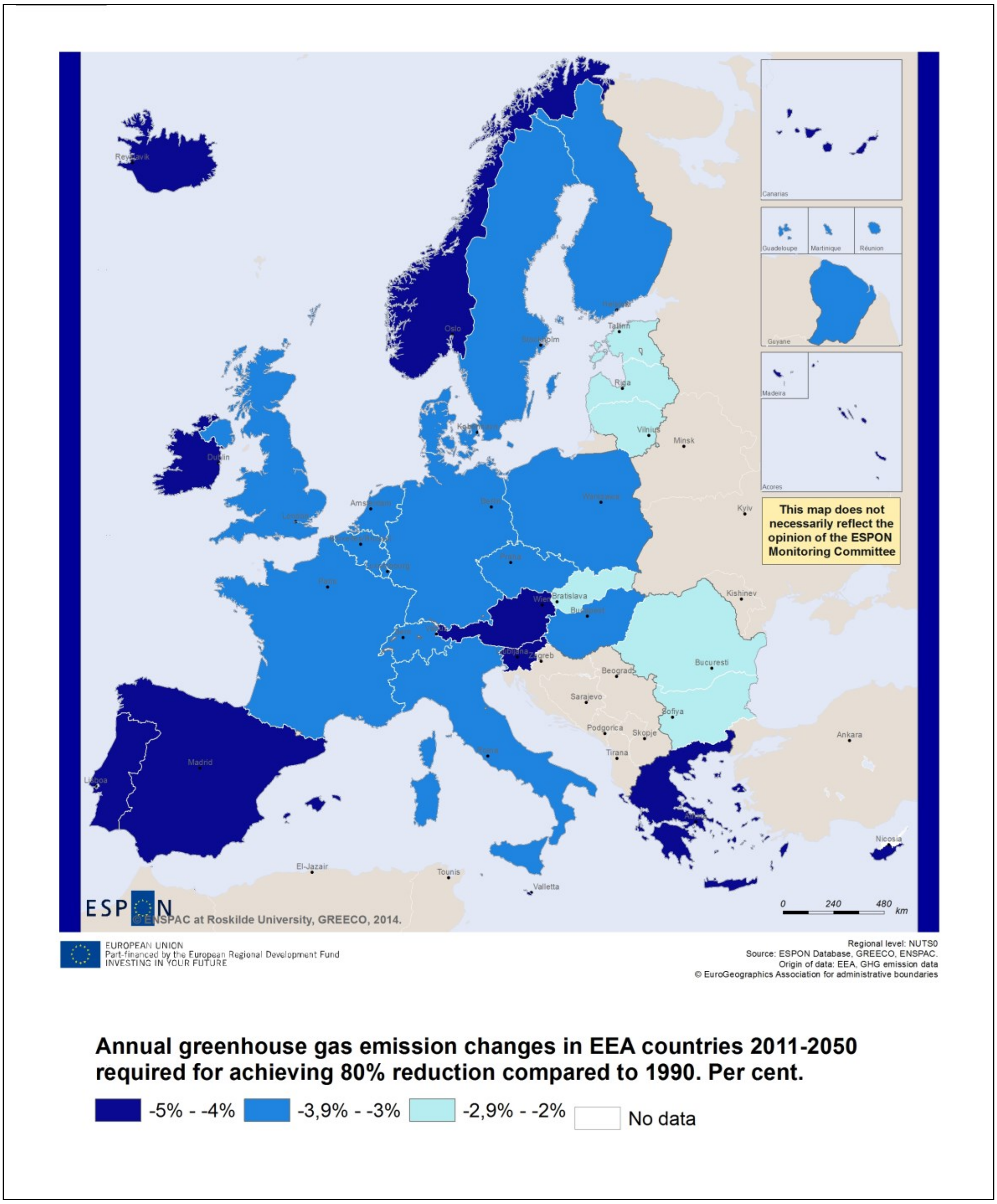
The above expected CO_2-emissions are of no use as baselines or monitoring indicators as they do not reflect regional changes in CO_2-emissions that deviate from the national. Nevertheless, according to the EU effort sharing agreement the rate of emission reduction for a member-state depends on the income level of the member-state. This principle can be transferred to the regions when regional CO_2-statistics are established.

Map 13 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 13. Greenhouse gas emission growth by EEA countries. Reported change 2008-2011 and required change for reducing by 80% of 1990 emissions in 2050. Per cent per year.
Source: Author's calculations based on GREECO datasets (Hansen, 2013b).

As shown in map 13, 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 3 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, 2010a).

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

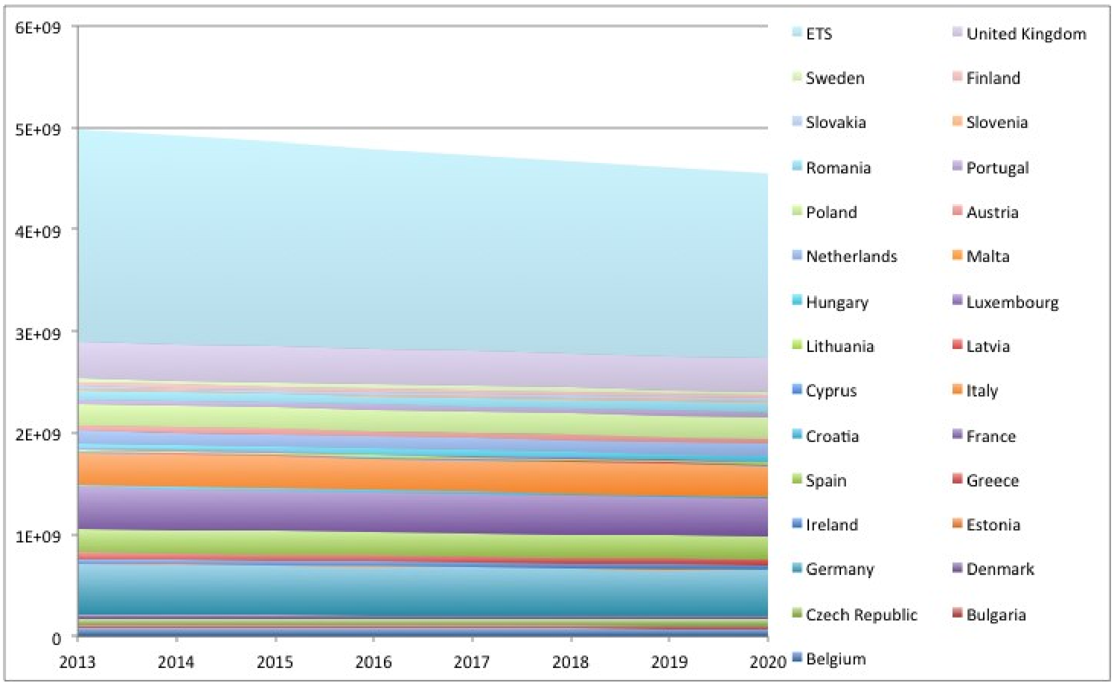


Figure 4. The EU GHG emission budget 2013-20 (Excl. international bunkring, offset credits and saved allowances). 1000 t.

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

The EU GHG emission budget in figure 4 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 5 below.

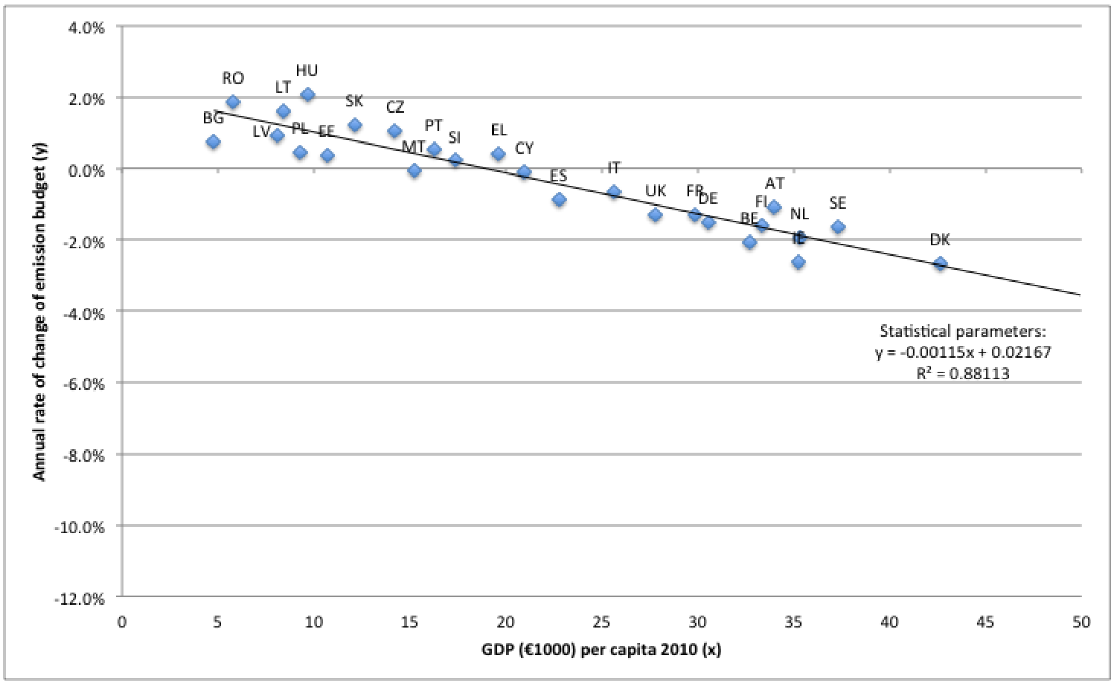


Figure 5. Dependency of reduction rate of annual non-ETS emission budgets on income level*.
Source: EU Commission (EC, 2013h) and EUROSTAT (EC, 2013j).
** Luxembourg is considered an outlier and excluded from the analysis due to its high income level.*

The income-adjusted emission reduction efforts shown in figure 5 actually allows for increased non-ETS emission in all member states with a lower per capita GDP in 2010 than Cyprus, that is, the other 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. Moreover, the carbon budget used in 2010-20 cannot be used again later on. A higher carbon budget in 2010-20 implies a smaller budget in 2020-50.

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 are be expected to be increasing in the long-run until the global demand for fossil fuels declines.

Thus, advancing the decarbonisation allows the economy to mitigate the otherwise foreseen fossil fuel drag on the economy cf. figure 11 and figure 12.

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.

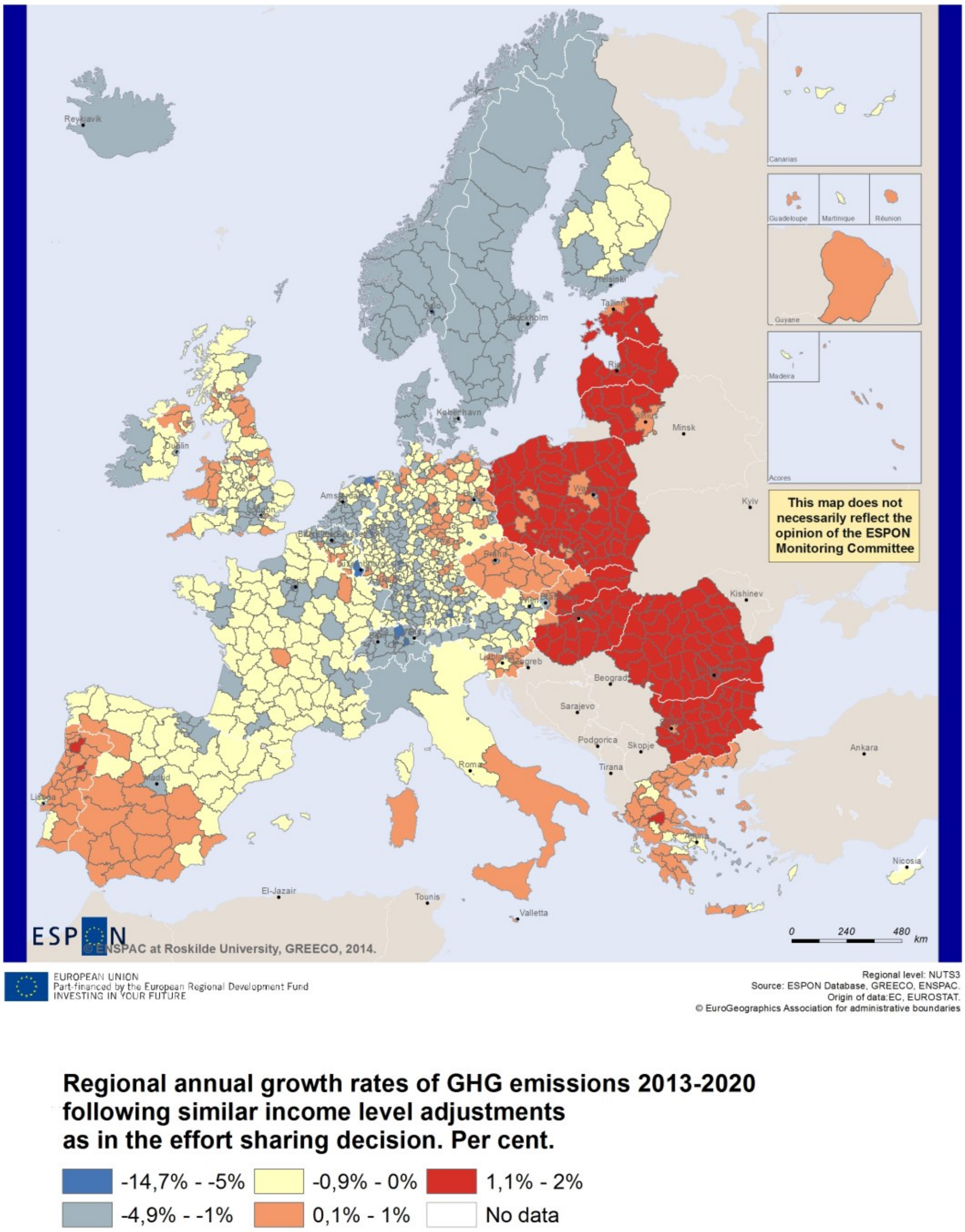
6.10. Regional emission budgets

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 5) plus the rate of population change. Map 14 below shows the income-adjusted rate of emission change by NUTS3 regions following the statistical pattern of figure 5.



Map 14. 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.
Source:

The regional income-adjusted benchmark rates follow the same pattern as that of figure 5. 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.

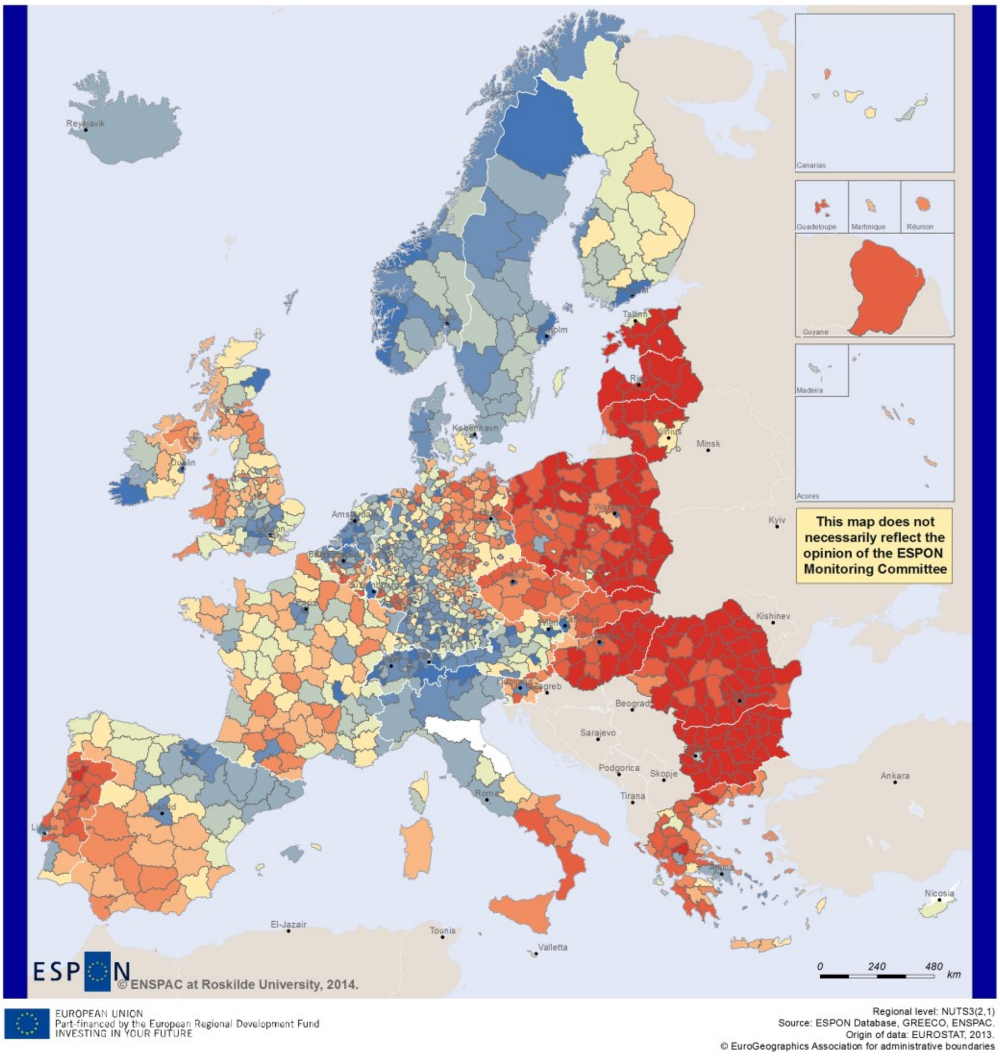
The whole idea of regional emission budgets or targets, however, requires that energy statistics is collected with a regional coverage that enables statistics at least by NUTS2 regions, but preferably at as high a spatial resolution as possible. At the present, data on the use of fossil fuels at a level of detail enabling regional statistics are only collected in some countries. The predictions shown in map 10 and map 11 are in the nature of the case not useful as indicators of the actual emissions.

The variation in emissions between countries and regions can be attributed to the economic activity producing it, the final energy consumption required to generate the economic activity, the gross inland consumption required to generate the final energy consumption and the fossil fuel consumption share of the gross inland consumption. Regional data on energy consumption are available in some countries. They do not necessarily follow the same statistical definitions, but it has been possible construct the partly regional and partly national level statistics on final energy use. The fossil fuel consumption share equals one minus the non-fossil energy share. Non-fossil energy is includes nuclear and renewable energy. The regional datasets generated through the GREECO project on final energy consumption and renewable energy potentials are described below.

7. Economic balances

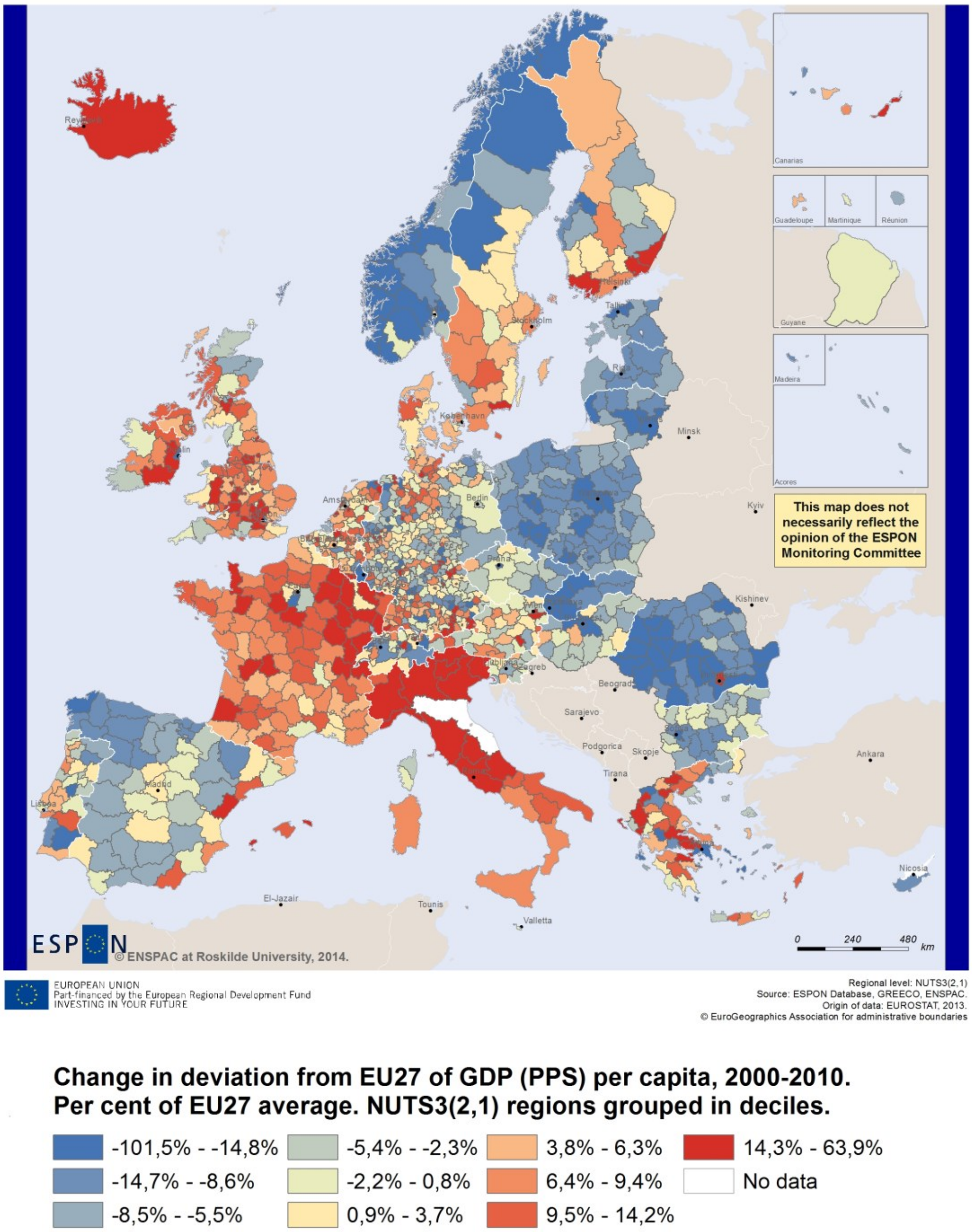
7.1. Productive potential

An economy also has a productive potential to unfold. Realising it appears as economic growth. Some of the new member-states with los levels of income are expected to unfold large productive potentials as they implement well-tried solutions of the rest of Europe. This is called the "catch-up potential" of the economies.



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

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



Map 15. Income disparities (2010) and catching-up (2000-10) in Europe.

The position of the European regions relative to the EU27 average of GDP per capita is shown in map 15. The upper map shows the dispersion of income levels in 2010. The sharpest contrast in average income level is still between the EU15 and the new member states (NMS10). Income levels in almost all regions of the new member states were still in 2010 far below EU average.

The lower map, however, shows that this pattern with large catch-up potentials appears after period of considerable catching-up from 2000 to 2010. It is a very long-term process.

The continuing specialisation of individuals and production units of an economy leads to economic growth and this is also expected for the high-income economies of Europe. The growth rate, however, is expected to be more modest than the growth rates of the low-income economies who additionally realise their catch-up potential.

7.2. The constant capital stock approach

The standard method of economics for assessment of the viability of an economic entity is to examine the bottom-line. If expenditures exceed the budget on a permanent basis the bottom-line has "red numbers" and the economic activity cannot continue without consuming its capital or being sponsored from outside. This concept of sustainability is the starting point for the economic sustainability indicators.

In conventional national accounting terms the wealth of an economy is the value of the fixed capital and stocks plus the net financial wealth of its inhabitants. This is, however, a rather narrow definition of material wealth the productive capacity of the economy also includes the human capital and the natural capital. Human capital enables the labour force and the firms to specialise and achieve high levels of productivity. Natural capital allows the production of raw materials and energy while harvesting a resource rent depending on the cost advantage of producing these goods at the territory of the economy.

The theoretical literature of this goes back to the environment and growth debate of the 1970s (Hartwick, 1977; Solow, 1974) and has subsequently been enriched with contributions driving it more towards operational indicators. The operational sustainability criterion suggested against this background is the "non-declining total capital stock" principle. If the sum of the man-made, natural and human capital stocks decreases, the development is not sustainable. If one of them is reduced, it can be substituted by increases in one of the others.

The ethical principle behind this criterion is that the future generations are entitled to a stock of capital – generalised productive capacity. They may inherit more, but are not entitled to more than the same stock of capital as the present generation enjoy – at least for developed economies (Solow, 1992, 1974).

Due to this fundamental assumption of substitutability between the different types of capital, the sustainability criterion can be defined in financial terms. Economic development is financially sustainable if the total capital stock (the sum of man-made, human and natural capital) does not decline.

This approach can be seen as an expansion of the current account or trade balance. Traditionally this is an indicator of whether aggregate spending of an economy is within the spendable "budget" - the GNI - of the country. Permanent or structural deficits are then seen as a sign of overspending, and thus an unsustainable economy. Investment spending, however, builds up assets balancing the foreign debt. The question thus is about over-*consumption* and the critical test is whether consumption exceeds the consumable income of the economy. The consumable income is the net-national income NNI (the GNI reduced by the consumption of fixed capital (depreciation) that cannot be consumed again). This is a more informative measure of over-consumption than the current account, but it has two major flaws in the analysis of changes in capital stocks.

First, the consumption of natural resources leaves a smaller resource stock to posterity and thus represents capital consumption as much as fixed capital depreciation does. Second, the some of the most important investments of the economy – the investments in education and health – enter into the national accounts as consumption.

Adjusting the NNI for these changes in natural and human capital gives a more exact measure of the consumable income and thus of over-consumption. It leads to *adjusted net savings rates* as an indicator of general over-consumption in the economy. Net-savings represent the difference between the consumable income and the actual consumption. Negative net-savings indicate over-consumption. There are several levels of net-savings rate adjustment.

The first level adjusts for the reduction of natural resource stocks (extraction minus natural regeneration). A second level additionally adjusts for the overconsumption of sinks such as unsustainable CO_2-emissions and PM10-emissions. The third level adjusts for the investment in education and a fourth level for other investment human (and even social) capital.

The international system of national accounts includes harmonised methods of accounting for changes in stocks and values of these natural resources. It is, however, much more difficult to arrive at reliable monetary estimates of the over-consumption of sinks. The results of the studies on these costs vary by orders of magnitude (See, e.g., Kuik et al., 2009). Internationally comparable datasets have recently become available for third level adjustments.

First level adjusted net savings rate of the EEA countries with data included in the World Bank database on adjusted net savings is shown in figure 6.

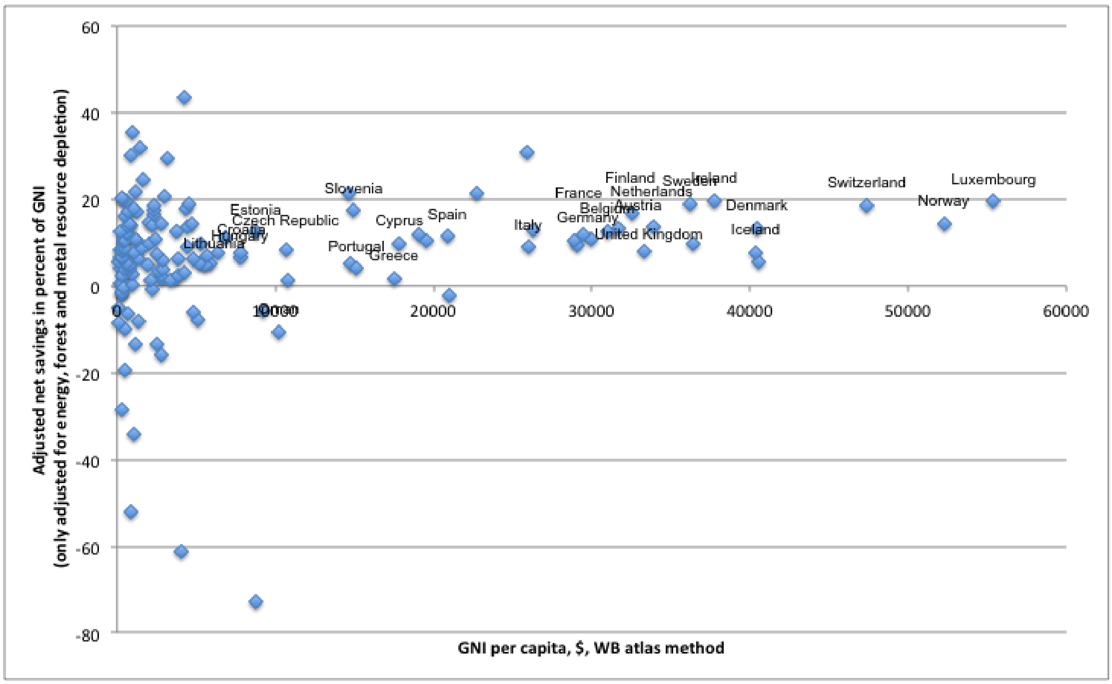


Figure 6. Adjusted net savings for 150 economies, adjusted for energy, metals and forest resource consumption, average of 2000-08. Per cent of GNI.

Source: Authors calculations based on the World Bank adjusted net savings database (The World Bank, 2011).

Figure 6 shows the average adjusted net savings rate over the period 2000-08 where the net savings rate only has been adjusted for over-consumption of the resource budget so that fewer resources are left to posterity. For transparency only the European economies are labelled by their name in the diagram.

The figure shows that the EEA countries generally had a positive adjusted net savings rate in the 2000-08 period. Greece 1.7%, Bulgaria 2.4% and Portugal 4.1%. The rest of the economies had comfortable net savings rates in the 10-20% band.

In second level adjusted net savings rate indicators, the overconsumption of sinks and space is expressed in monetary units. The World Bank, for instance, includes a cost per emitted ton of CO_2 and PM10 (The World Bank, 2011). Others would claim that human lives and health, biodiversity and climate stability belongs to value categories that are unique and incommensurable. These are not substitutable by financial or man-made capital. They are "critical capital". Against this backdrop the literature distinguishes between "strong" and "weak" sustainability criteria, where weak sustainability ignores critical capital (see, e.g., Ekins et al., 2003; Neumayer, 2010).

It is important to note that the net-savings rate is a measure of financial capacity, which cannot measure ecological balance and compliance with sink and space budgets. These are matters for natural science.

The idea of strong sustainability implies a multidimensional framework such as the idea of "four capitals" including man-made, human, natural and social capital – the latter including financial capital as well (Ekins et al., 2008).

This perspective on sustainability lends from the framework of portfolio management where stocks of various types of assets can be exchanged and passed on from one year to another. The ecological assets do not fit well into such a paradigm. The carbon budget for instance cannot be halved from year to another and replaced by another asset. It takes time to replace the fossil fuel design of the econosphere with a sustainable design - at least a generation or two. In that perspective what is passed on to future generations is not stocks of natural and man-made assets, but an economy that can work without the unsustainable flows of fossil fuel that the present economy is dependent of. From that perspective, the overconsumption of sinks is not the so-called damage costs of emissions, but the investments in the capital basis of a green economy, that are *not* done. This would presuppose an investment budget for the entire transformation of the capital basis allocated to each year.

A positive net savings rate indicates how much an economy *could* spend additionally for purposes that do not add to future productive capacity, that is, investments that do not increase future GNI. It could be consumption or investing in other assets than those resulting in financial returns and marketable goods. For instance investments in ecosystem restoration, clean air and organic food that don't provide more economic value, but do improve quality of life.

Thus, Figure 6 shows that most European countries in the 2000-08 period have a comfortable financial potential for such investments. From a financial perspective, it is not a question whether it is possible to ensure economic sustainability and ecological sustainability at the same time. Most European economies could spend 10-20% of their national income on such investments without reducing their future consumption. The question is, first, a matter of choice between investing it in GNI-generating capital or in capital that generates ecological and social value. How much economic growth and how much non-income related quality of life?

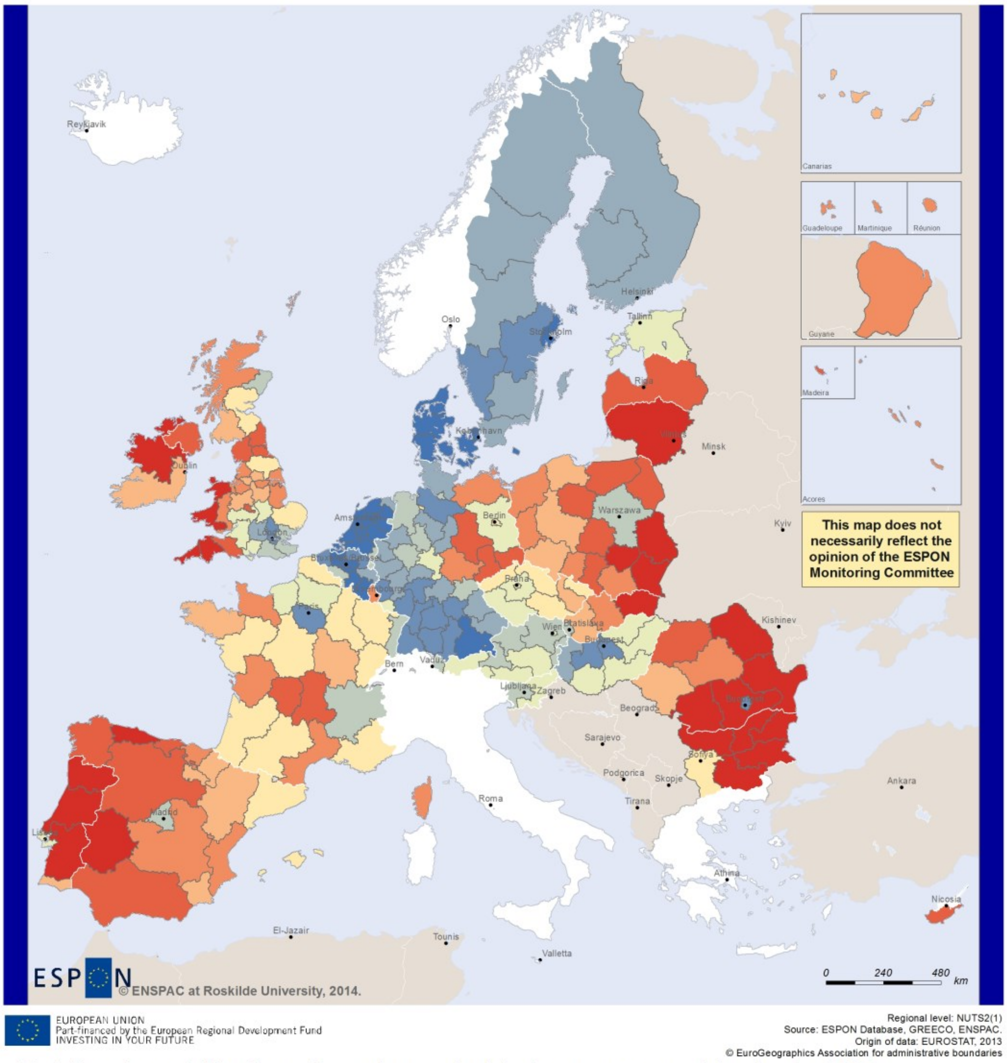
Neither does the adjusted net savings indicator carry any information about what the saved income is invested in. This is unfortunate because investment in more of the unsustainable system of boilers and engines designed to use large amounts of fossil fuels will not bring the economy closer to a green economy, but investment in efficient systems of renewable energy, heat pumps and electro-motors will. Moreover even high levels of investment can be in assets of dubious viability such as it was experienced in economies with a real estate bubble up to the financial crisis.

The consensus on the intergenerational balance in economic development has given rise to a debate of what future generations really are entitled to. The political definitions of a green economy reviewed above point to their right of development and it could be a more operational approach than the paradigm of future generations being entitled a constant sum of various man-made and natural asset stocks. Then a the progress towards a green economy can be monitored by collecting data on the rate of installed fossil fuel boilers and engines vs. renewable electricity generators, heat pumps and electro-motors, the rate of replacing chemically harmful substances with harmless, replacing throughput solutions with circular supply chain management etc. The problem today is that data on these processes are not collected systematically and harmonised in the EU.

7.3. Fiscal sustainability

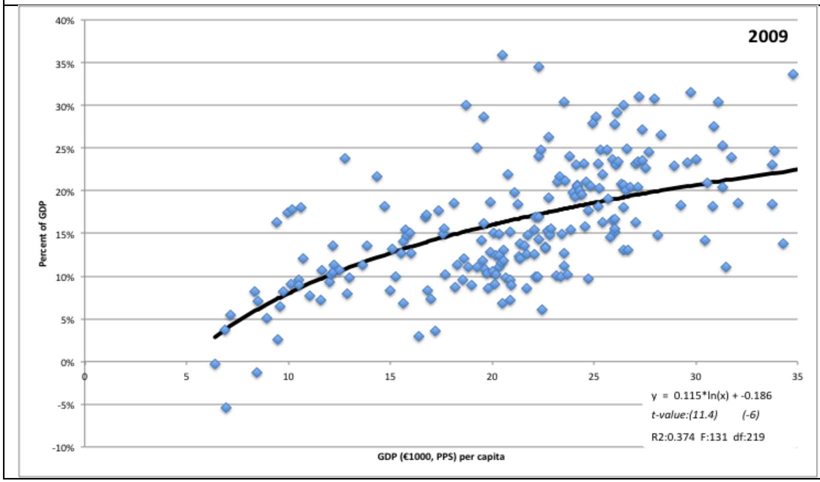
Fiscal sustainability is a central objective for the Economic and Monetary Union and not least after the fiscal crisis. The fiscal crisis revealed unsustainable financial budgets in the public sector as well as in the private sector. This is primarily a national challenge, but many regions that are unable to contribute to the fiscal sustainability of national government.

The mobilisation of public funds and their investment in infrastructures and human capital has served as a growth engine for the European economies in the 20th century. These potentials are far from exhausted in all regions but the mobilisation of funds is a necessary condition for realising such potentials. The map in figure 7 shows the net fiscal contribution from the regional economies at the NUTS2 level to financing such investments. This indicator is similar to the "modified tax burden" (OECD, 2000), but it does not include corporate and capital taxation.



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

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



Income-level and net-contribution rate, 2009. Per cent of GDP and €1000 (PPS)/person.

Figure 7. Net fiscal contribution (taxes net of transfers) from households to public budgets. Per cent of regional GDP. 2009.
Source: Author's calculations (Hansen, 2013b).

The lower diagram in figure 7 shows that the rate of the net fiscal contribution of an economy to the aggregate income generated in the region level of net-contributions to some extent is linked to the level of income. Regions with higher levels of income tend to contribute a higher share of the income generated in the region to public investments. Regions with lower levels of income, however, generate less public funds to invest in the region as well as nationally. Some regions even receive more transfer incomes from the other regions than they pay in taxes.

It is difficult to define an operational criterion for the net-financial contribution that is financially sustainable. The Treaty on Stability, Coordination and Governance (TSCG) lay down sustainability criteria for government budget balances at the national level in the "Fiscal Compact". These criteria cannot be transferred directly to regions because they play different roles in the regional specialisation within the national economy and in the geographic localisation of the population. Metropolitan regions specialise in corporate headquarter functions, government institutions etc. all which need highly specialised and well paid labour and services. Other regions specialise in industries that intensively use low-skilled labour. Some regions "specialise" in being a good area for retired citizens, nature and tourism ensuing relatively low levels of primary income. Thus, the surpluses that can contribute to public finances differ between regions. As shown in figure 7 some regions were even net receivers of public funds from other regions. A permanently negative net fiscal contribution, however, can hardly be classified as "sustainable" under any perspective.

It should further be noted that the regions differ with respect to commuting. Regions adjacent to metropolitan centres often serve as commuting hinterland to these. Thus, they have more out-commuters than in-commuters and these out-commuters often have higher incomes. Thus, the tax in such regions will tend to be higher in proportion to GVA and GDP than in proportion to the incomes of the residents. This is because GVA and GDP reflect incomes generated in the firms of the region, whereas the taxable income is the income earned by households and firms residing in the region. Regions with a high inward net-commuting will inversely tend to have some of their high GDP or GVA taxed in neighbouring regions.

8. Social balances

8.1. Social inclusion and government finance

The indicators chosen for monitoring social balances in the EU sustainable indicators set and the Europe 2020 strategy contains Population at risk of poverty or exclusion (i.e., People living in households with very low work intensity, People at risk of poverty after social transfers or Severely materially deprived people). The Europe 2020 target is to reduce poverty by aiming to lift at least 20 million people out of the risk of poverty or exclusion.

Achieving this target is important for generating financial resources for investment in any economic development towards a green economy. The relation between the net fiscal contribution and poverty risk of NUTS2 regions appear from Figure 8.

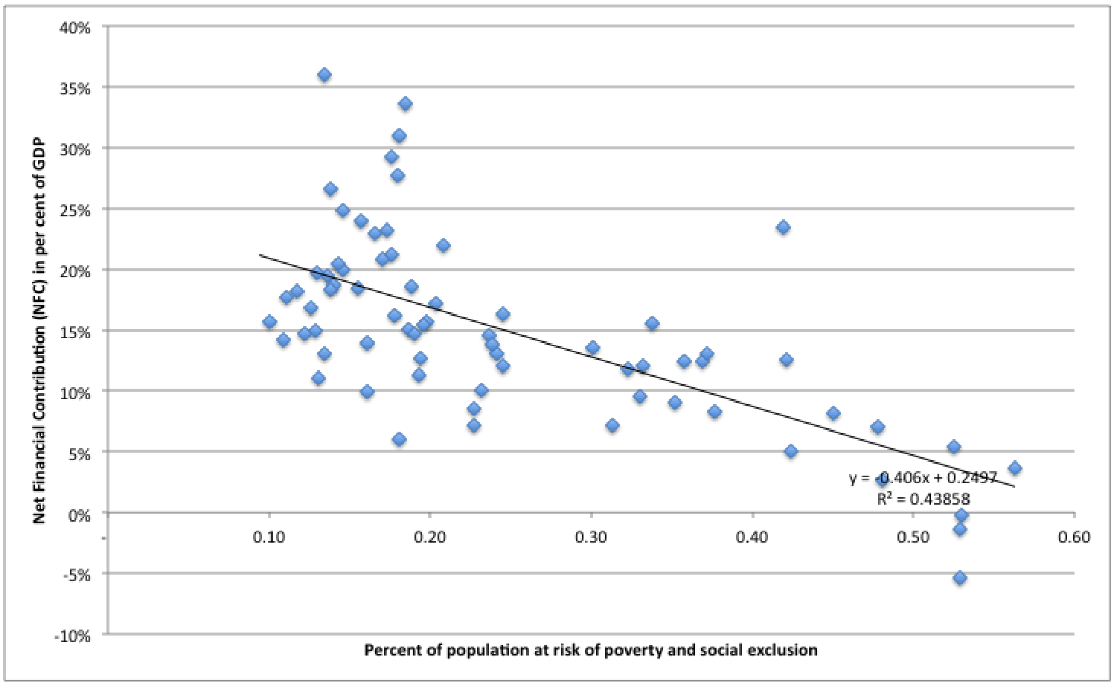
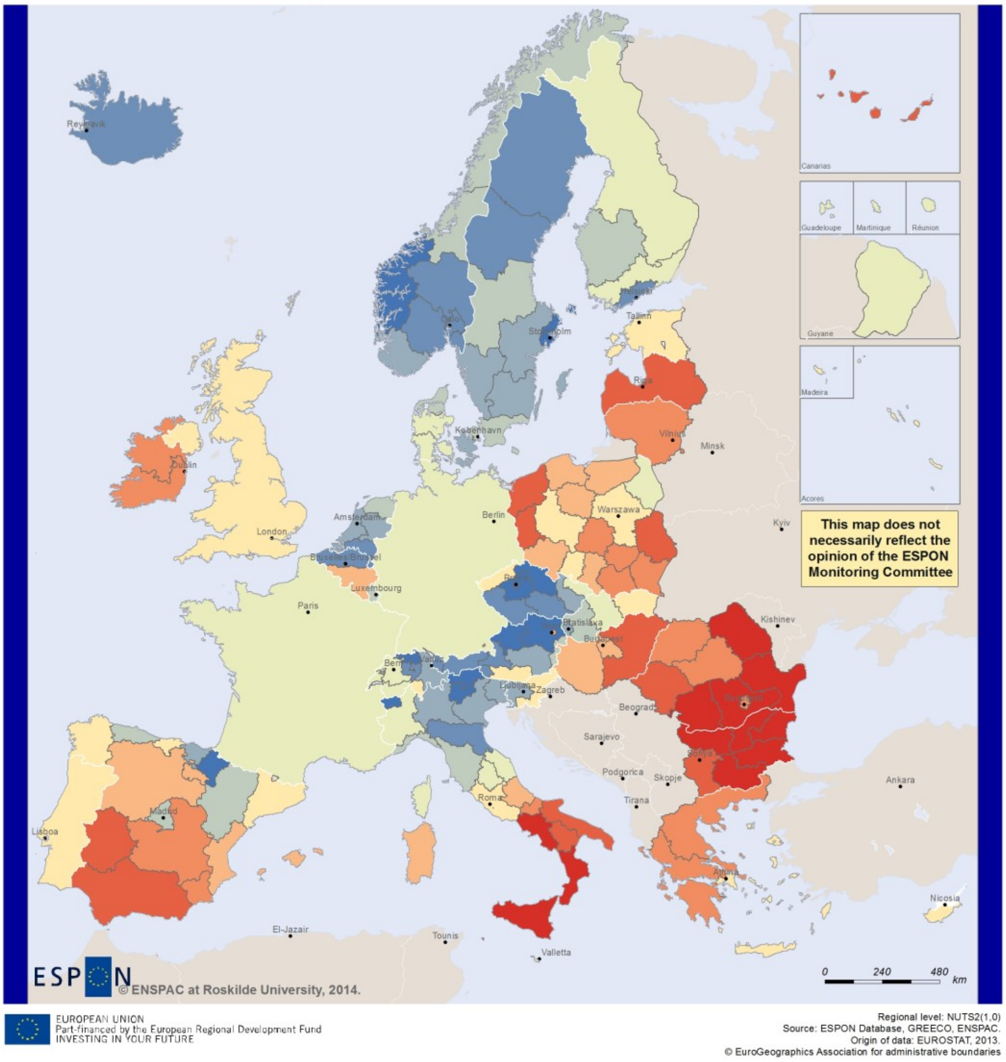


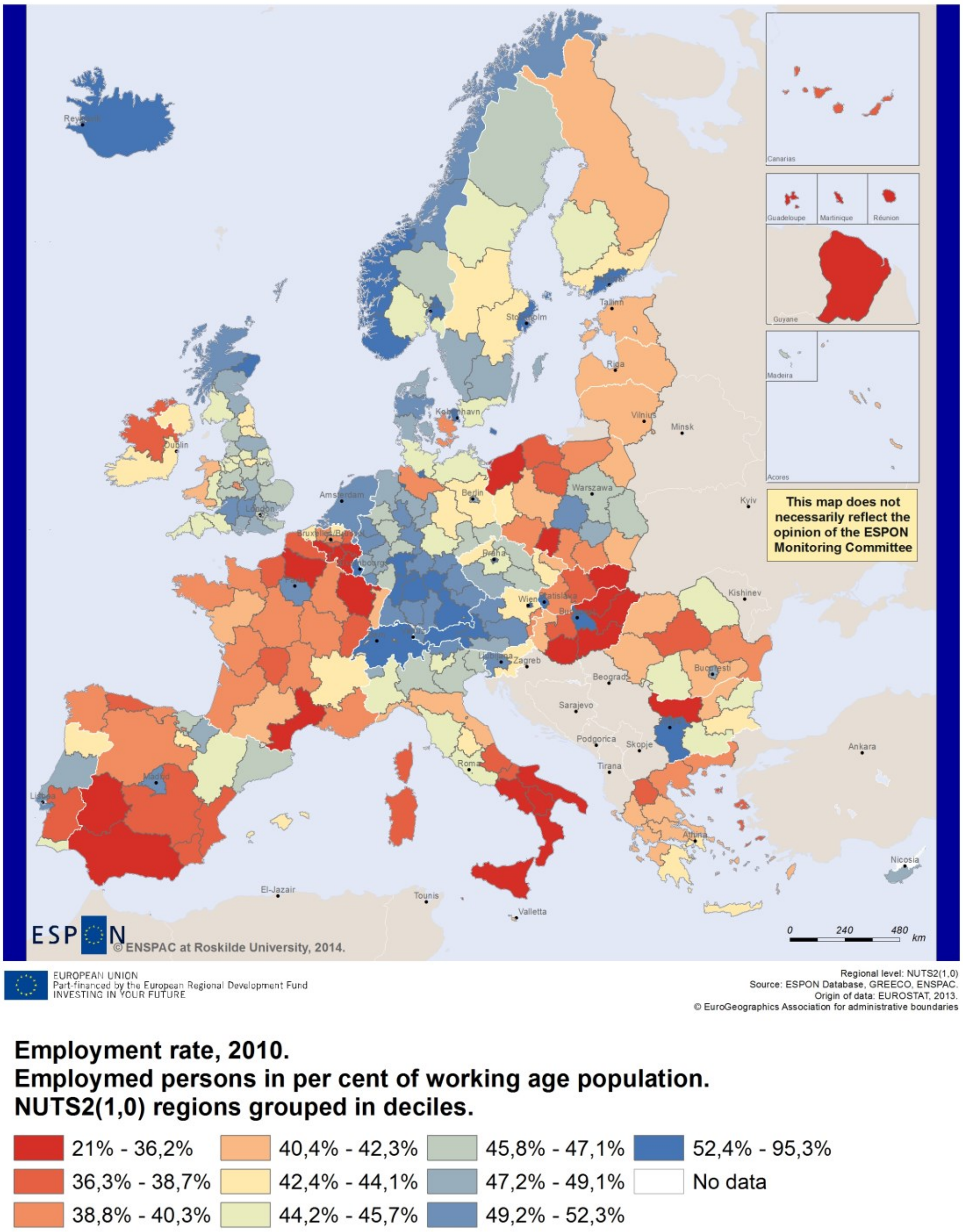
Figure 8. Dependence of the net financial contribution rate on the per cent of population at risk of poverty or other social exclusion in NUTS2 regions, 2009.
Source: Author's calculations based on the GREECO datasets (Hansen, 2013a).

Achieving the EU target of bringing 20 million EU citizens out of the risk of poverty and social exclusion holds the potential of transforming entire regions from being net receivers of fiscal contributions from other regions to become net contributors or from being modest to become average net contributors.



Population at risk of poverty, 2011.
Per cent of total population.
NUTS2(1,0) regions grouped in deciles.

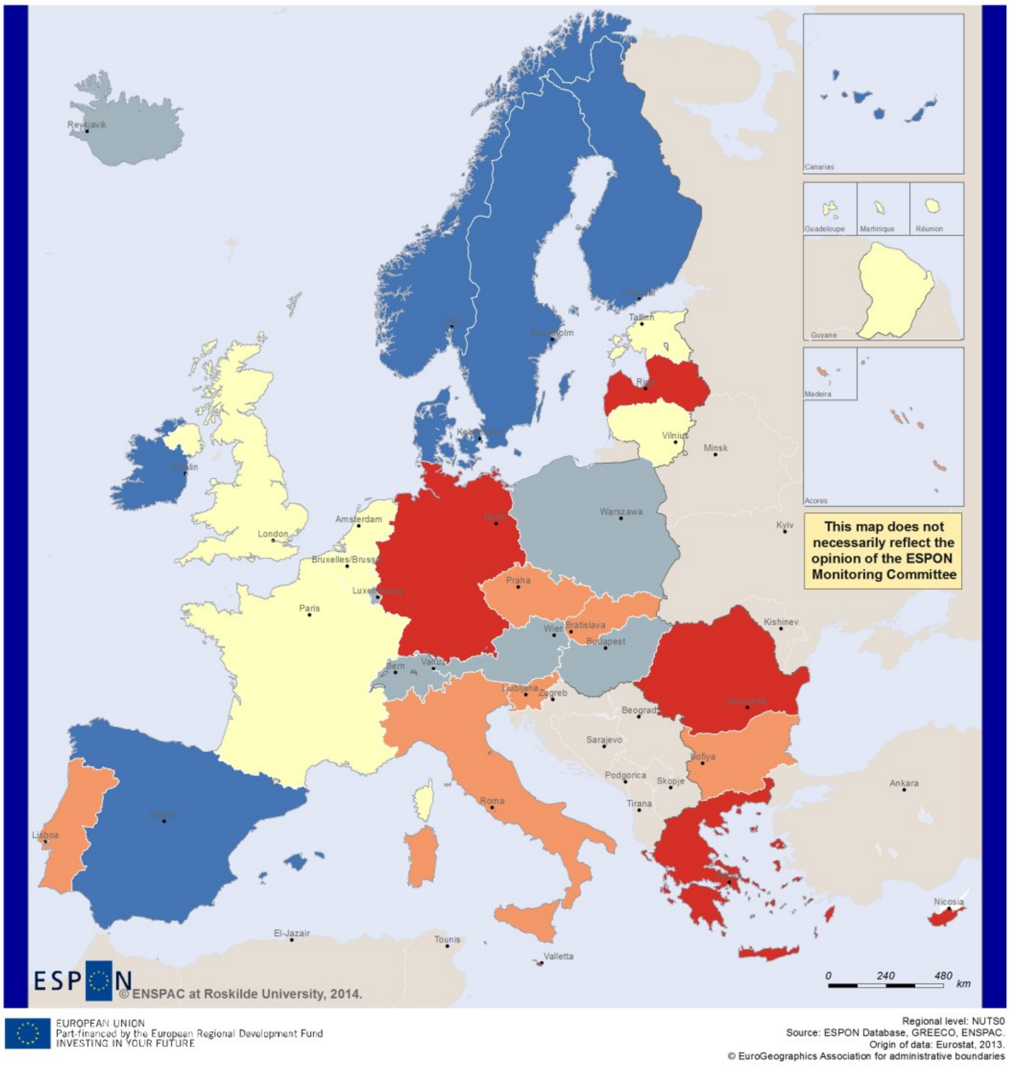
8,1% - 13,3%	16,9% - 19,1%	25% - 28%	42,5% - 59,1%
13,4% - 15,1%	19,2% - 21%	28,1% - 33,5%	No data
15,2% - 16,8%	21,1% - 24,9%	33,6% - 42,4%	



Map 16. People at risk of poverty and social exclusion (average 2010-11) (upper map) and employment rate 2010 (lower map).
Sources: (Hansen, 2013a).

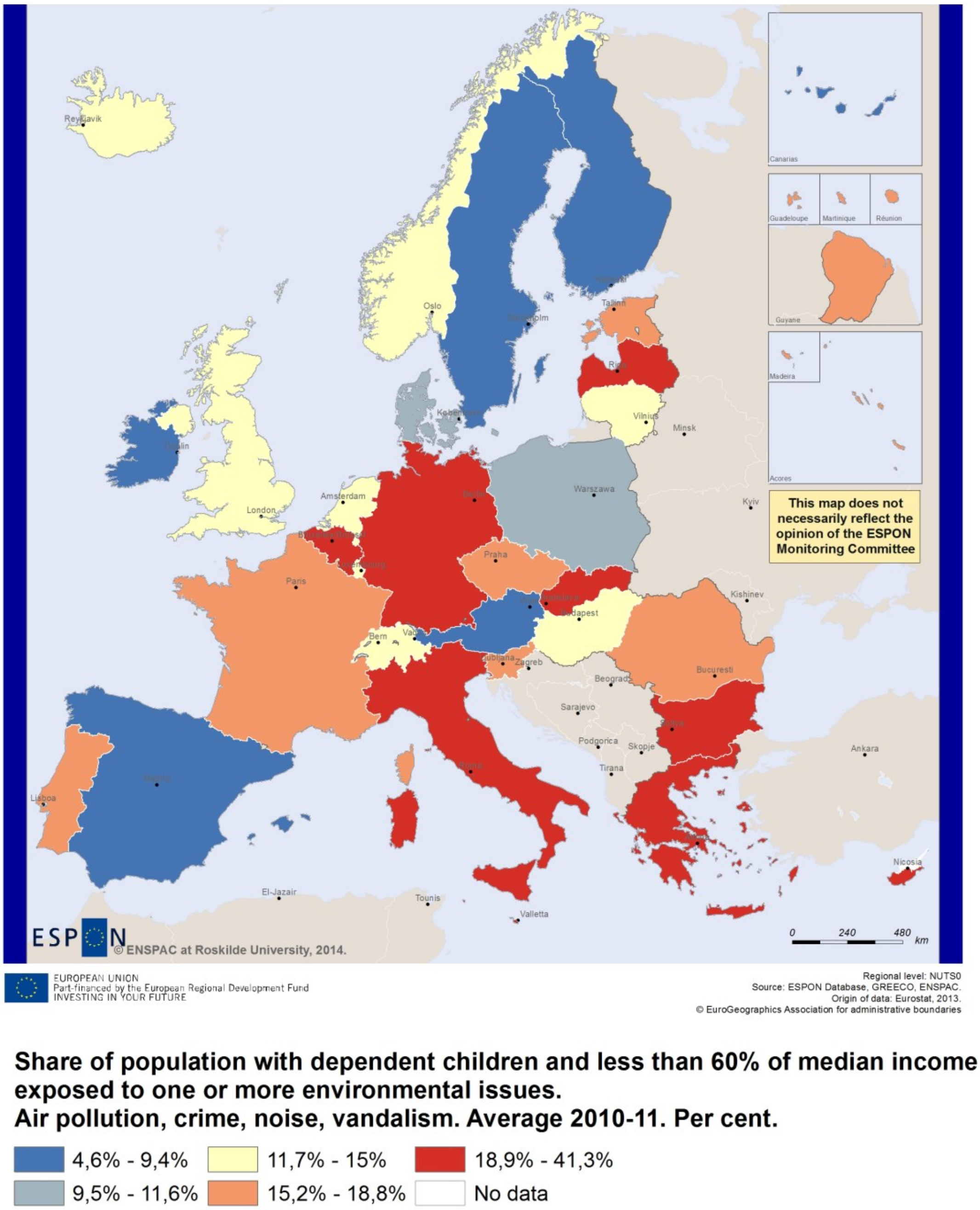
The at-risk-of-poverty rate coincides to a wide extent with the rate of employment (inverse), but far from perfectly. The expected impact of advancing future investments in a green infrastructure, near-zero-energy buildings etc is that the employment rate will increase and consequently the poverty rates and financial balances improve.

In urban agglomerations and their hinterland the residential segmentation by income groups often follows ecological assets such as green surroundings and air quality. Citizens that can afford residences in areas with green surroundings, low levels of air pollution and good water and waste infrastructure tend to prefer to settle in such areas rather than in areas with the opposite characteristics. Thus, it is natural to expect that improving access to nature for areas with poor access, reducing exposure to air pollution in areas with high exposure and improving coverage of adequate water, wastewater and waste infrastructure in areas with deficient infrastructures bring the living conditions of the people at risk of poverty and other social exclusion closer to the rest of society.



Share of population exposed to one or more environmental issues.
Air pollution, crime, noise, vandalism.
Average 2010-11. Per cent. Countires grouped in quintiles.

4,6% - 9,4% | 11,7% - 15% | 18,9% - 41,3%
9,5% - 11,6% | 15,2% - 18,8% | No data



Map 17. Share of population exposed to environmental issues (air pollution, noise, crime and vandalism), average 2010-11. Per cent. All households (upper map) and households with children and income below 60% of median income (lower map).
Source: Author's calculations based on Eurostat data.

The patterns of map 17 show that the European populations are exposed to environmental issues to different degrees. The same map based on data for households with children with incomes below 60% of the median income (at risk of poverty) shows that a higher fraction in most countries of this part of the population is exposed to environmental issues.

The differences, however, are not large at the national level of aggregation. The environmental issues primarily occur in and around urban agglomerations whereas in many countries a relatively large part of the rural population is at risk of poverty measured by their income level.

The environmental burden of disease in six European countries was estimated to account for 3% of the total burden of disease in Finland and 6.5% in Italy. The environmental burden of disease was calculated in discounted age-weighted DALYs per 1000 people with 3.9 in Finland and 7.2 in Italy (population figures weighted according to exposure) (Hänninen and Knol, 2011).

The energy bill makes up a larger share of the budget in low-income households than in high-income households. This pattern is pervasive in almost all European countries.

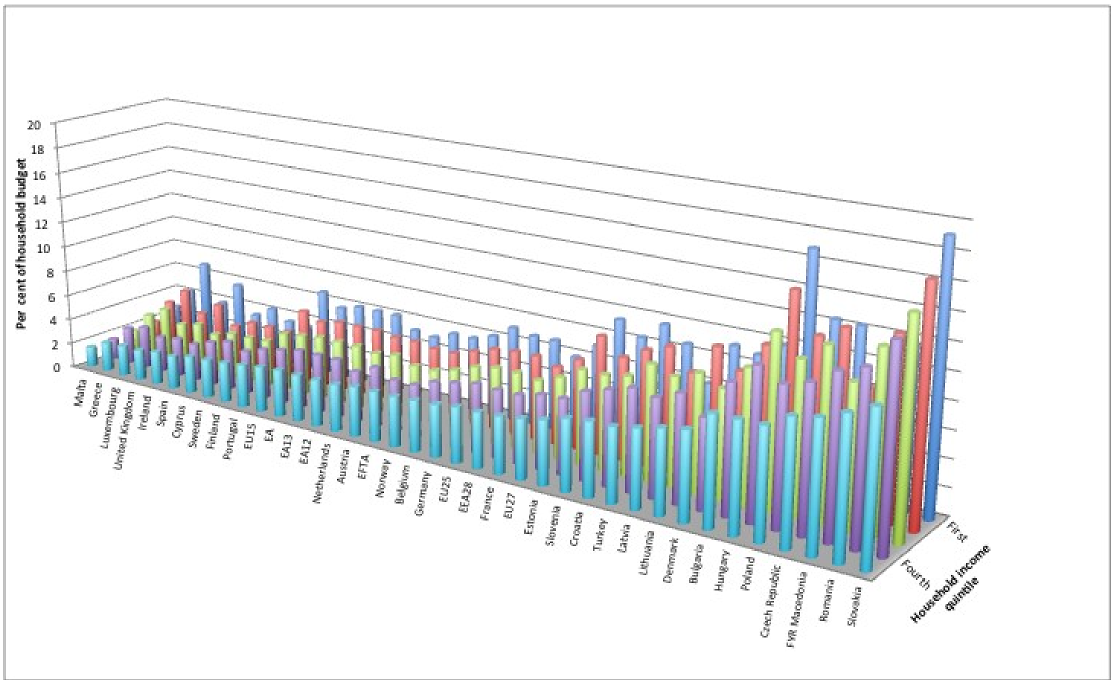


Figure 9. Share of energy expenditure in total consumption budget of households by quintile (first-fifth) in European countries, 2005. Per cent.
Source: Author's calculations based on EUROSTAT household budget survey 2005 (EC, 2013k).

Figure 9 shows the share of fuels, heat and electricity in the budgets of European households by country and income quintile. In almost all countries these expenditures make-up a higher share of the consumption budget the lower the income quintile. Realising the economically attractive energy saving potentials in Europe could thus be expected to be particularly favourable to lower income groups.

The replacement of fossil (and in some countries nuclear) energy by renewable energy involves the additional costs of learning. The ability to master the efficient production and use of immature renewable technologies has improved dramatically over the recent decades and is expected to continue to improve over the next two decades. Thus, the additional cost of investing in wind and PV-technologies in the past are investments in the enhanced productivity of the technologies in the future. This applies to the investment in energy generating plants, infrastructure and electricity storage solutions as well. These costs, however, are typically financed via electricity, heat and natural gas tariffs and via energy taxes paid irrespective of income. Moreover, these costs may be born disproportionally by households to protect industrial activities from loss of competitiveness.

Energy is an essential good – i.e., we cannot live decent lives without a minimum of energy services – and the energy consumption of households is thus in the short-term not very elastic to changes in incomes and energy prices. Energy consumption to a high extent is build-in in the physical structure of the residential building and the equipment installed in it. Thus, final energy use changes relatively slowly in response to price changes.

Additionally, low-income households in the EU are more frequently tenants (as opposed to owners) than higher income groups. For tenants the ability to respond to increasing energy prices by investing in insulation and more efficient heating systems is limited. For low-income households it is also typically more difficult to achieve adequate and low cost finance for such investments. Thus, higher energy prices tend to result in a higher share of energy expenditure in the household consumption budget of low-income households than of high-income households.

Thus, the energy delinking process may entail changes in the final distribution of consumption opportunities (real disposable household income). This type of unintended changes in the distribution of disposable *real* income involves a risk of jeopardising the *political* sustainability of the transformation process. Raising electricity and gas prices give rise to political response with varying political consequences from Bulgaria to Germany and the UK.

The notion of energy poverty combined with imperative of eradicating poverty implies that some sort of right or norm regarding energy consumption must be defined for EU citizens. From a green economy perspective it is essential to distinguish between consumption of energy and consumption of energy *services*. EU citizens may be entitled to a number of a floor area of some size with a healthy temperature all year round, but not to a specific amount of energy consumption. The energy service measured in heated square metres is essential, but energy consumption due to the high heat loss from buildings is neither morally not economically well-founded.

By the same token, it is not possible to understand the impact of energy prices on the social distribution without including the income transfers, taxes, allowances etc that aim at enable a decent life for all groups of society. In particular, when energy taxes generate a revenue that is earmarked to neutralising the public
price of energy cannot be seen detached from the income transfers and tax allowances enabling low-income households to purchase a sufficient amount of energy. In Denmark, for instance, household electricity consumption costs around c28/kWh due to electricity taxes. This is far above the electricity price of other EU-countries, but as the electricity tax gradually has been raised, it has been accompanied by higher income transfers and by compensating tax measures maintaining the social balance. Higher income transfers to pensioners, unemployed, students and citizens with sickness benefits. The tax and related measures include, for instance, raising the personal tax allowance, "children family checks", "senior citizen checks" and recently a "green check" compensating citizens at low income levels for energy taxes. Other safety nets of the Scandinavian welfare system catch citizens that despite these measures should be on the route to poverty due to energy prices, if any. This example shows that it is perfectly possible to have high energy prices without energy poverty if the rest of the government tax and income transfer systems are designed to offset the unintended distributional impacts of the higher taxes or tariffs.

The available indicators of social inclusion combine the measures of low disposable income, inability to pay the monthly bills and exclusion from the labour market. These indicators will in the long-term capture adverse impacts of higher energy prices in the form of the poverty symptom of not being able to pay the monthly bills. In the short term, however, it could be useful for local as well as national government to monitor the immediate impact on household budgets of changes in energy prices whether induced by international prices, infrastructure investment financing or government taxes.

The patterns also underline the importance of introducing redistributive mechanisms when energy taxes on household energy consumption are raised. Fortunately, the revenue of such taxes also offers the means for neutralising unintended distribution effects. Otherwise the durability and impact of such taxes is questionable.

Whereas it is important to integrate the *objectives* of social, economic and economical balance, it is nor necessary, neither possible to obtain all of the three objectives with *adjustments of energy prices*. Fortunately, governments have a large palette of instruments at their disposal and it is through their combination that all three objectives can be reached.

Ensuring the social balance by providing subsidies to the heat loss the buildings in which low-income households reside would be unsustainable in the economic and the ecological dimensions. Subsidising commodities for distributional purposes is leads to over-consumption of the subsidised commodities and economic theory is thus clear on the recommendation that redistribution should use other taxation and income transfers for redistributional purposes. Subsidising low-income heat loss at the same time as high-income heat loss is taxed is not financially sustainable. Enabling households to continue energy consumption for the heat loss is not ecologically sustainable. Subsidising the refurbishing or replacement of older buildings by near-zero-energy buildings can unite progress in all three dimensions.

Whereas taxes and income transfers are typically the responsibility of national government in Europe, renewal of the building stock is much more a task that lies within the responsibilities of local government (from NUTS2 to the municipality level). The national government, however, must provide the necessary institutional framework, e.g., on the citizens' right to energy services and the instruments to ensure that the necessary investments take place. It is important also for local government to see these investments in supply chain perspective as for instance the oil-well-to-heated-floor-space chain requires other end-use investments than the wind-to-heated-floor-space chain.

A statistical framework that could enable benchmark-analysis of the state and progress of the building sector in the regions would be useful for the regional and local policies for catching up with the European standard. Identification and quantification of energy poverty and of floor space by heat loss and heating system would be easier. It would facilitate the comparison to "peer-regions", setting quantitative targets and monitoring the progress towards them.
Second, statistics on the exposure of the population in various areas to environmental risk such as air pollution, inadequate drinking water and sewage, noise, chemical pollution and other pollution issues would be useful.

The statistics referred to above is the exposure *reported* by the income survey respondents. If local government and regional policy actors want to address the ecological-social dimension it would be useful to develop statistical indicator frameworks based on the known exposure of different areas to link it to area-specific socioeconomic/income statistics. Many of the necessary primary data are already collected cf. the analysis of air pollution in Europe below and some of the data could be produced in a top-down procedure.

9. The ecological-economic nexus

9.1. The econosphere – linking nature and economy

The real challenge of the transformation to a green economy is to achieve progress in all three dimensions simultaneously. In the great debate on environment and growth in the 1970s it was a widely distributed premise that it was impossible. It was a choice between growth as in the industrialised economies with massive ecological losses or no growth. The concept of sustainable development and now the green economy is also a statement of its feasibility. Economic prosperity in ecological balance is possible.

The broad character of the concept of a green economy makes it desirable to define more exactly what it is that should be changed in the interface between the economy and nature. Many of the decisive differences between economies have very little or nothing to do with it. The experience from the 20th century was that centrally planned and market economies alike engaged in building supply chains and infrastructures that are unsustainable. The profound differences between Nordic welfare state economies the southern economies and the economies of the new member states have immense importance to the social welfare of the populations in the countries, but the ecological-economic trade-offs are the same. The financial sector and its regulation has differed widely between countries, with fateful consequences for the economy of the countries, but without importance for ecological over-consumption.

A green economy that keeps its balances should be possible in a wide variety of economies with different balances between the public and the private sector, the regulation of the financial sector etc. The key properties that have to be changed are the physical patterns of production and consumption.

This change should enable the unfolding of productive potentials along reducing emissions to sustainable budgets. It has been labelled *delinking* the materials and energy flows from economic growth.

In the longer term it is only possible with a different physical interface between economy and nature than the throughput economy of the 20th century. The case of fossil fuels is illustrative.

The 20th century European growth model was built on a progressively more pervasive use of fossil energy to fuel the economy. Fossil fuels equipped productive units with incredible physical power and enabled them to specialise in highly productive niches. The relief of coal by oil and later in the century by natural gas did, however, result in a slow "decarbonisation" of the economy. The ratio of emissions to primary energy supply was declining. The cause was that oil has a higher energy content per ton of carbon than coal and natural gas a higher energy content per ton of carbon than oil (Grübler and Nakićenović, 1996).

The oil economy built through the three decades after WWII utilised that oil is a fuel of much higher quality than coal. The unprecedented productivity growth of that historical period was markedly influenced by the potentials of the sets of infrastructure, flows of oil and oil products and end-use equipment that were built up in that period.

In particular the so-called Well-to-Wheel chain of oil-based energy flows that still today fuel 93% of global motorised transport. This Well-to-Wheel chain cannot deliver the transport within the ecological balances, in particular when considering the need for transport of a 9 billion population without poverty and continuous growth in productivity. Even with very optimistic assumptions on energy efficiency it would not be consistent with a 80-95% reduction of the emissions from transport fuels. A green economy providing the transport services within the balances must rest on totally different sets of energy and materials flows, vehicle fleets and infrastructures. Rather than a Well-to-Wheel chain it will be a Wind-to-Wheel chain (or Solar-to-Wheel) with intermediate storage links.

Similar sets of energy flows and infrastructures and capital equipment designed to handle them will be replaced by green alternatives in other supply chains of the economy. The building stock now providing its floor space heated by natural gas, gasoil or coal will be replaced by a "near-zero-energy" building stock as new "vintages" replace older. Their heating technology will probably be make use of electricity with heat pumps. The electricity sector delivering the energy from wind, solar and other energy sources will have to be organised with a much more flexible demand-side, "smart-grids", and integrated in much larger European "supergrids".

These coherent sets of flows, infrastructure, end-use equipment and technologies providing the interface between nature and the economy have been called the *econosphere* (Boulding, 1966). This term is useful for describing that the transformation of the economy to a green economy involves more than shifting from coal to gas and shifting from less to more fuel-efficient cars. These steps are important and necessary, but a green economy also means that over a longer period a shift to an entirely different econosphere is necessary. Otherwise the economy cannot deliver the high level of economic well-being to all and still keep the ecological balances.

A related term is *socio-technical systems*, which is often used in analyses of the same phenomenon. The econosphere can be perceived as the total of all socio-technical systems making up the physical basis of the economy. The term "econosphere" is preferred here because it is more about the physical link between economy and nature and has a more macro-scopic meaning.

The econosphere is not a term in the conventional economic vocabulary. In the mainstream of economic analysis, the economy is described as a real value circuit and a financial circuit. In the real value circuit production activities convert inputs of labour and capital services to outputs of consumption and investment goods. They are consumed and invested respectively in consumption and investment activities. The reincarnated labour force and capital stock deliver new inputs etc. The financial circuit runs in the opposite direction and keep the real value circuit running.

From a natural science point of view, the econosphere is an intermediate stage transporting materials and energy between the four spheres, lithosphere, atmosphere, hydrosphere and biosphere. It does so irrespective of social system.

The econosphere thus consists of

- the capital stocks used for extraction of materials and energy, transport storage, processing, conversion and final use.
- The flows of energy and materials through it
- The areas allocated to the above activities and to function as sink for the eventual exit of the materials as waste and emissions

The types and volumes of materials and energy carriers are determined by the fixed capital, invested in the economy: Buildings, infrastructures, plants, machines, transport vehicles. They are designed to deliver particular services by using particular fuels and to process particular types of materials in particular volumes. A car is designed to use a specific fuel – mostly petrol or diesel – deliver its vehicle kilometres. A house is designed to use a specific amount of a specific energy carrier to deliver its 150 heated square-meters. The energy sector and its infrastructures are designed to deliver these energy carriers within its capacity limits.

The global flows of oil, oil products and their combustion in transport constitute an important part of the econosphere. On average 92 million barrels leave the oilfields on a daily basis in a continuous flow from sources to sinks (International Energy Agency (IEA), 2013). This flow is necessary to sustain the transport services we need. 93% of all transport depends on it (International Energy Agency (IEA), 2012).

With the current policies the share of transport fuelled by oil will be reduced to 89% by 2035, but this would still represent over-consumption of the sink-budget. The IEA estimates that a reduction to 77% by 2035 is required to keep global warming below 2°C.

In rough figures it means that 16% of the world transport vehicle fleets and their supporting infrastructure must be replaced by vehicles and infrastructure using electricity and biofuels until 2035. The corresponding flows of oil must be replaced by flows of other energy carriers – electricity, gasses, biofuels - and supporting infrastructures.

The thus transformed econosphere will be able to deliver more transport services (vehicle-, ton- and person-kilometres) than today, but leaving a third of the otherwise extracted oil and the contained CO_2-emissions in the ground.

There are important differences between policies aiming at changing the econosphere and policies aiming at using the existing econosphere better ("remembering to turn of the light"). Whereas both are necessary, econosphere transformation is the long-term solution.

The EU Commission has prepared scenarios for how this change of the transport econosphere may take place in Europe (EC, 2011c). According to these scenarios the replacement of oil based by renewables based transport in European cities could be completed in 2035. This will require the rate of transformation of the transport econosphere in Europe to be much higher than elsewhere.

The EU and individual member-states have decided to undertake sweeping renewals of the econosphere over the next decades in a number of important respects. The European Union has since the 1990s pursued a goal of limiting global warming to 2°C. A global agreement about that was achieved at the COP15 summit in Copenhagen 2009 and it involves the replacement of the present econosphere by an econosphere that enables maybe twice the present economic prosperity, but only 10% of the present emissions.

The EU target for greenhouse gas emission reduction by 2020, however, is only 20%, which is very modest compared to the overall goal. According to the integrated energy and climate policy 30% emission reduction is the preferable level of ambition, but as long as other large emitters such as the US and China do not make similar concessions it would be at the cost of international competitiveness and thus loss of economic values without gains in global balance in GHG emissions. The COP19 in 2015 is set to change that.

The Covenant of Mayors initiative, which now has almost 5000 signatories – cities and municipalities – is committed to (at least) realising the 20% target by 2020 in their geographical area. This is, however, an inadequate pace of decarbonisation, which is already being overtaken by national frameworks in many countries and is likely to be so in all EU countries.

In some countries longer term strategies are taking shape or have already been implemented. The United Kingdom and Scotland have adopted climate change acts in 2008 and 2009 respectively to ensure a time consistent and continuously progressing reduction of greenhouse gas emissions to a sustainable level through the first half of the century. In Germany, the "energie-wende" is pursued with a focus on developing a long-term institutional framework for achieving 80% renewable energy in 2050. In Denmark a climate change act is under preparation aiming at a 100% decarbonisation of the economy by 2050. In Sweden a roadmap is being prepared aiming at eliminating greenhouse gas emissions totally in 2050. Regions in countries with such programmes for green transformation will have to target a more ambitious pace of progress towards a green energy economy.

The replacement of the physical basis of the economy does not only concern the production and use of energy. Other unsustainable flows of materials and energy and unsustainable "consumption" of areas similarly involve major redesigning and refurbishing of supply chains and their supporting capital stock and technology systems. They can be grouped in two types of transformations, one called "dematerialisation" and the other called "ecosystem restoration". Together with the "decarbonisation" and "energy delinking" processes they constitute a more efficient use of resources in the sense that less tons, cubic-meters, megawatthours etc are required for achieving a given level of economic prosperity.

The transformation processes also share the property of being long-term coherent changes.

Capital stock changes are not always essential for instance when an environmentally harmless substitute for a chemical substance entailing environmental risks exists.

9.2. Key economic properties of the green transformation

Transforming the econosphere to a physical basis of the economy that can provide the necessary services, but with less flows of energy and materials and less area consumption have important impacts on the value creation and financial flows of the rest of the economy.

First, it is more *capital-intensive*. Less flows is made possible by more capital. The flows are substituted by more and more smart capital equipment. Green solutions are characterised by either deriving the same services from a reduced throughput of the flows, deriving it from cleaner flows or recirculate the flows in order to derive services from them repeatedly.

The changes in the econosphere towards a green economy thus consists of changes in the capital stock capacity

- towards other flows (enabling substitution)
- towards recycling (enabling circular supply chain management)
- towards waste elimination (efficient use)

and changes in the flows through the econosphere

- at the entry point (materials)
- at the exit point (emissions and waste)

Taking the transformation to sustainable production and use of energy as an example, investments in wind and PV electricity is more expensive per MW output than investment in natural gas or coal power plants. On the other hand the costs of the constant flows of natural gas and coal are saved. Household and industrial (including agriculture and forestry) waste and wastewater contains biomass that can be converted to biogas and liquid fuels, fractions that can be recycled as materials and fractions that can serve as solid fuels. Establishing such circular supply chain management requires investment expenditures but reduces the volumes of flows entering and exiting the econosphere. Cars and washing machines that use energy more economically are often more expensive because more sophisticated automatic control of energy use is built into them. Near-zero-energy buildings cost more to build than their 20th century predecessors, but they save the energy bill through their lifetime.

Consequently, the key property of the transformation from an economic perspective is the *replacement of flows of materials and energy by capital*. Not any type of flow by any type of capital, but capital *designed* to handle flows that are within the ecological budgets.

This transformation can be measured by
- the *investment* in the green versus the conventional solutions,
- the resulting change of the *flows* at entry and exit points of the econosphere and
- the resulting *sets* of capital stock, services and flows

Three types of indicators are particularly important for regional policies:
Flows:
- catch-up potentials for resource efficiency
- delinking performance

Capital stocks:
- renewable resource development rates
- infrastructure and final use equipment renewal rates

Catch-up potentials and delinking are usually measured by relating the physical flows to the value creation of the economy. Below, this is attempted for the regional economies at NUTS levels.

Data on the capital stock changes and investments in green solutions are generally not available at the NUTS2 or NUTS3 levels and not necessarily in comparable form at the national level.

The changes of the econosphere can be grouped in classes of green transformation.

Reforming the econosphere provision of energy services can be divided in two transformation processes. *Decarbonisation* processes reduce the carbon content and thus CO_2 emissions of the energy flows and *delinking* processes reduce the energy required to deliver specific services.

Substitution of coal by wind, recirculating of cooling water in district heating and complete insulation of buildings are examples of the green solutions and they all involve substitution of flows by capital.

Other aspects of the econosphere are subject to parallel transformations. The flows of other substances that imply environmental risks include as different materials as, e.g., the phosphorous and nitrogen flows through agriculture, the flows of chemicals through economic activities and food chains and the flow of materials that eventually becomes municipal waste and wastewater.

The reduction and replacement of these flows could be characterised as "dematerialisation". Naturally, the economy cannot function without materials, but without overconsumption of natural resources and sinks for materials.

The transformation of the econosphere towards a sustainable consumption of *areas* can be divided in three groups of processes. First, the allocation of land between urban and non-urban purposes with infrastructure and mining included in "urban". Second, the allocation of non-urban land between land where economic purposes have priority (agriculture, forestry etc) and land where natural ecosystems have priority (nature parks, wild nature etc). Third, the restoration of the natural ecosystems.

One type of reform of the spatial extent of the econosphere is the notion of "compact cities" as opposed to urban sprawl. The transformation towards compact cities is treated in other GREECO reports. The question of measuring the allocation of land between economic and nature purposes is addressed below. The restoration of natural ecosystems in areas where they have priority depends on the reduction of pollution pressures to sustainable levels and the ability of ecosystems to recover ("resilience"). In some cases additional investments are required.

These transformations of the econosphere depend on the innovation of green solutions. Innovation processes can be viewed as *product innovation* and *process innovation*. It is important to note that product and process innovation are two sides of the same coin although some firms profit from delivering the products and other firms from using them in processes. Indicators of green innovation are explored below.

10. Decarbonisation and delinking

10.1. Transforming the energy econosphere

The general result of the decarbonisation process is the delinking of fossil energy use from economic growth. The standard tools monitoring progress in this transformation of the economy are indices of emissions or energy intensity (ratios of emissions or energy consumption to GDP). However, these indicators do not provide any information about development since they only register the ratio of the flow to GDP.

In times of economic collapse such as has been observed in the 1990s for many of the new member states and after the financial crisis in other countries, it can happen that energy consumption drops faster than GDP. That would show as reduced energy intensity of the economy, but it is not what we understand by sustainable development or building a green economy.

Deindustrialisation without new economic activity to replace it can also cause the population and GDP in some regions to decline over a longer period. The energy intensity can decline too, but it will not reflect a green economic development.

Thus, there is a need for a measure that takes into account the general trend in economic development.

Another distinction is the size of the change in resource efficiency as it is measured by, e.g., the energy intensity. In particular, it is important to know whether the progress in energy intensity is sufficient to reduce energy consumption in the light of the upward pressure from economic growth.

We present below an indicator of delinking that also takes account of whether the delinking is sufficient as well as of the overall economic development. Such an indicator must distinguish between delinking and relinking, absolute and relative delinking, absolute and relative relinking as well as between a growing or a recessive economy.

The mathematical model framework for the delinking measure is described in the appendix to this report. The variables included in the delinking framework for analysing the overall appear from table 4.

In the following table the decomposing the growth of per capita emissions into annual average growth rates of the following variables:

Table 4. Components of the model for analysing delinking.

Variable code	***Label***	***Growth rate code***
Z	*GHG emissions*	z
GIC	*Gross inland energy consumption*	gic
FEC	*Final energy consumption*	fec
L	*Employment*	l
N	*Population*	n
Z/GIC	*Emissions intensity*	z-gic
GIC/FEC	*Gross/final energy consumption*	gic-fec
FEC/L	*Final energy intensity of employment*	fec-l
L/N	*Employment rate*	l-n

The growth of per capita emissions can be decomposed into the four key factors described in the lower five rows of table 4.

(6) Z/N= Z/GIC * GIC/FEC * FEC/L * L/N

The model defines changes in CO_2-emissions per capita as a result of changes in

- the emissions per unit of primary energy consumed
- the use of primary energy per unit of final energy consumed
- the use of final energy per employed person and
- the employment ratio
-

The figure below shows the result of decomposition or shift-share analysis based on this model.

The contributions to per capita emissions growth from the four key factors in the European countries are shown in figure 10. The countries are arranged according to the growth in their per capita emissions.

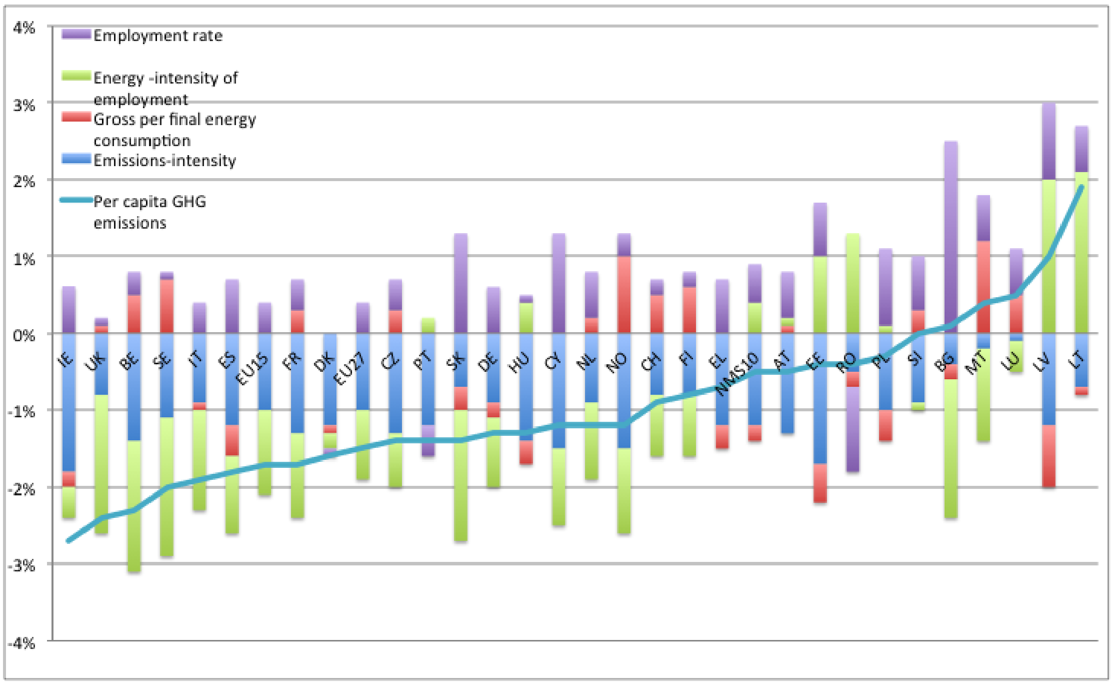


Figure 10. Factors affecting the growth of per capita GHG emissions 2000-09 in European countries.
Author's calculations based on Eurostat data.

The emission intensity of energy reflects the share of fossil fuels in gross energy consumption. The negative change in all countries reflects the combined effect of a growing share of other energy sources than fossil energy and change towards less emission intensive fossil fuels.

In most of the countries with decreasing emission rates, the energy intensity of employment has been a major factor behind the decreasing emission rate. All of the EU15 countries except Austria and Portugal share this characteristic, but Cyprus, The Czech Republic and Slovakia do as well.

On the other hand, the employment rate has increased in all countries except in Portugal and Romania. This has pulled in the opposite direction, that is, towards higher emission rates.

The gross per final energy consumption reflects the conversion and transport losses of the energy sector. It may, however, also be affected by the changes in the amount of energy that is imported or the fraction of final energy demand satisfied by on-site conversion. This factor is not systematically linked to the decline in the emission rate.

Countries with small emission reductions or even growing emissions include Slovenia, Bulgaria, Malta, Luxembourg, Latvia and Lithuania. The analysis does not reveal why these countries differ from the other countries as to the trend in emission rates.

It should be noted that two methodological choices could be of importance for the results. First, the time period 2000-2010 is composed of a period before and one after the financial crisis in 2008 (or 2007-8). The trends could be quite different in the two sub-periods. Second, the growth rates are estimated as geometric compound rates rather than by log-linear regression. This choice could make start and end points very influential.

10.2. Competitiveness and international specialisation

These processes will also affect the market share of the relevant markets. To most European economies, renewable energy sources are indigenous, whereas fossil fuels are imported. Conversion from fossil to renewable energy thus typically also involves a higher market share for the economy in its own final demand. The impact of dechemicalisation processes on market shares is probably more mixed. Decarbonisation, dechemicalisation and recycling all have a strong component of resource efficiency involving less overall materials and energy costs and thus increased cost-competitiveness. Investment in ecosystem restoration has impacts on the attraction of areas that are environmentally improved and thus, their competitiveness to other areas.

The share of the total income generated in the EU27 reserved for import of fossil fuels is shown in figure.

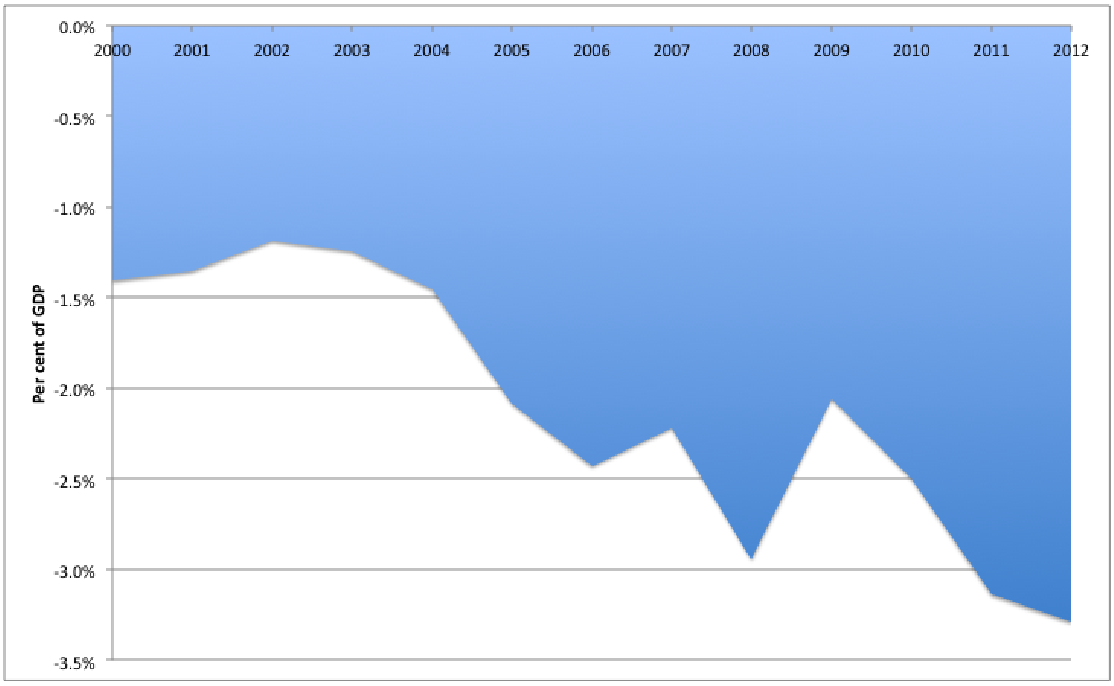


Figure 11. Net import of mineral fuels, lubricants etc. (SITC3) to EU27 in per cent of GDP 2000-2012.
Source: Author's calculations based on EUROSTAT data (EC, 2013l, 2013m).

Figure 11 shows that the share of the total economic budget of the EU reserved for import of fossil fuels has more than doubled from the early 2000s to the early 2010s. Most of the net imports consists of natural gas whereas oil is the second and coal the third largest cost item. This share, however, differs considerably by country.

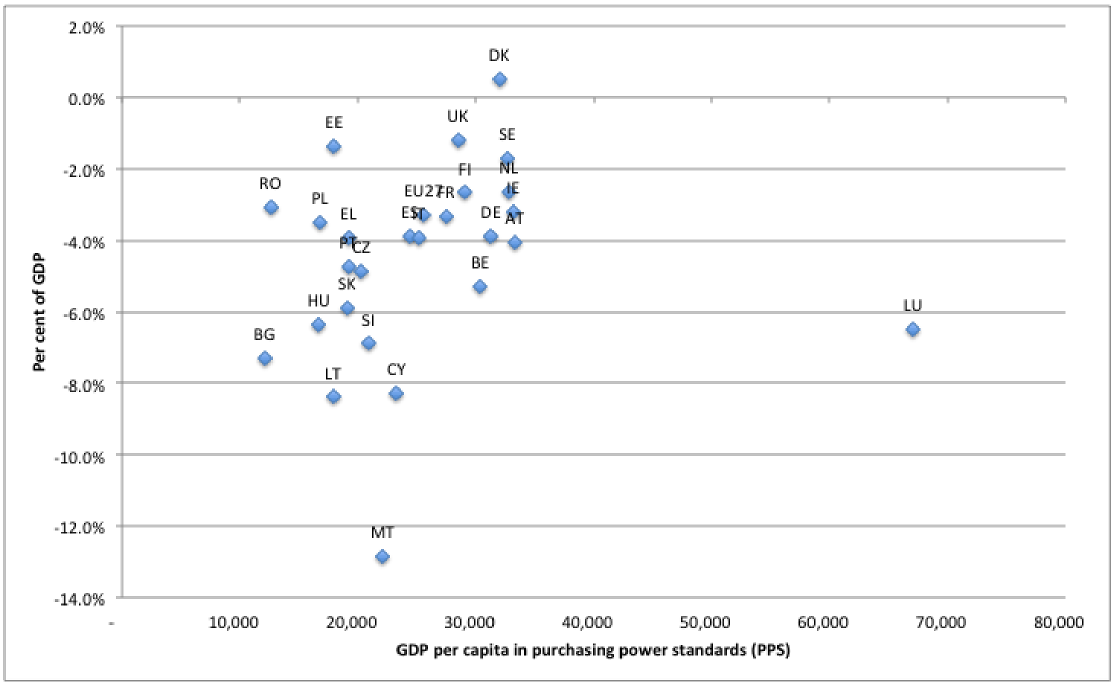


Figure 12. Net import of mineral fuels, lubricants etc. (SITC3) in per cent of GDP to member-states by per capita GDP (PPS*) in 2012.
* PPS is "purchasing power standards", i.e., euros with average EU purchasing power.
Source: Author's calculations based on EUROSTAT data (EC, 2013l, 2013m).

Figure 12 reveals a pattern of higher fossil fuel import burden on the economies with the lowest income levels. On the one hand a high fossil fuel burden impedes self-sustaining growth of the economies. On the other hand it represents a potential for employment and income generation by replacing the imports by indigenously produced renewable energy.

The EU harmonised statistics on fossil fuel consumption is not collected and processed at a level that allows the analysis of the fossil fuel burden of the regional economies as in figure 12, but previous studies have attempted to identify regions with high fossil fuel burdens using the share of energy intensive industries in regional GVA as an indicator for where we could expect to find high fossil fuel burdens (ESPON, 2011).

As noted above, reducing the fossil fuel burden represents a potential for employment and income generation, but this potential differs by region according to natural resource endowment rather than to energy demand.

The regional potentials for generating income from wind power and photovoltaic energy have been analysed by the GREECO-project. The potential earnings from wind energy generation can be measured by the potential resource rent defined as the difference between the social value of wind energy and the levelised costs of wind energy. The social value of wind energy materialises in the fixed feed-in tariffs and other support mechanisms to wind energy. To enable comparisons between countries and regions, it is all converted to a feed-in price that is assumed constant throughout the lifetime of 20 years. The levelised costs depend on the local wind energy potential and the technology applied (Hansen, 2013a).

The results show that in many regions, onshore wind energy has the potential of contributing considerably to regional income generation. This is particularly the case for regions in the North European wind belt where the productivity of the wind turbines are highest. Coastal areas around Europe, however, also host rich wind energy potentials (Hansen, 2013a).

The solar energy captured by photovoltaic panels is also increasing across Europe. The potential resource rent calculated in a similar way also represents important contributions to regional GVA.

As expected, the ratio of potential rent to GVA is highest in areas with good wind potentials and low population density and good natural conditions. In these regions, the potential area per capita that could be used for renewable energy generation is large. However, in the case of PV energy, buildings surfaces also represent a potential area for electricity generation. Similarly, the technical landscapes such as harbours, highways and industrial areas can often offer good locations for wind turbines without loss of landscape qualities. Thus, urban areas also have important renewable energy resources (Hansen, 2013a).

The employment impact of wind energy and PV energy is modest as they deliver their services without the massive flows of fuels characterising fossil energy based technologies. They do, however, generate income in the form of a resource rent.

The employment effect of these technologies is mainly in the manufacturing and installation of the turbines and PV-panels, that is, in the investment phase. The regional market share of this investment demand depends on the attractiveness of the region to industries delivering these particular solutions. A region becomes more attractive to particular industries as its labour force and service providers become more specialised in exactly the skills and services needed by that industry. The dynamics of agglomerations can be explained by benefits related to this geographical pooling of otherwise rare competences. It is a self-reinforcing process because industries depending on these competencies tend to locate where they already are and providers of the competencies tend to locate where their competencies are in demand. This naturally leads to a strong interest in identifying the "autonomic pole" that started the agglomeration process.

11. Decarbonisation

11.1. Renewable energy potentials

The renewable energy directive sets the target of a 20% supply of renewable energy relative to final energy consumption (including transmission losses) (EC, 2009c). The target has been allocated to member states as national overall targets for the share of energy from renewable sources in gross final consumption of energy in 2020. This also represents a set of commitments much like the above effort sharing decision.

The progress towards these targets achieved by 2011 appears from the figure below.

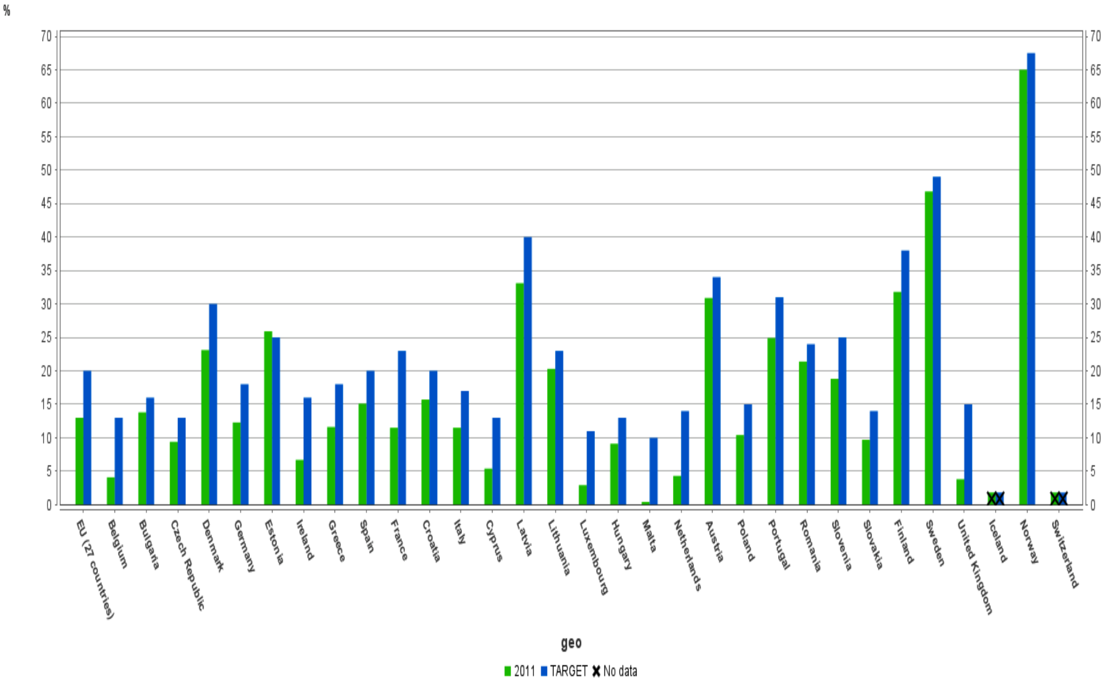


Figure 13. The share of renewable energy supply in gross final energy consumption by 2011. Per cent.
Source: EUROSTAT (EC, 2013n).

The status of the renewable energy plan of the EU by 2011 is according to figure 13 is that 21 countries have attained more than half their targets while 7 countries still miss more than half of their targets. 1 country has even reached its target. Obviously, many countries are able to proceed to higher targets than those originally committed to in the directive. Denmark, for instance, is expanding its renewable energy production to 36% rather than the EU-target of 30%. Such expansions will lower the need of CO_2-allowances in the future and enable a faster pace of lowering the cap of the ETS market.

The directive also includes an opportunity for countries that are about to miss their targets or obligations to buy capacity from other countries that have already fulfilled their obligations.

11.2. Regionalisation of renewable energy targets

These or a revised set of targets could also be allocated to regional units such as NUTS2, NUTS3 or LAU1. It would, however, not make much sense to assign a uniform target to all regions, such as, e.g., 20% of its gross final energy consumption. The renewable energy potentials of a territory are given by the geography of that territory, which is not related to its energy consumption.

Alternatively the ambition level of the regions could be set in the framework of a *regional* renewable energy obligation system. That is, a set of regionally specific obligations for installing renewable energy capacity. These obligations could then be made "tradable" similar to the national targets cf. above.

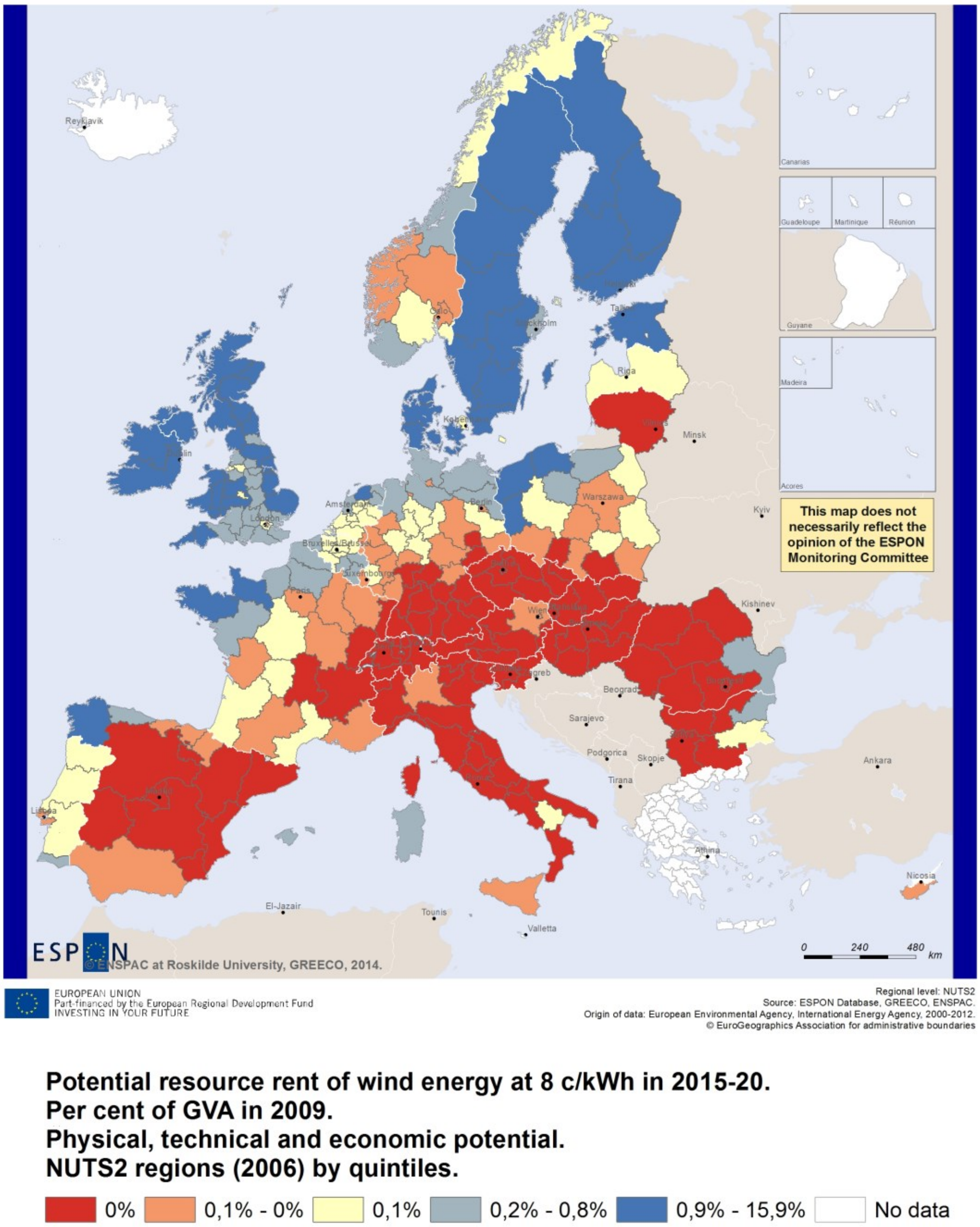
Tradable obligations involve payments to the region that assumes the obligation from another region. This is opposite of the payments involved in tradable emissions allowances because the former is an obligation and the latter an entitlement. Otherwise the principles of tradable obligations are similar.

This system would help solving the conflicts of interests involved in onshore wind-farm planning. Many of the North European regions with the best wind conditions have experienced a premature saturation of wind-farms installations. The regions risk loosing landscape qualities because the national obligation is likely to be met by locating the wind energy capacity at the locations with the best wind energy potential. This loss is not compensated without establishing some form of compensation scheme. The owner of the land is compensated and the investor and thus owner of the wind-farm off course as well, but the residents in the area and others with interests in the landscape qualities are not compensated for their losses.

In some cases wind-farms can add aesthetics to a landscape, for instance when the landscape is a technical landscape such as a harbour. In natural landscapes, however, technical installations usually make the landscape *less attractive*.

The tradable obligation system can contribute to a balance between the loss of landscape values in the regions with good wind potentials and the enjoyment of renewable energy in the other regions. The payments to the regional or municipal authorities would provide a budget that could be invested to make the areas in question more attractive. For instance, in forest and nature parks, wetland restoration, bicycle paths or kindergartens. Which investments that could make an area more attractive differ by area, but as a rule there are investments to make that could offset the loss of attractiveness from technical installations such as wind farms. Or phrased differently: If such options do not exist, the area is probably not suitable for wind farm investments.

The GREECO project has assessed the wind energy potentials of all the European regions. They are presented below.



Map 18. Potential wind resource rent in per cent of regional GVA (2009) at 8c/kWh and 1.2 MW/km2.
Source: Author's calculations based on GREECO datasets (Hansen, 2013b).

The potential wind resource rent shown in map 18 is the result of a meso-scale assessment, that is, all the pockets of good wind locations that can be revealed with micro-scale assessments are not included. In particular, potentials in mountainous areas probably underestimated.
Forest areas are included with same density of 1.2 MW/km^2 as agricultural areas, but the possible future wind-energy density in forest areas is still subject to research. All potentials in areas designated for nature purposes are excluded.

The wind resource rent is defined as the social value of wind energy represented by an 8c/kWh feed-in price minus the expected levelised costs per kWh in 2015-

20 multiplied by the amount of wind energy that can be generated competitively by wind farms at each location.

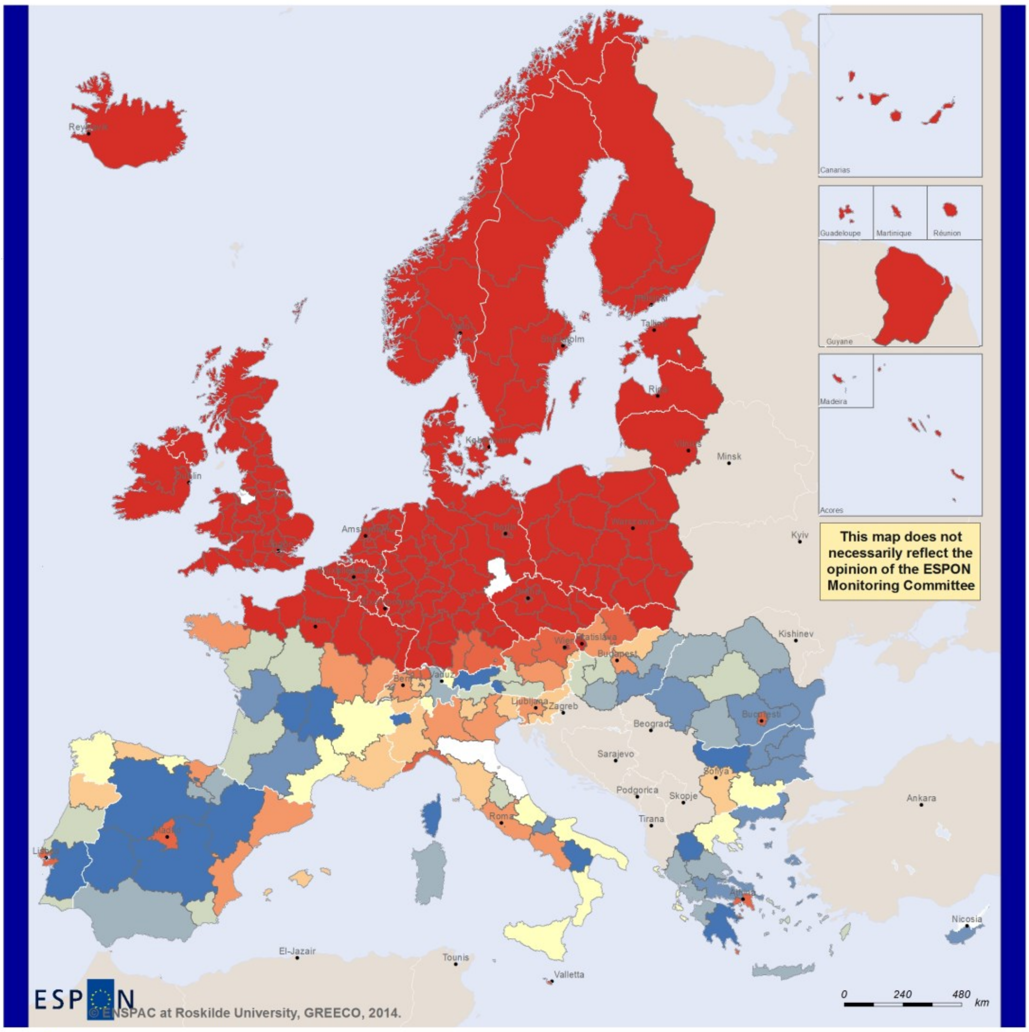
Specific grid-connection and grid-enforcement costs are not included. They can be high in many regions, e.g., in remote areas like Northern Finland, Estonia and Scotland due to distance to grid etc.

In any case, the map shows that there is a North-European wind-belt, where most of Europe's wind resources are located. It should be noted that the GREECO project also assessed the offshore wind energy potential. It is by far the most important renewable energy potential and it is mainly located in the North European wind belt too.

This has consequences for the regional patterns of the green economy: 1) These regions have particularly large investment potentials 2) Electricity exports from the wind-belt to the rest of Europe (EU supergrid/transmission-grid reinforcement).

The future reliance on renewable energy also forms the basis of synergies between energy producing regions and regions capable of electricity storage - primarily pumped storage in hydropower reservoirs - as well as smart grid/flexible demand solutions in all regions with access to the resource.

A similar assessment of the photovoltaic (PV) energy resource rent was made by the GREECO project with the following results.



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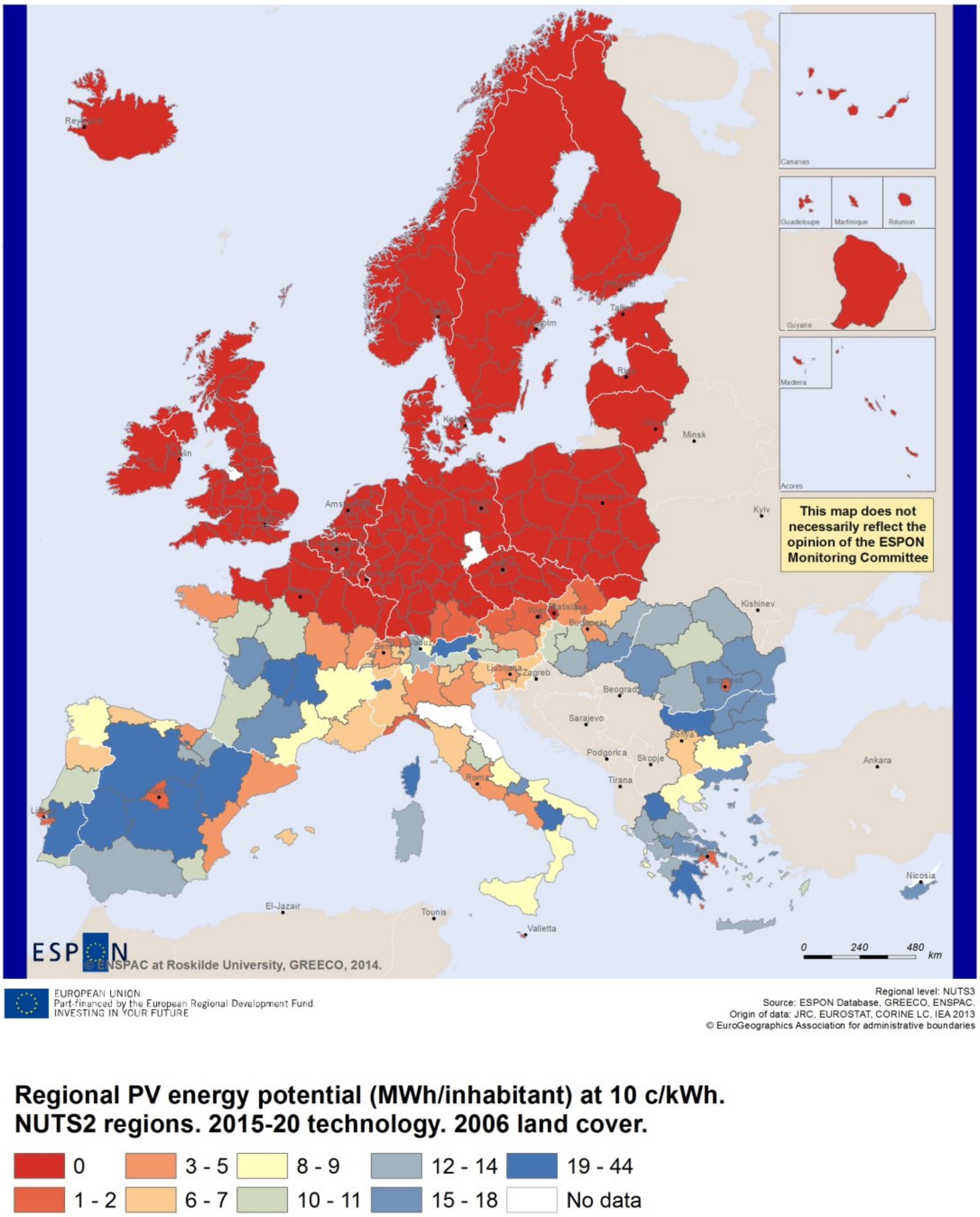
Regional level: NUTS3
Source: ESPON Database, GREECO, ENSPAC.
Origin of data: JRC, EUROSTAT, CORINE LC, IEA 2013

Regional PV energy potential (MWh/inhabitant) at 10 c/kWh.
NUTS2 regions. 2015-20 technology. 2006 land cover.

0 | 3 - 5 | 8 - 9 | 12 - 14 | 19 - 44
1 - 2 | 6 - 7 | 10 - 11 | 15 - 18 | 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, 2013b).

The PV energy potential is proportional with the solar irradiation and the area suitable for PV panel installation. Thus, it is no surprise that the richest PV potentials according to map 19 are found in the south.

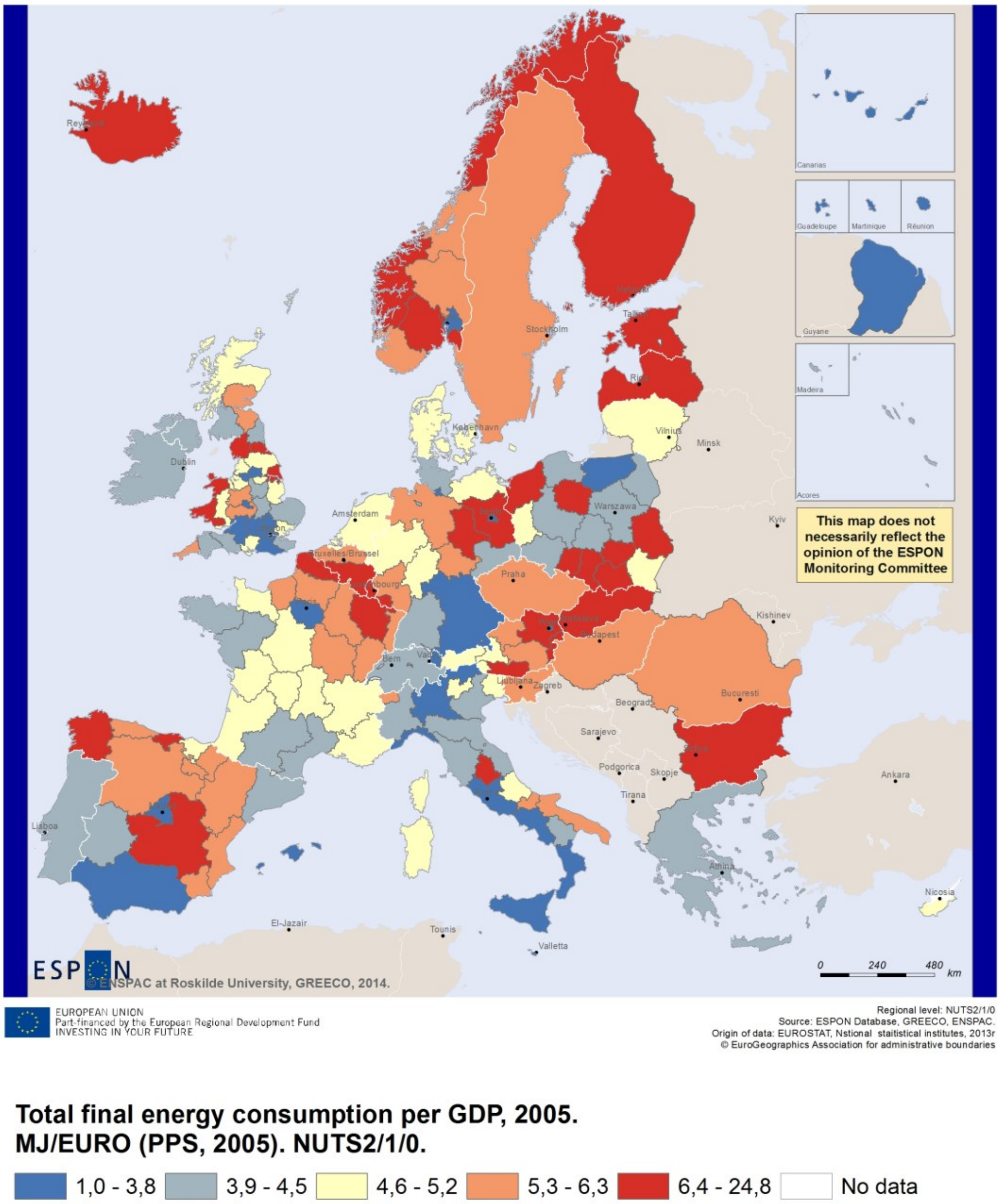
The PV energy assessment includes the potential area of utility-scale as well as building integrated solar panel installations.

12. Energy dependency

12.1. Resource efficiency gaps and catch-up potentials

Energy use is closely linked to economic activities and any economic activity sets an energy chain into motion causing consumption of source and sink budgets along the chain. The final energy consumption is the energy used for specific economic purposes ignoring the energy consumed along the chain in conversion processes etc. Thus, the analysis of resource efficiency gap uses the final energy consumption related to general measures of economic activity (GDP in Purchasing Power Standards (PPS) per capita and population).

The total final energy consumption by region is split in energy for production, residential and transport use. Map 20 shows the ratio of total final energy use to the economic value created in the region.

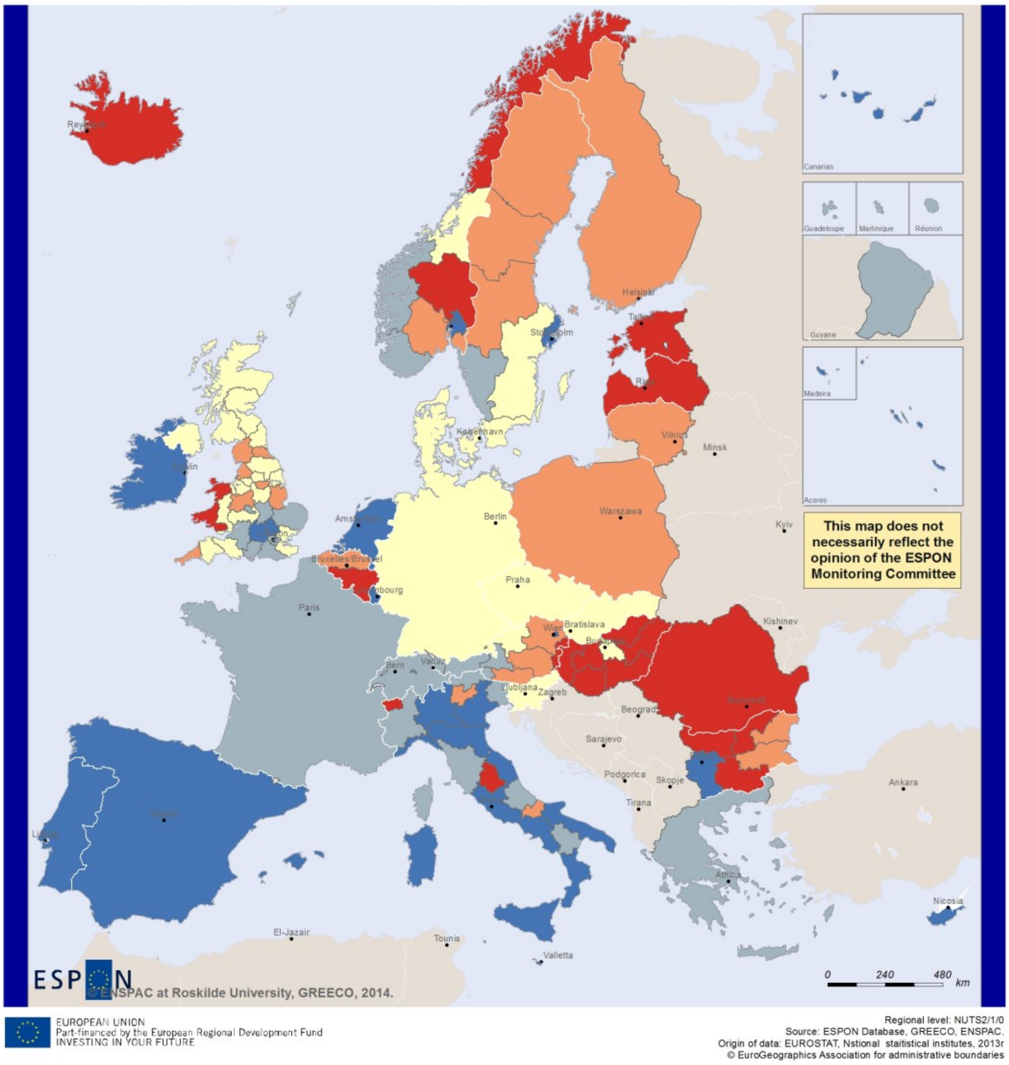


Map 20. Total final energy consumption per GDP (PPS), 2005. MJ/Euro (PPS, 2005).
Note: NUTS2 distributed energy consumption data were unavailable for some countries and NUTS1 or NUTS0 data have been used instead.
Source: Author's calculations based on GREECO datasets (Hansen, 2013a).

The interregional disparities of energy intensity shown in map 20 reveal considerable gaps between European regions as the energy consumed to produce the GDP of the region. A region is, however, not necessarily comparable with any other region as they play different roles in the national and international specialisation. The City in London should not aim for the same energy intensity as a region in Finland or Norway with industries specialised in energy intensive paper or aluminium industries. The need for energy for heating buildings also differs across Europe by climate conditions. Thus, the operational measures of resource-efficiency useable for target setting and monitoring of progress needs more detailed accounts of energy use and a careful selection of other regions with whom to compare.

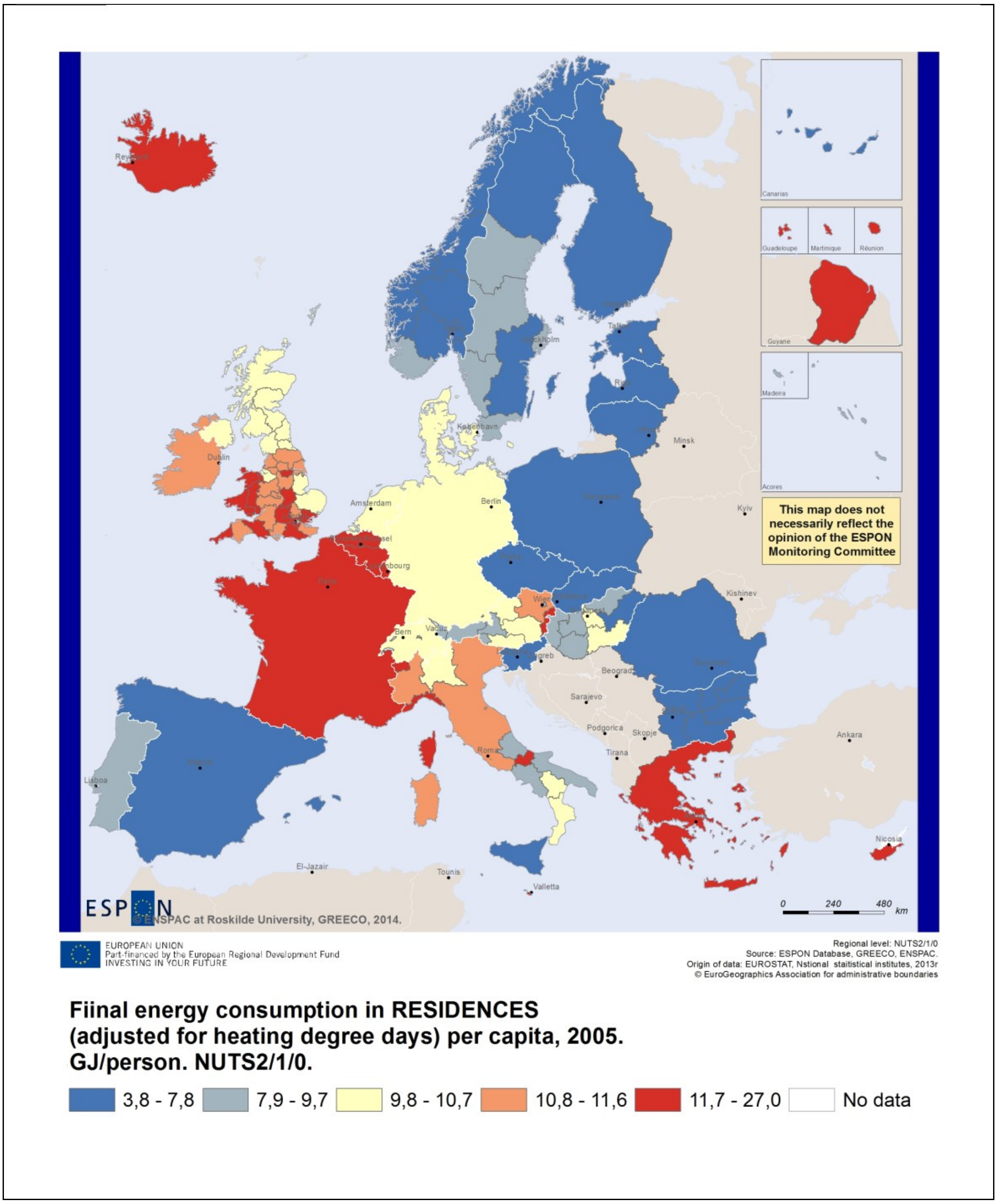
This is also the case for other measures of resource efficiency. Different regions face different challenges and the regional policies aiming at transforming the regional econosphere to the natural budgets without giving up producing the economic services it delivers need to define their own benchmarks for a region specific set of indicators.

The final use of energy for residential purposes in the European regions appears from map 21.



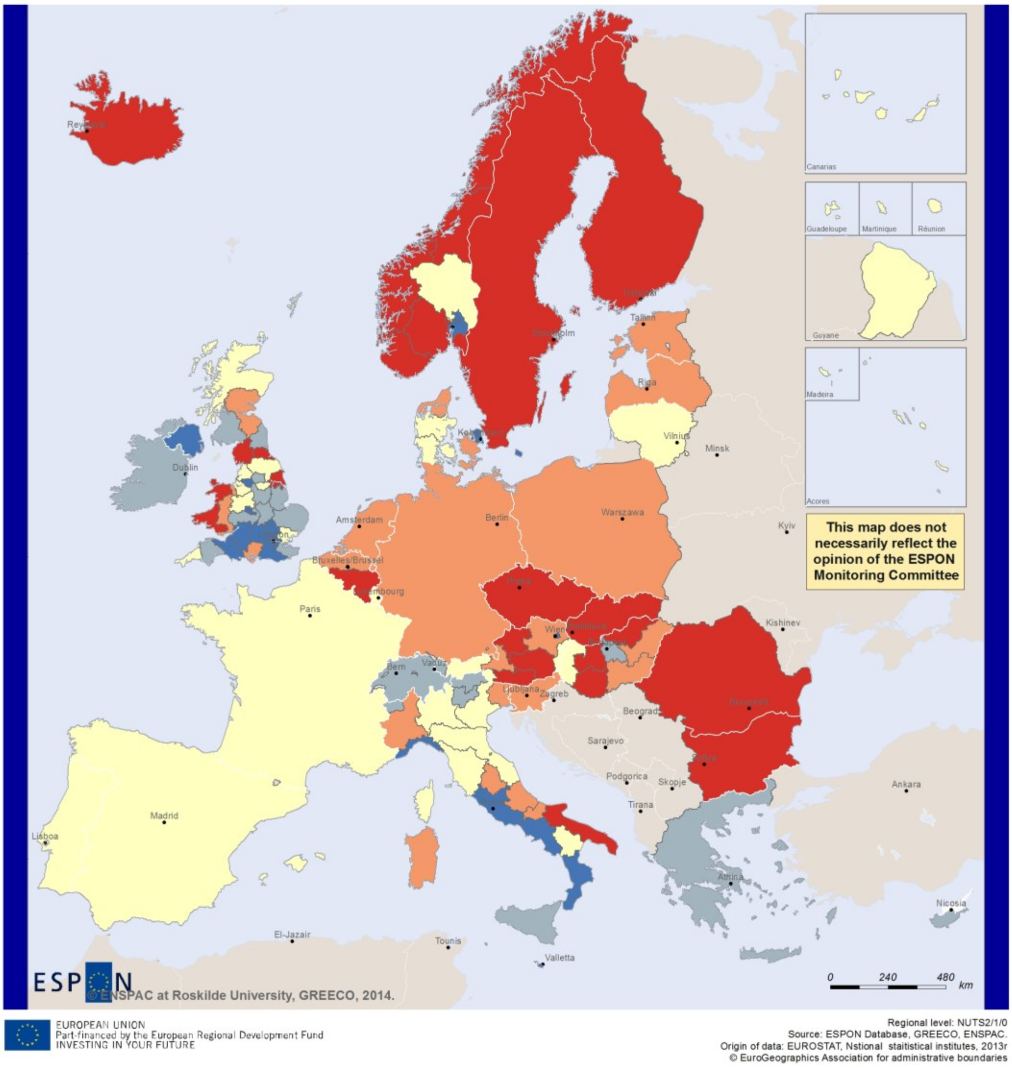
Fiinal energy consumption in RESIDENCES per GDP, 2005.
MJ/EURO (PPS, 2005). NUTS2/1/0.

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



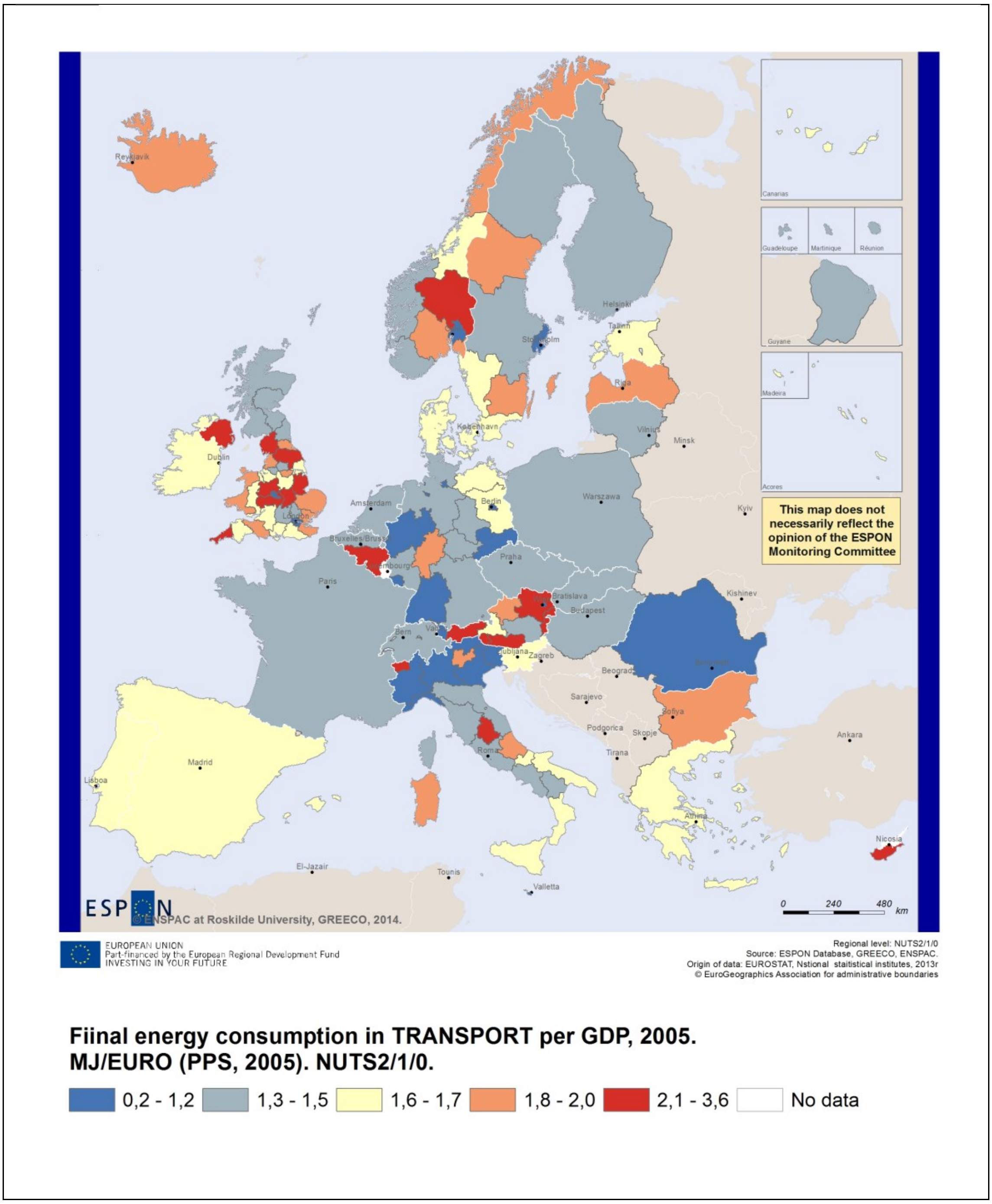
Map 21. Residential energy use per capita (MJ/person) without and with adjustment for heating degree days (GJ/person) 2005.
Source: Author’s calculations based on GREECO datasets (Hansen, 2013b).

The residential final energy use per capita is shown with and without correction for heating degree days. The variation from South to North in the upper map becomes markedly smaller when adjusted for heating degree days in the lower map. The heating day adjustment is, however, made in a simple way and the map should be interpreted with caution. The topic deserves further study.



Fiinal energy consumption in PRODUCTION per GDP, 2005.
MJ/EURO (PPS, 2005). NUTS2/1/0.

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



Map 22. Final energy consumption in production and transport per GDP (PPS), 2005. MJ/Euro (PPS, 2005).

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

The ratio of final energy used in production to GDP (PPS) per capita is shown in the upper map and the ratio of final energy use for transport in the lower map of map 22.

As mentioned above, progress towards a green economy does not necessarily mean that the regional economies specialised in energy intensive industries in countries like Norway or Finland achieve the same low energy intensity as in service intensive economies. Particular

For all regions, however, it is important to eliminate wasteful energy use while increasing employment. Moreover, it follows from equation (6) that the resource efficiency has to grow at least the same rate as the economy to stabilise the resulting resource consumption. This means that low-income regions that are expected to catch up with the income level of high-income regions have to increase their energy efficiencies at higher rates than the high-income regions to prevent energy consumption from growing.

12.2. Delinking and resource efficiency catch-up

The catching up process can be analysed in a framework of absolute and relative delinking and relinking against the background of a growing or recessive economy. This approach is inspired by the categorisation used by de Bruyn and Opschoor (Bruyn and Opschoor, 1997).

In the model listed in Table 4 materials and energy productivity indices (or resource efficiency indices) relate an economic activity (G) to the physical flow (Z), it depends on. The ratio of G/Y grows approximately at a rate of g-z, where g and z are the growth rates of G and Z, respectively. If $z<g$, the index and the resource efficiency grows. The physical flow is delinked from the growth of the economic activity.

An increasing indicator is, however, not unambiguously an indicator of progress towards a green economy.

First, $z<g$ does not guarantee that the flow is actually reduced to sustainable levels. Thus, we distinguish between relative and absolute delinking, where the latter requires $z<0<g$. That may even not be sufficient to attain the goals of government programmes for development of the economy. If these goals imply $z<z^*$ and $g^*<g$, respectively, the targeted delinking criterion becomes $z<z^*<0<g^*<g$.

Second, even a reduced Z may follow from a reduced G, which is not a sign of sustainable development. Such developments have been observed at numerous occasions in Europe, notably in connection with the economic downturn in Eastern Europe in the 1990s and with the cascade of crises in the recent years.

Third, the undesirable mirror image of delinking is *relinking*, where $g<z$. It comes in a similar set of varieties.

Against this backdrop, it is important to classify regional performance in different categories according to relinking/delinking, recessive/growth and relative/absolute.

The classification of resource efficiency growth patterns is shown in Figure 14.

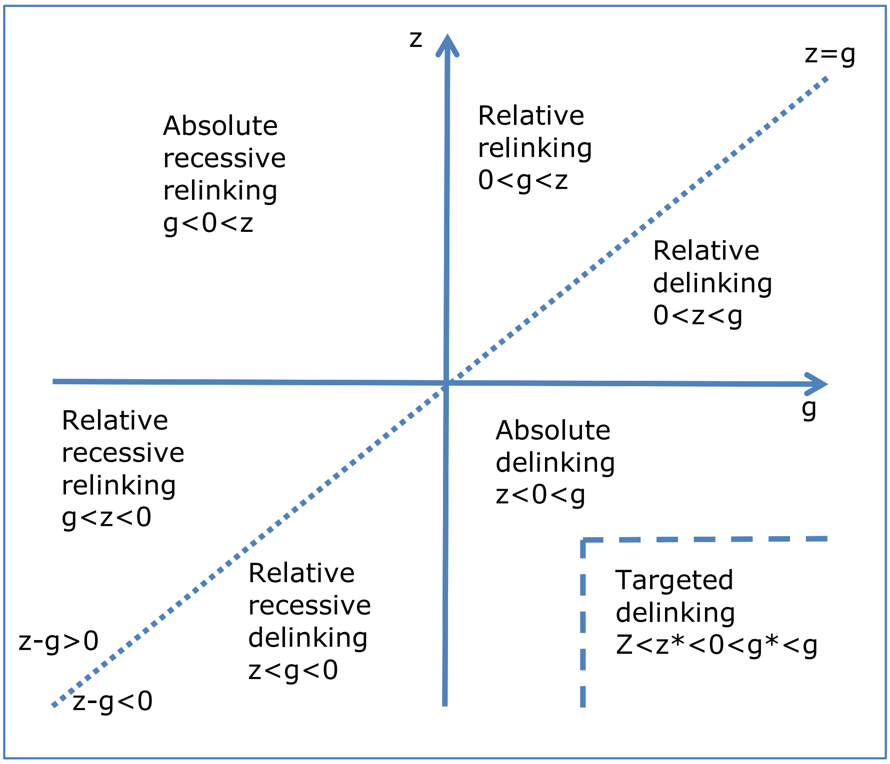


Figure 14. Delinking properties of materials and energy productivity index growth patterns.

All of the indicators in figure 14 can be related to the economic value creation they are linked to. The key resource efficiency indicators appear from figure 14.

The diagonal line in the diagram divides delinking countries from relinking countries: Delinking means that final energy consumption grows less than the unemployment rate whereas relinking is the reverse change. Absolute delinking means that the energy consumption actually declines whereas the employment rate is decreasing. Absolute relinking means the opposite: employment declines whereas energy consumption increases.

The combined progress in energy savings and employment in the EU is top priority in the Europe 2020 strategy, but it is also a set of targets that involve an inherent conflict. The model represented by equation (6) demonstrates the inherent conflicts of the strategy. The energy savings policy reduces greenhouse gas emissions, whereas raising the rate of employment tend to increase greenhouse gas emissions as long as the econosphere links fossil energy to economic activity. Delinking means reducing energy consumption per capita at the same time as it increases the rate of employment and the delinking performance shows the ability of the economy to solve this conflict. The delinking performance of the European economies is shown in figure 15.

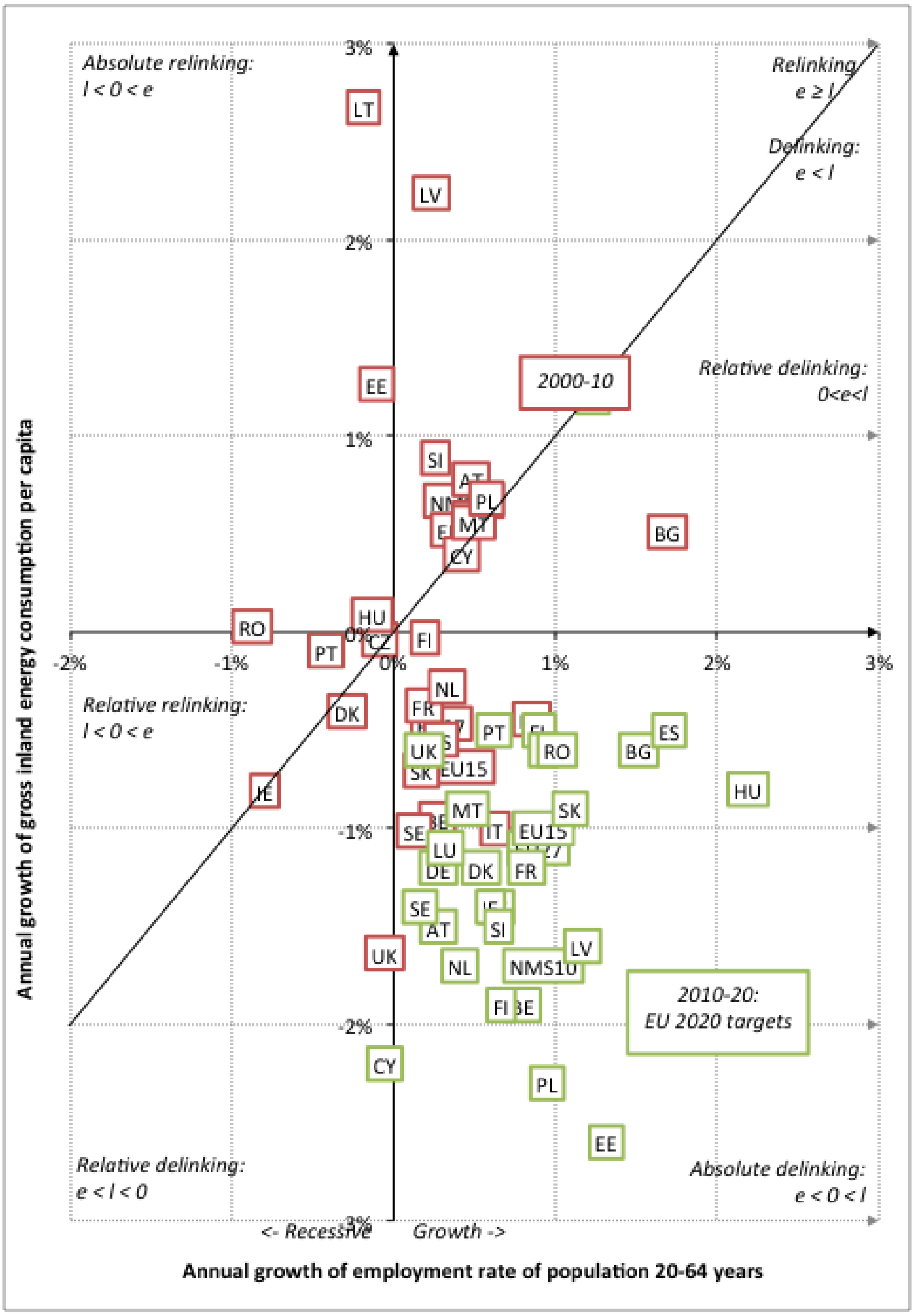


Figure 15. Delinking of final energy consumption from employment growth in 2000-10 and the implicit EU 2020 delinking targets.
Author's calculations based on Eurostat data.

The red boxes in Figure 15 represent the delinking performance of each country in 2000-10. The green boxes represent the delinking targets that must be obtained in the period 2010-20 for reaching the goals of the EU 2020 strategy.

The 2020 strategy targets simultaneously to increase employment per capita (employment rate) to 75% in 2020 and reduce energy consumption by 20% less than the projected energy consumption in 2020. These targets differ marginally by country, but in this analysis, it is assumed that they are equal to all countries. The average annual growth rates of the employment rate and gross energy consumption per capita are denoted *l* and *e*, respectively.

The position of the countries in the map can be used to categorise the delinking performance of each country in the period 2000-10 according to figure 15.

The split between relinking and delinking countries was about 50-50, but many with a very small margin. EU15 countries dominated the delinking side whereas many NMS10 countries relinked. It should be kept in mind that the change in employment and energy consumption through 2000-10 went through a boom period followed by a severe recession.

Some countries experienced a reduction of final energy use alongside with a reduction in employment, but this cannot be characterized as sustainable development. As it follows the reduction in employment, it must be expected to reverse when the employment rises again.

The Europe 2020 targets include the aggregate targets of an employment rate of 75% and a final energy consumption of 20% less than the projected level in 2020. The growth rates required to reach these goals from 2010 through 2020 are calculated based on the actual energy consumption and employment rates in 2010. The targets for many member-states differ slightly from the overall EU target and this is reflected in the employment growth requirements.

The combined employment and energy efficiency targets are important components part of how the EU defines sustainable development.

12.3. Energy delinking in regional economies

The GREECO dataset on final energy use have been used further to analyse the progress of energy efficiency in European regions.

In the dataset the final energy consumption statistics is aggregated to the three broad sectors production, transport and residential. The statistics available for distributing these aggregate on NUTS2 and NUTS1 regions differ by country, sector and years. The resulting dataset thus has a varying coverage in these dimensions.

The delinking of the growth of energy use from economic growth has been examined for total final energy consumption and the results are shown at the map below. Economic growth was represented by GDP per capita in purchasing power parities and deflated with the GDP deflator.

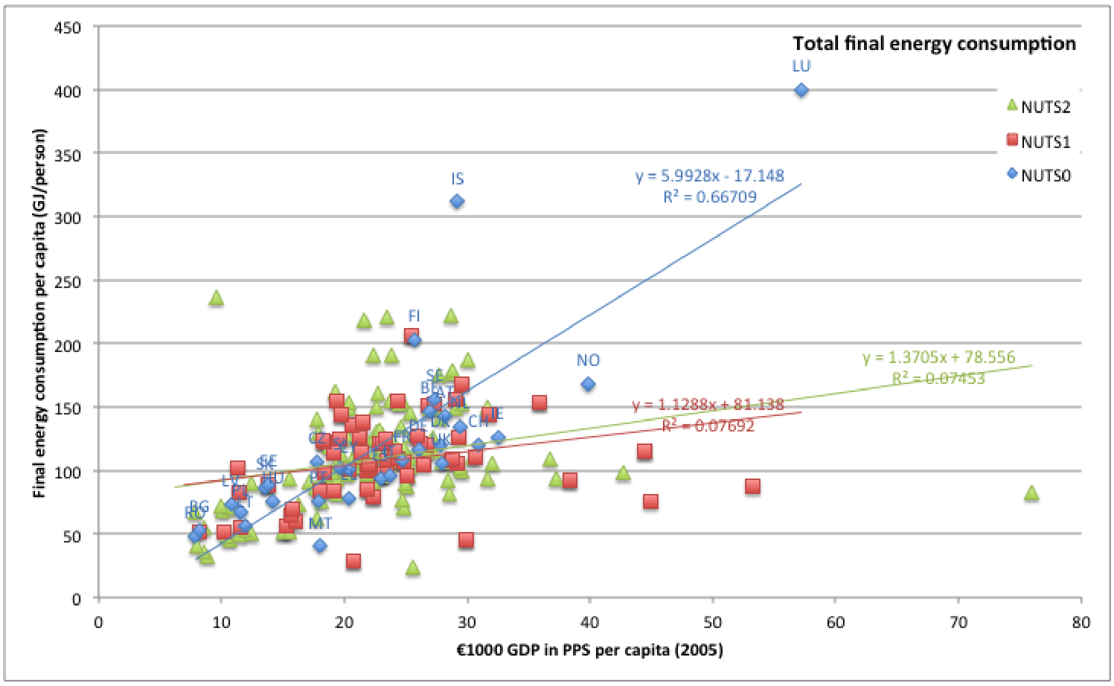
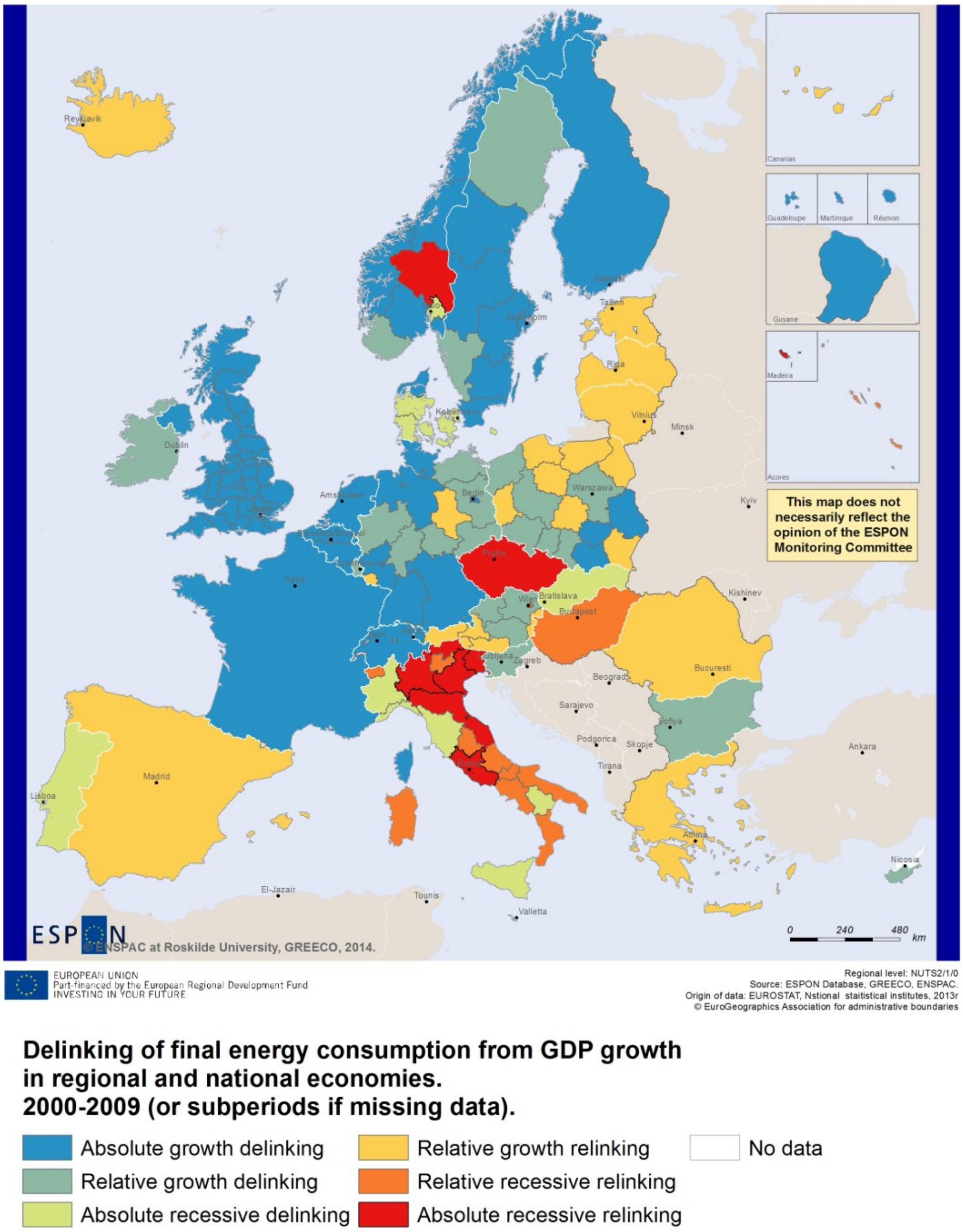


Figure 16. Final energy consumption and GDP per capita, 2005 (GJ/person and PPS€1000/person).
Source: (Hansen, 2013a).



Map 23. Delinking of total final energy use from economic growth 2000-2009.

The analysis was carried out for the period of 2000-2009 thus including the period of unsustainable growth up to 2008 and the deep recession 2008-09. The average growth rate over the period as a whole thus averages over cyclical ups and downs. The period, however, has been shortened for some regions due to missing data.

Many European economies did succeed in reducing total final energy consumption relative to the economic growth. They are represented with the green colours on map 23. However, they did not delink in the same way. Some economies did not delink sufficiently to achieve an absolute reduction of energy consumption. Others delinked against a background of negative economic growth, that is, where the recession more than neutralised growth in the preceding growth period.

The energy intensity of the blue colour economies developed in the opposite direction of the EU goals. They became more energy intensive through the period. The delinking performance was not fully identical for production, transport and residential energy use.

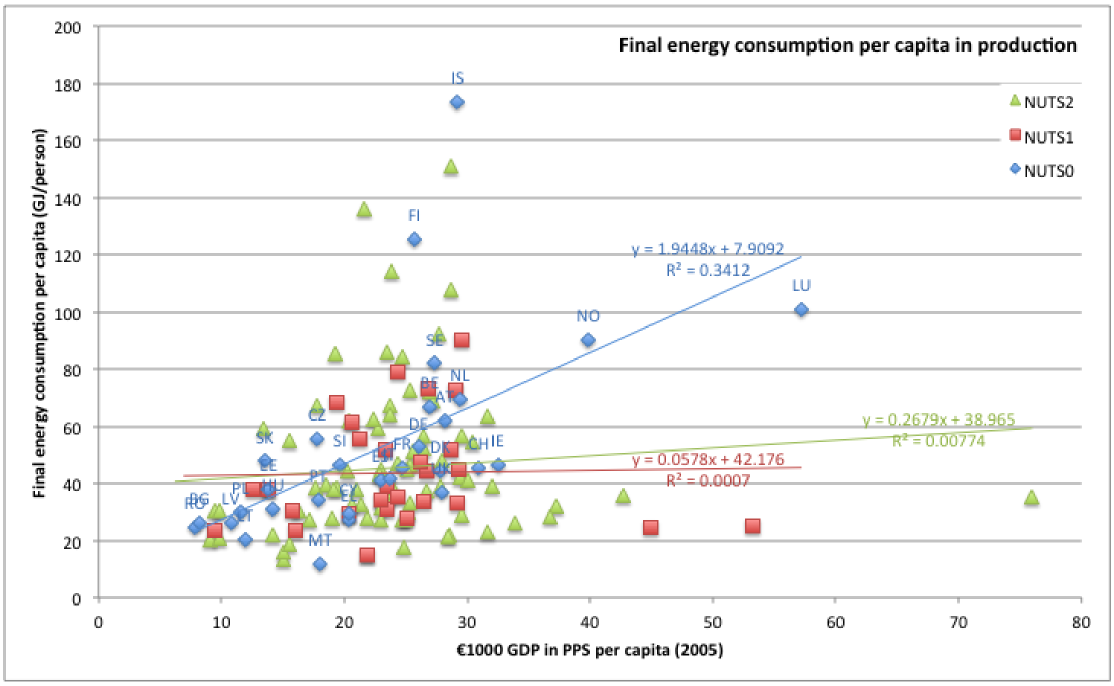
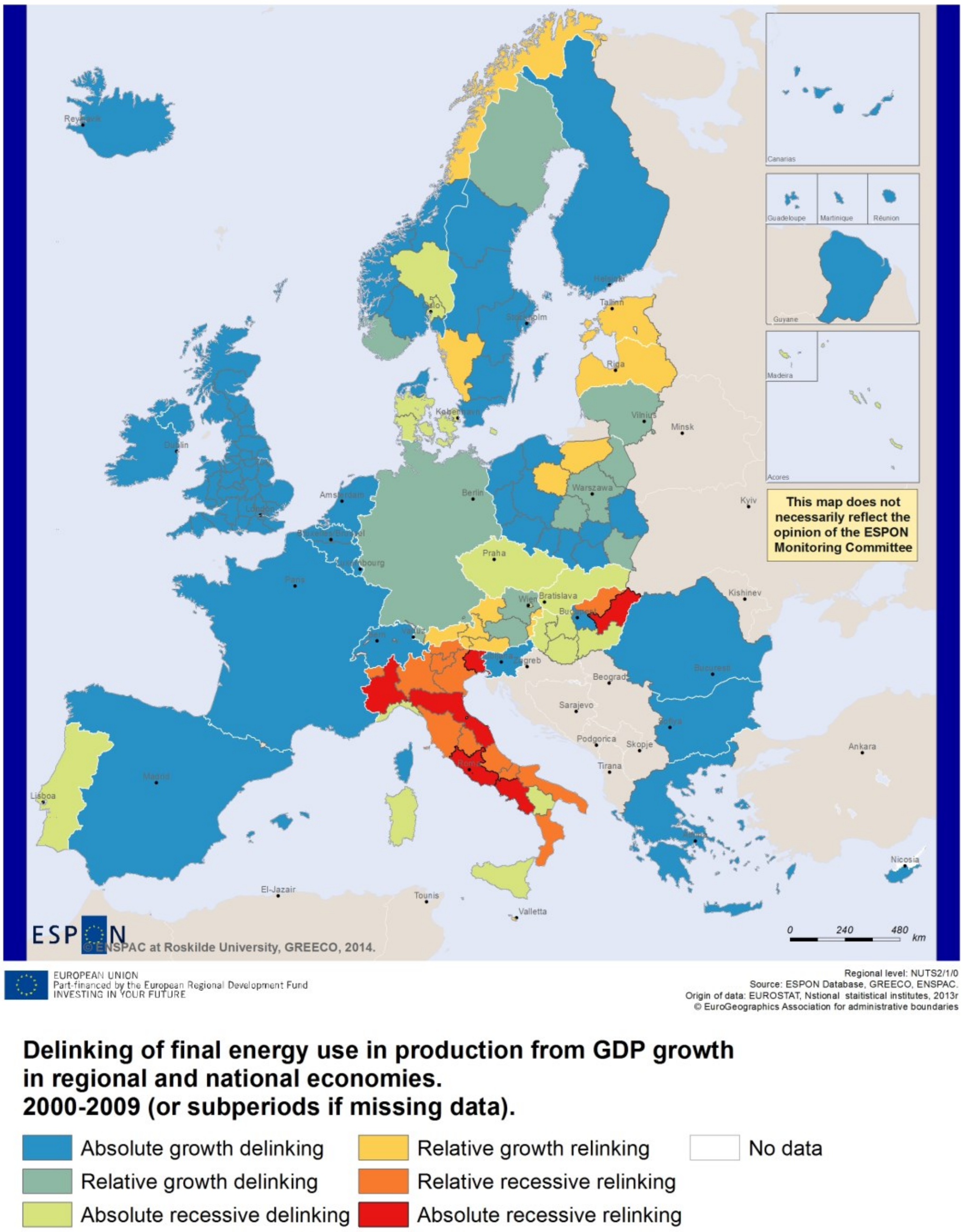


Figure 17. Final energy consumption in production and GDP per capita, 2005 (GJ/person and PPS€1000/person).
Source: (Hansen, 2013a).



Map 24. Delinking of final energy use in production from economic growth 2000-2009.
The production activities generally became less energy intensive in the period according to map 24.

The analysis was also carried out for the dual goals of reducing energy consumption in production per employee and simultaneously raise the rate of employment of the economy. The result is shown below.

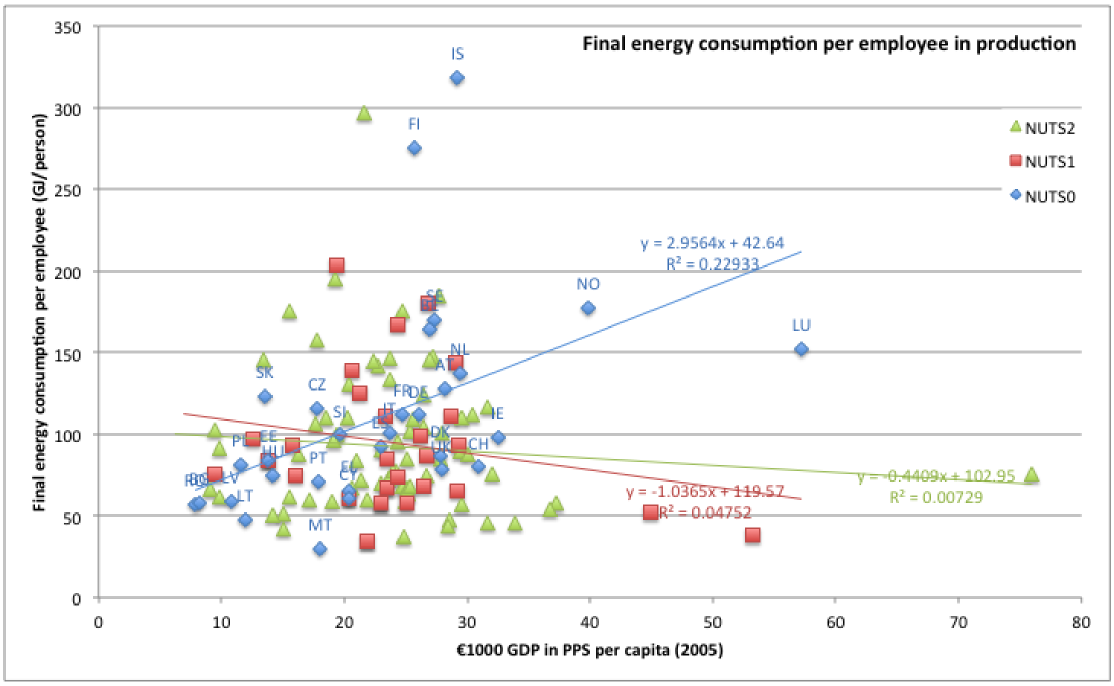
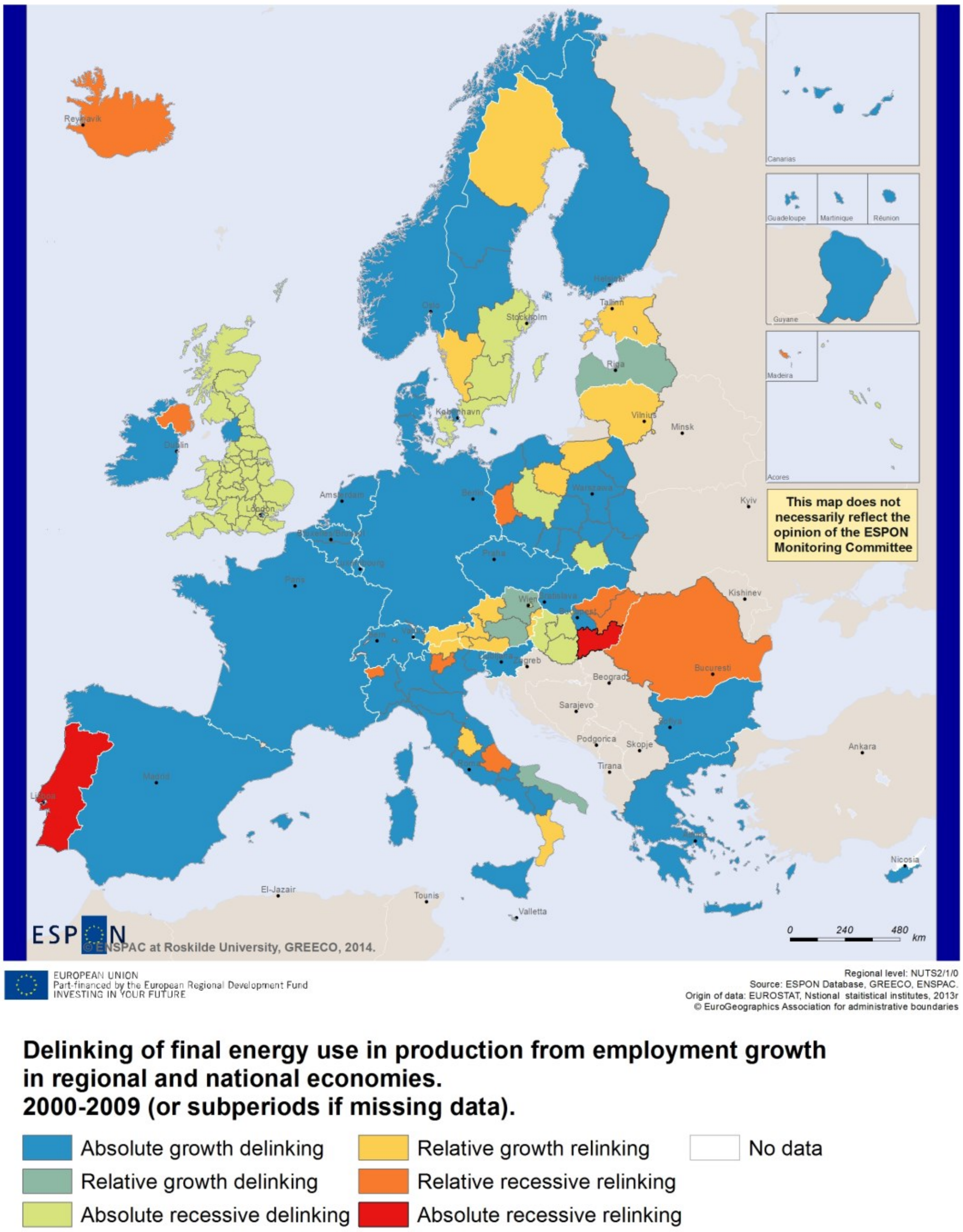


Figure 18. Final energy consumption in production per employee and GDP per capita, 2005 (GJ/person and PPS€1000/person).
Source: (Hansen, 2013a).



Map 25. Delinking of energy use per employee in production from changes in the rate of employment 2000-2009.

The delinking performance measured in this way is as shown in map 25 also positive in most of the economies, but some economies shift colour from green to blue and *vice versa*.

Energy use in the transport sector grew at a higher rate than GDP in many economies.

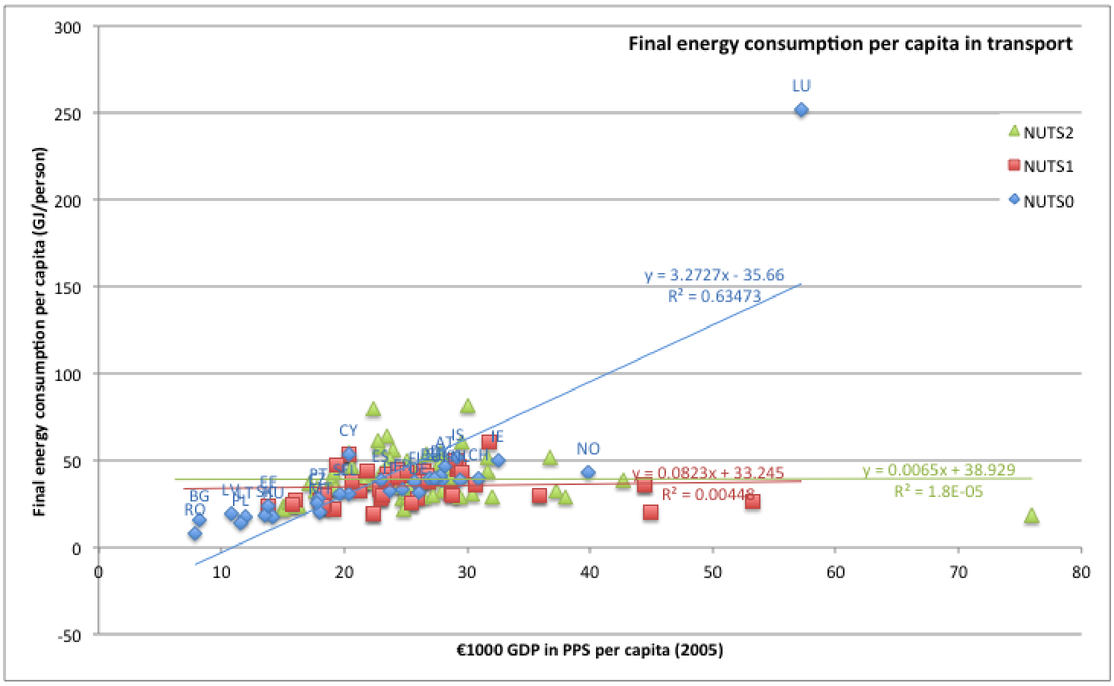
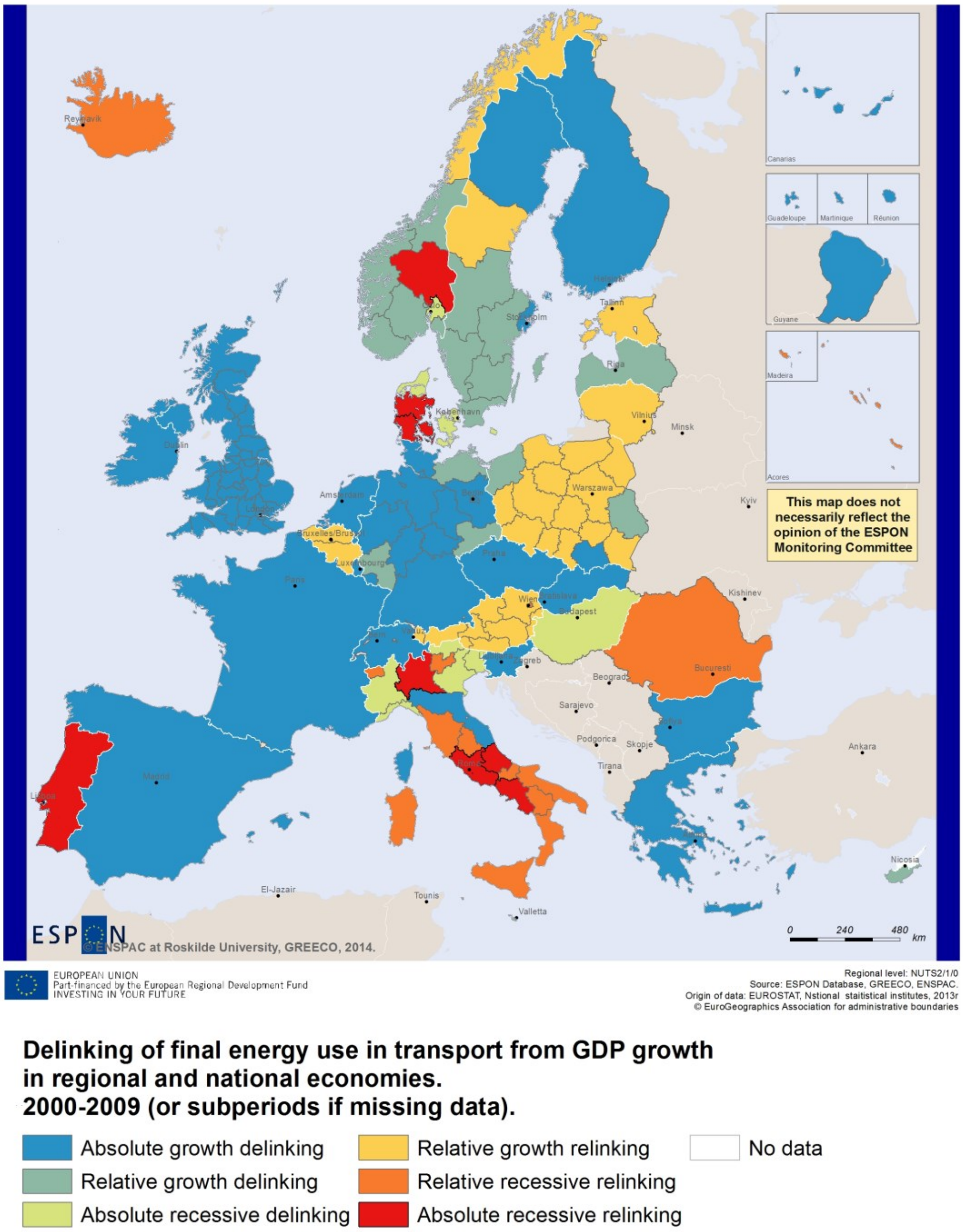


Figure 19. Final energy consumption in transport and GDP per capita, 2005 (GJ/person and PPS€1000/person).
Source: (Hansen, 2013a).



Map 26. Delinking of transport energy use from economic growth 2000-2009.

Particularly in the south and the east and also in some northern regions of Europe the intensity of transport energy in GDP has risen. In these economies the use of transport fuels have become closer linked to economic growth.

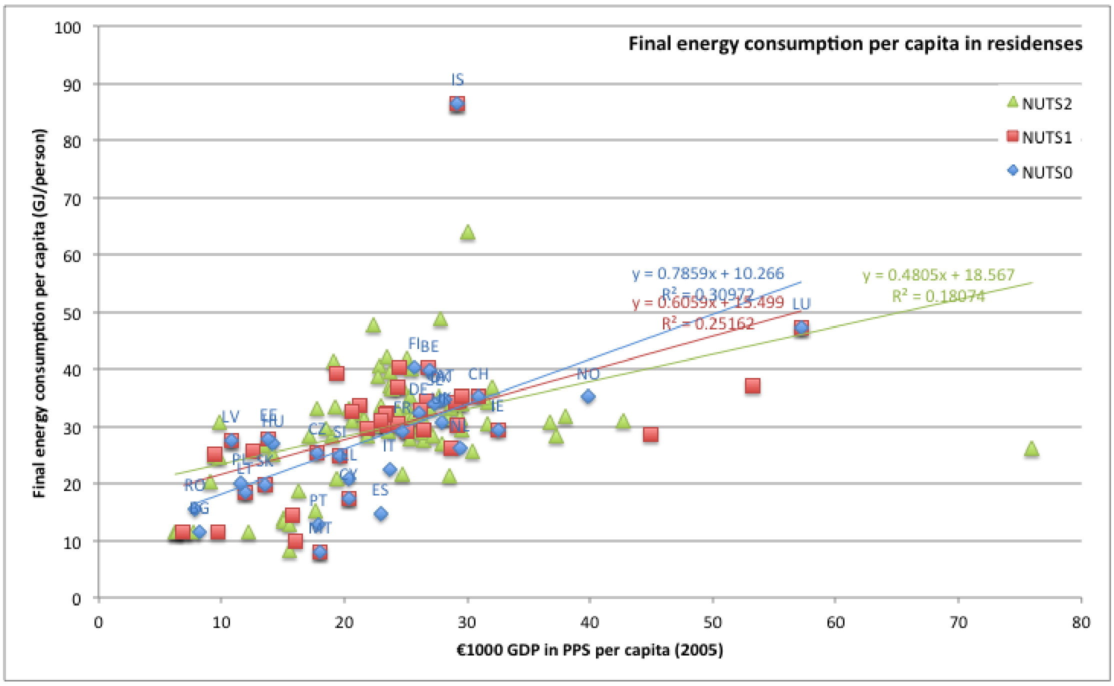


Figure 20. Residential final energy consumption and GDP per capita, 2005 (GJ/person and PPS€1000/person).
Source: (Hansen, 2013a).

Most European economies made progress towards a lower residential energy use compared to GDP, but also in this sector some economies moved in the opposite direction. Residential energy use is, however, also influenced by the temperature and wind. Thus the energy use is not only related to GDP on the map below, but also to adjusted by heating degree days.

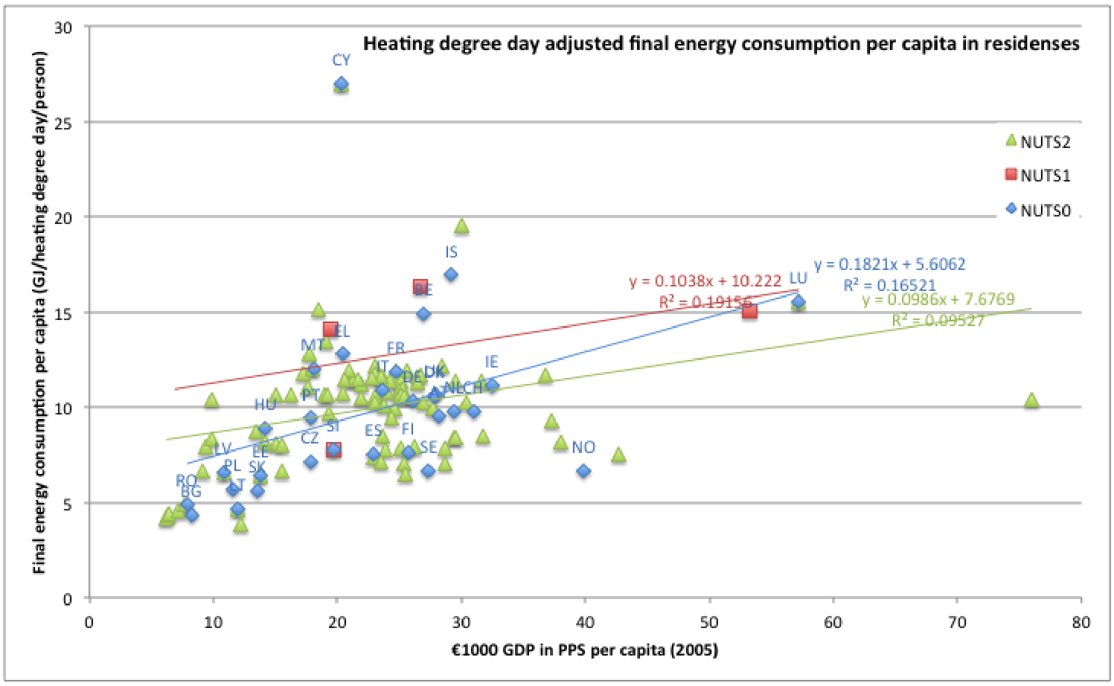
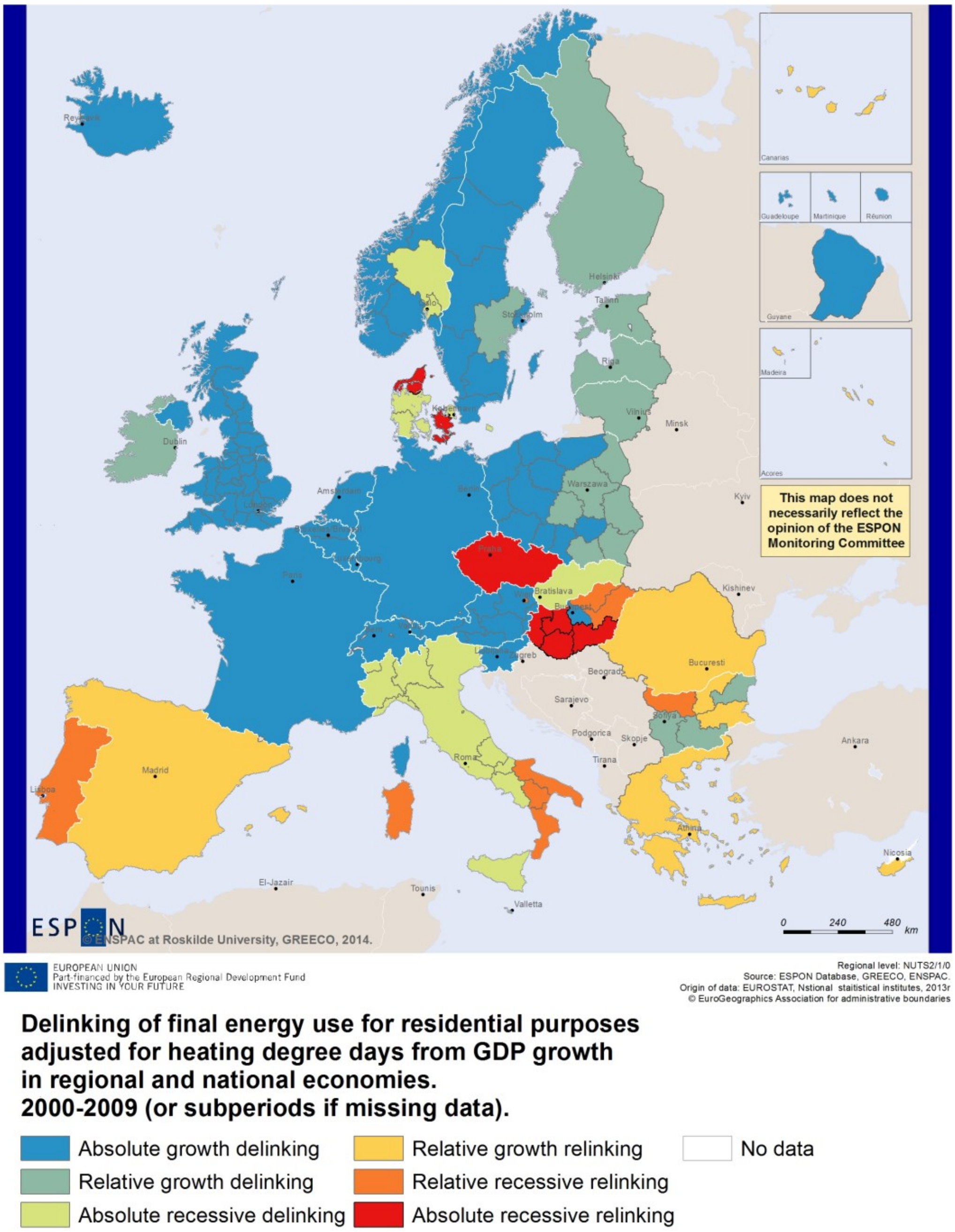


Figure 21. Residential final energy consumption adjusted for heating degree days and GDP per capita, 2005 (GJ/heating degree day/person and PPS€1000/person).
Source: (Hansen, 2013a).



Map 27. Delinking of residential energy use (per heating degree day) from economic growth 2000-2009.

The adjustments behind the results in
map 27 shows that much of the relinking is due to variations in heating degree days.

The delinking performance with respect to energy reviewed in this chapter can be a useful tool in monitoring the progress of decarbonisation. A better and harmonised European energy statistics with full coverage at NUTS2 level can be very useful for regional bodies. It should also include production and capacity statistics on fossil, renewable and nuclear energy.

13. Other materials flows – dematerialisation

13.1. Introduction

There are many other flows of materials through the econosphere that are unsustainable. These flows represent over-consumption of nature either as a sink or as a resource.

They include, for instance, metals, chemicals with adverse environmental effects and municipal waste and wastewater. In this section, we will confine the analysis to a general framework for material flow accounting developed by EUROSTAT and the regional pattern of wastewater and waste treatment.

13.2. Material flow accounting

Statistical accounting of the material flows goes back to early studies by Ayres and Kneese (Ayres and Kneese, 1969). In Europe, the EUROSTAT has been engaged since the 1990s in documenting the material flows through the economy. Figure 22 shows a simplified scheme of the material flow accounting framework.

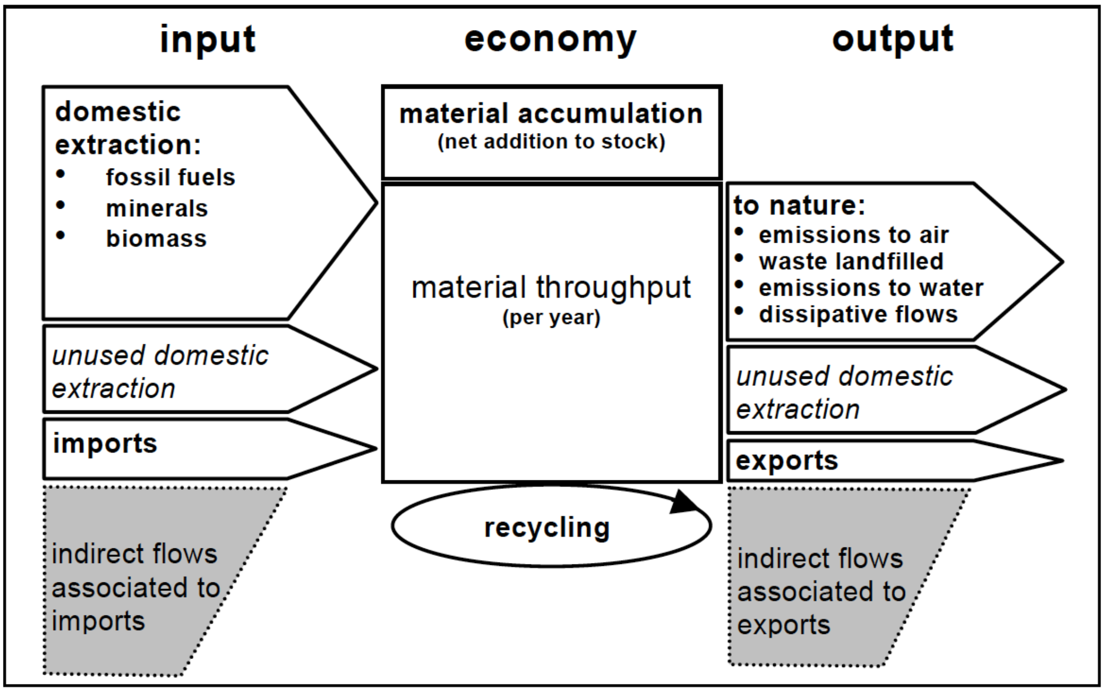


Figure 22. Material flow accounting framework.
Source: (EC, 2009d, 2001)

Air and water flows are excluded from the scheme, but they play an important role in the material balance. Evaporation is, for instance, an important balancing item.
The Direct Material Inputs (DMI) is the aggregate weight of materials. Unused domestic extraction includes materials that are moved with a purpose and using technology. Examples include overburden from mining and quarrying, soil and rock excavated during construction and dredged sediments from harbours. These flows do not enter into final products but are side-effects of the primary production of materials and investments and maintenance of the capital stock.

Indirect flows include material flows derived from the imported and exported materials.

Resource productivity is defined as Gross Domestic Product (real)/Domestic Material Consumption. It is a key figure in monitoring the load of materials through the economy and it is natural to expect it to increase as the economy transforms to a green economy.

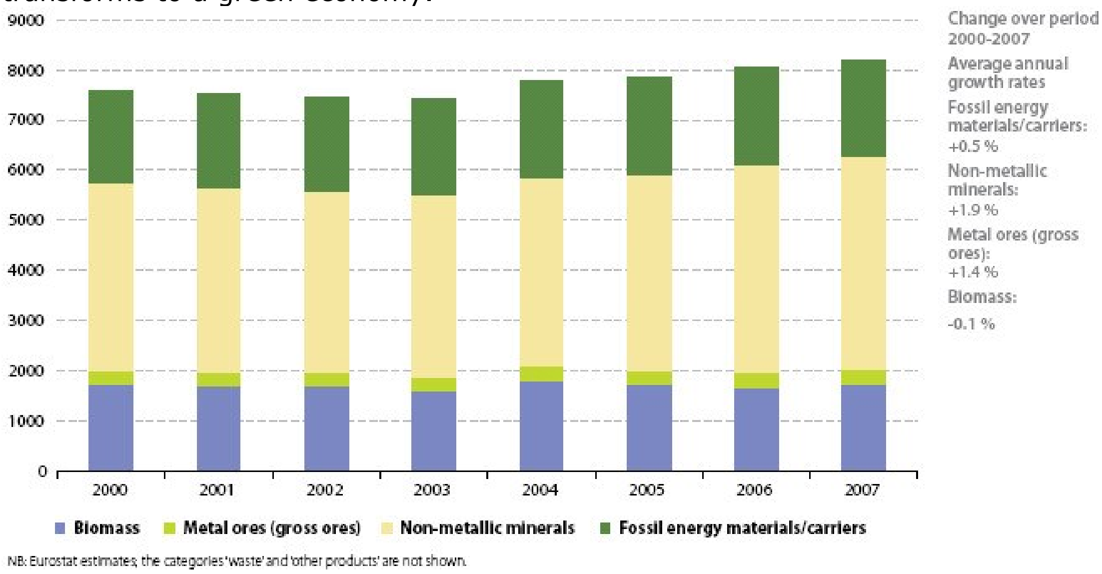


Figure 23. Materials consumption in Europe (domestic). Million tons.
Source: (EC, 2009d).

Figure 23 shows the aggregate weight of *all* materials. The aggregate weight, however, is of little informative value as to the resource scarcity and environmental pressures related to specific materials. Organic fibres and heavy metals, for instance, are not equally undesirable flows.

About half of the materials flow measured by weight consists of non-metallic minerals, that is, raw materials for construction: Sand and gravel, limestone, clay etc. Most of the other half is split between biomass and fossil fuels. A considerable share of the fossils fuels are used transporting and processing these materials – including fossil fuels. Flows of waste and other products are not shown.

The most problematic flows are the non-renewable resources – metals and fossil fuels – causing source as well as sink problems. The aggregate weight of these did however remain almost unchanged through 2000-2007.

An increasing weight of biomass flows could even be socially preferable the biomass substitutes non-renewable resource flows, e.g., when pellets substitute natural gas. In many other cases, a green economy is supposed to use biomass instead of mineral materials due to its low carbon, non-toxic, recyclable and biodegradable properties. But the moisture content of biomass can easily cause the gravimetric resource productivity to increase. For instance, it can be considered a progress towards a green economy if 2 tons of biomass replace 1 ton of lignite. Depending on the energy density (gravimetric) the resource productivity could go either way.

At a higher level of detail, the accounts can be very useful in tracing throughputs and flows. The combined benefits of saving environmental damage and high cost resources can be comprehensively accounted for on solid basis.

The level of detail at the subnational territorial level does, however, not allow for an intensive use of this statistics for the green economy analysis.

Resource productivity and *eco-efficiency* indicators are used to analyse progress towards the delinking of the unsustainable physical flows from the final and valuable services. They include resource productivity, energy intensity, emission intensity and other indicators. These indicators relate the economic performance to the environmental pressure.

Thus, the statistical description of the progress towards a green economy needs a range of economic variables as well as variables describing the physical environment. The concept of eco-efficiency involves all three categories of economic activities: Production, investment and consumption.
In the process of *production*, materials and energy are used as inputs and useful products as well as waste and emissions are the outputs. The standard measures of the efficiency of these processes include, e.g.,

- resource productivity (ratio of materials inputs to production volume or value added)
- energy intensity (ratio of final or gross energy to consumption to production volume or value added)
- conversion efficiencies (ratio of energy contents of output to inputs)
- emission intensities (ratio of emissions or waste to production volume or value added)

In the process of investment, i.e., at the micro-economic level, the standard measures of economic sustainability and optimality include, e.g.,

- energy resource shares of conversion capacity (renewable or non-renewable, combustible or non-combustible)
- levelized cost (cost per designed energy production at normal use during the life-time of the investment)
- levelized services (designed energy or materials flow per unit of services produced or per value of services produced)
- rate of return (ratio of profits to circulating and fixed capital stock relative to alternative investments - Return on Investments, Internal Rate of Return, Net Present Value)
- payback ratio (economically and for energy producing/saving equipment the time it takes to generate or save energy enough to balance the energy consumed in the investment process)

In the process of consumption, standard measures include, e.g.,

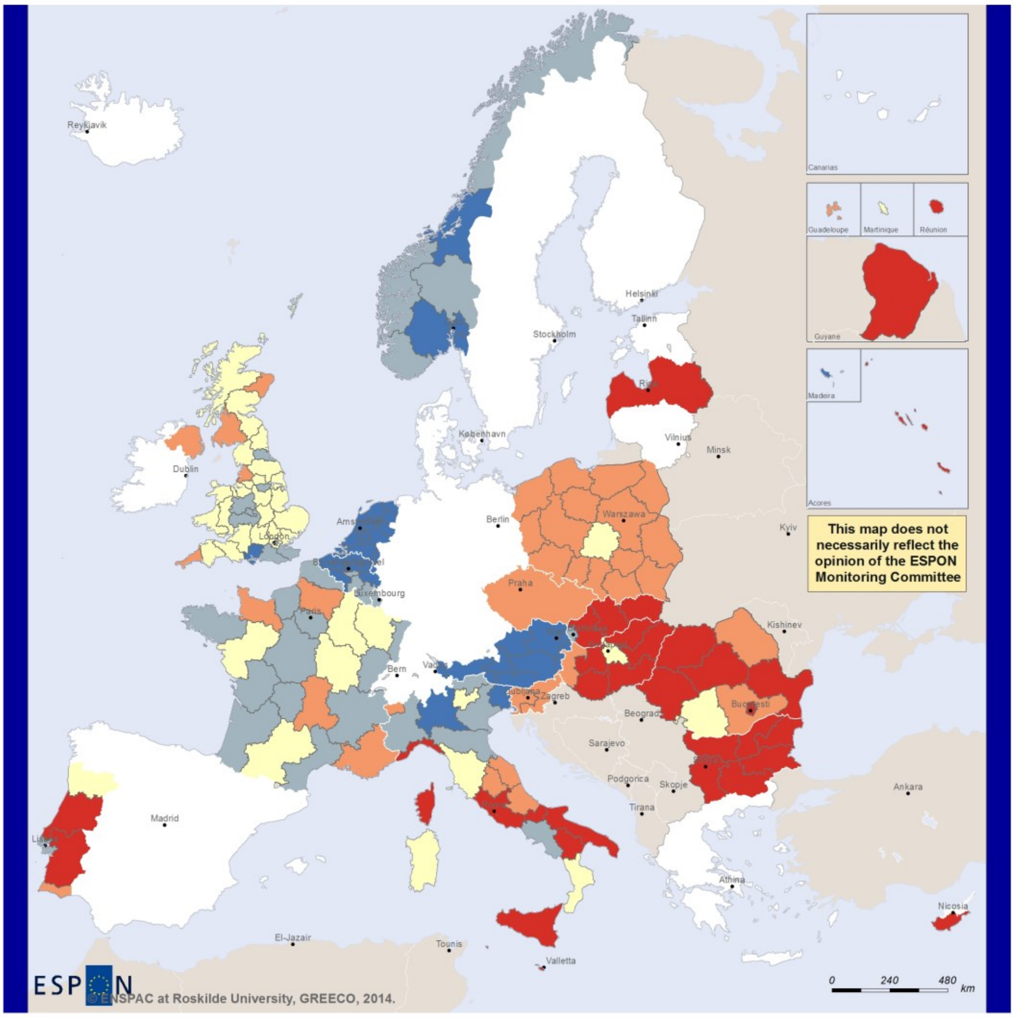
- Direct and indirect material flows lifecycle impact of global energy and material flows set into motion by the consumption per value of consumption
- Flows bypassing valuable final services (food waste rates, drinking water leakage)
- Mobility to direct and indirect energy use rates

Against this backdrop, it can be concluded that changes in the aggregate materials flows measured by weight are not very accurate as indicators for regional progress towards the green economy. They are, however, very useful for analysing the specific materials intensity of the economy, which varies by the natural resources endowments of the countries.

13.3. Materials flows, waste and wastewater

Another feature of the 20th century econosphere that is unsustainable is that part of the materials flows end up in land-ills and other deposits. The limited reserves of non-renewables as well as the limited land available for landfills and deposits represent obvious constraints on the growth of material flows.

Material flows statistics are only available at national level and information on the recycling of materials is difficult to derive from the statistics. The Materials flow statistics divide materials into four groups: Biomass, Metal ore (gross), Non-metallic minerals and Fossil fuels. The throughputs of these flows are accounted for at the entry and exit points of the economy. Major exit points are emissions and waste. Some properties of the treatment of municipal waste appear from map 28.



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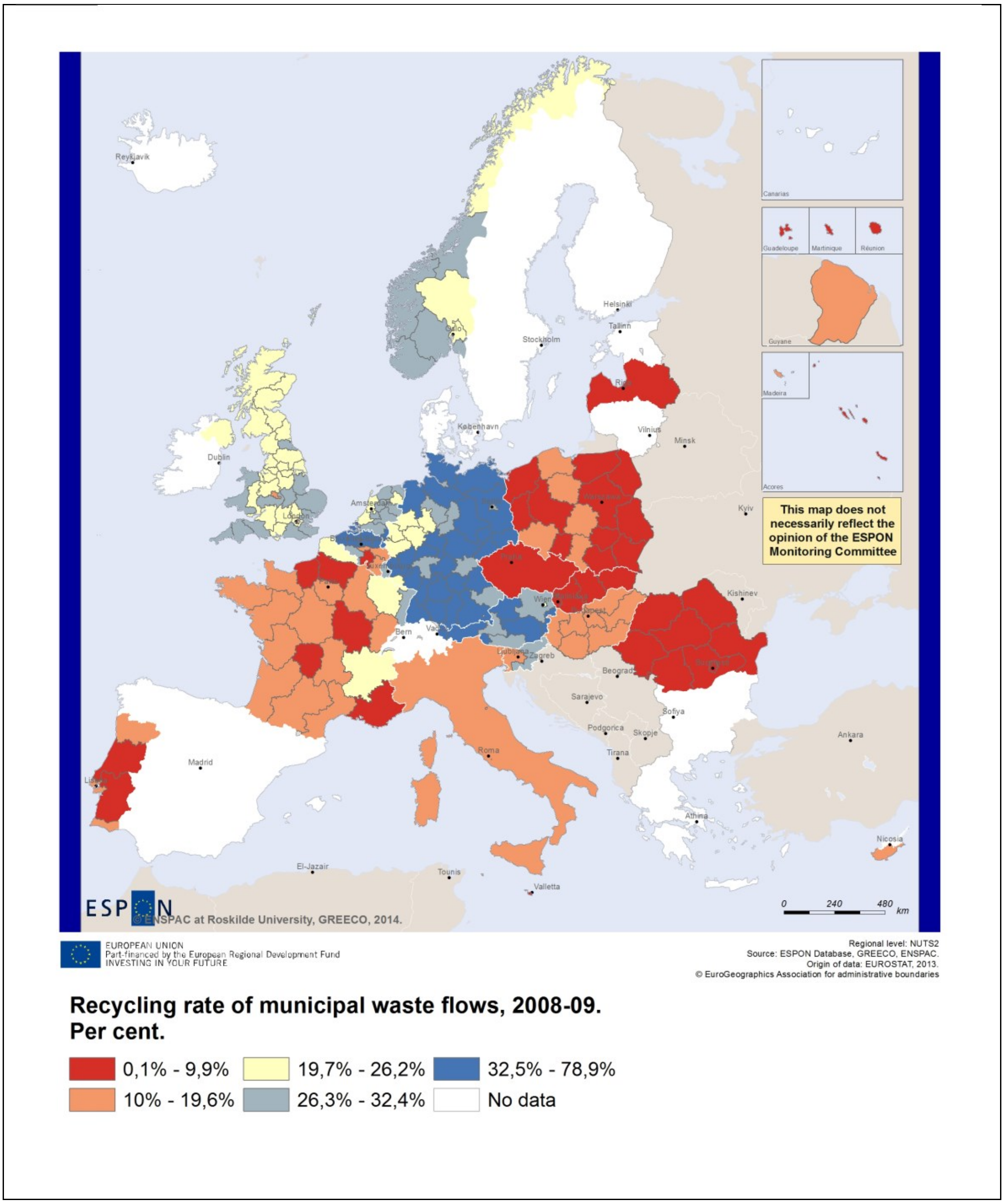
Regional level: NUTS2
Source: ESPON Database, GREECO, ENSPAC.
Origin of data: EUROSTAT, 2013.

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

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



Map 28. Municipal waste deposition and recycling shares. Average 2008-2009. Per cent.
Source: Author' s calculations based on EUROSTAT data (EC, 2013o).

At the national level, some of the waste streams outside the municipal waste system are accounted for as well. They include among others end-of-life vehicles and packaging waste. Some of these statistics cover recycling activities as well, but not on a regional level.

14. Restoration of natural ecosystems

14.1. Restoration of ecosystems

The third major area for transformation to a green economy is the interface between the economy and the natural ecosystems. The EU policy goal is to halt and reverse the decline in biodiversity by 2020. Important contributions to this end include the water framework directive and the nature conservation policy.

The trend of nature scarcity expressed as area left for nature purposes per capita emphasises the importance of the EU biodiversity strategy. The central target of the strategy is "*to halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, restore them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss*". This target is set after the EU failed to attain its previous target on halting biodiversity loss by 2010. Target 2, however, on "*maintaining and restoring ecosystems and their services*" aims at "*by 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15 % of degraded ecosystems*" (EC, 2011d).

In the following three physical properties that are important for this goal will be addressed. They include the emissions to the aquatic environment, the allocation of land between economic purposes and natural ecosystems and

14.2. Allocation of land between economic and nature

In Europe the area covered with artificial surface, i.e., land used for urban purposes, continued a growing trend from 2000 to 2006 at the expense of agricultural and semi-natural land cover (OECD, 2012). Despite the evidence that land-use for economic purposes is the major cause of terrestrial biodiversity loss, the EU biodiversity strategy contains no targets as to land-use. The Committee of the Regions proposes to give regional and local authorities a key role in pursuing local and regional sub-targets on environmental pressure and land-use (EC, 2010b).

The pressure for increasing land-use for economic purposes will increase through the 21st century as a result of an increasing world population with increasing demand for, also increasingly, animal food. This pressure can result in a higher human take of the primary production and smaller areas available as habitats for species and ecosystems.

The land-use changes that must be associated with progress towards a green economy necessarily differ from region to region according to their biodiversity and potentials for biodiversity, environmental amenities, access to nature experience etc. and the potential gains from economic use of the areas.

14.3. Human appropriation of net primary production (HANPP)

The human tak on the primary production can be analysed by a new accounting framework accounting the actual human appropriation of net primary production (HANPP).

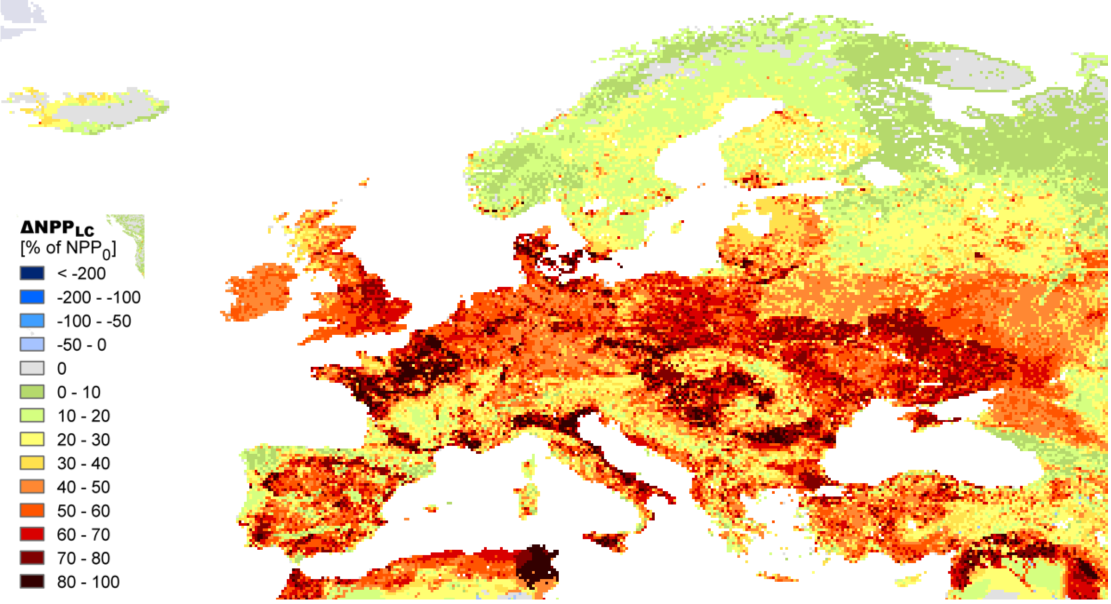
The net primary production of a territory is the generation of organic material from carbon. The "net" refers to cell respiration loss. This net primary production is the basis for all other life in the biosphere as the carbon passes along through the food chain. "Human appropriation" designates share of it that is used for food, fodder, timber, fibres and any other input to economic activities.

An early estimate of the HANPP was 40% (Vitousek et al., 1986), but there is still far from a scientific consensus on how to define "human appropriation" and thus on the actual share (Haberl et al., 2007).

A NASA research team has applied satellite data to estimate NPP and the matched them with human use of organic material from the FAO database. The found that the HANPP was 20% in 1995 rising to 25% in 2005 and with the prospect of 55% in 2050 (Imhoff and Bounoua, 2006).

This HANPP framework for analysis of the ecological-economic structures invite to further studies of territorial variation in NPP-carbon-efficiency and of inter-territorial NPP-carbon-flows.

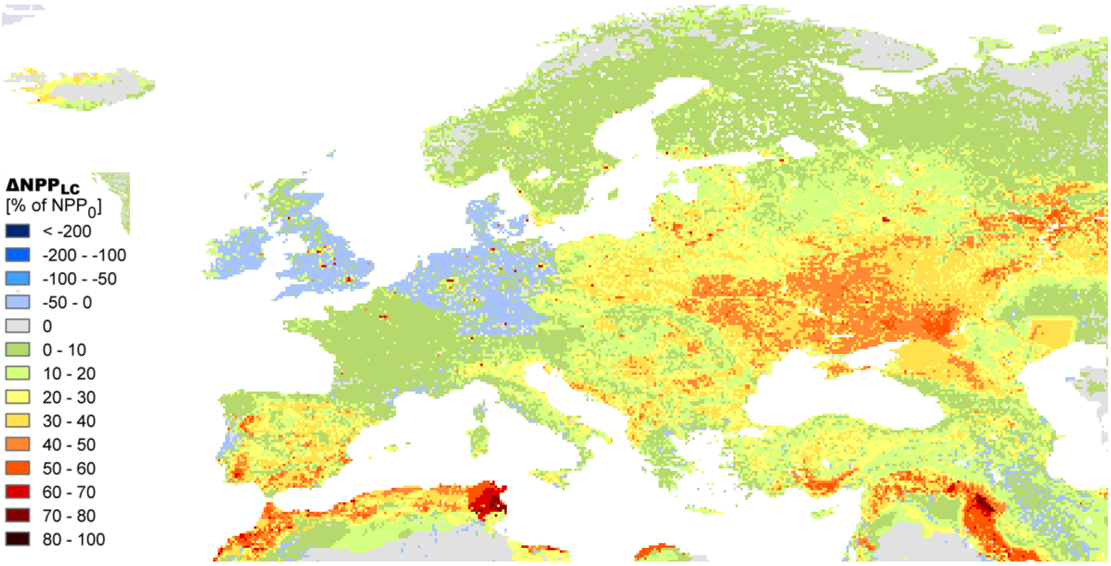
The net primary production of biomass per area varies across European regions and so does the human appropriation of it.



Map 29. Human Appropriation of Net Primary Production in Europe (%), 2000.

Source: (Haberl et al., 2007).

The NPP is also affected by the change in land use as shown at the following map.



Map 30. Change of net primary production due to land-use (%), 2000.

Source: (Haberl et al., 2007).

Whereas the HANPP provides a scientifically well-founded aggregate measure of anthropogenic pressure on ecosystems, it is not obvious how to define a sustainable HANPP at the regional level except for the fact that the HANPP obviously cannot increase indefinitely.

Map 30 shows that the sharing of land between use for economic purposes and for natural ecosystems impacts HANPPP as well as the habitat function.

14.4. Allocation of land between the economy and nature

In growth economies the space required for economic activities seems to grow. The spatial patterns of growth of urban land are to a very high extent coincident with the growth regions of the period.

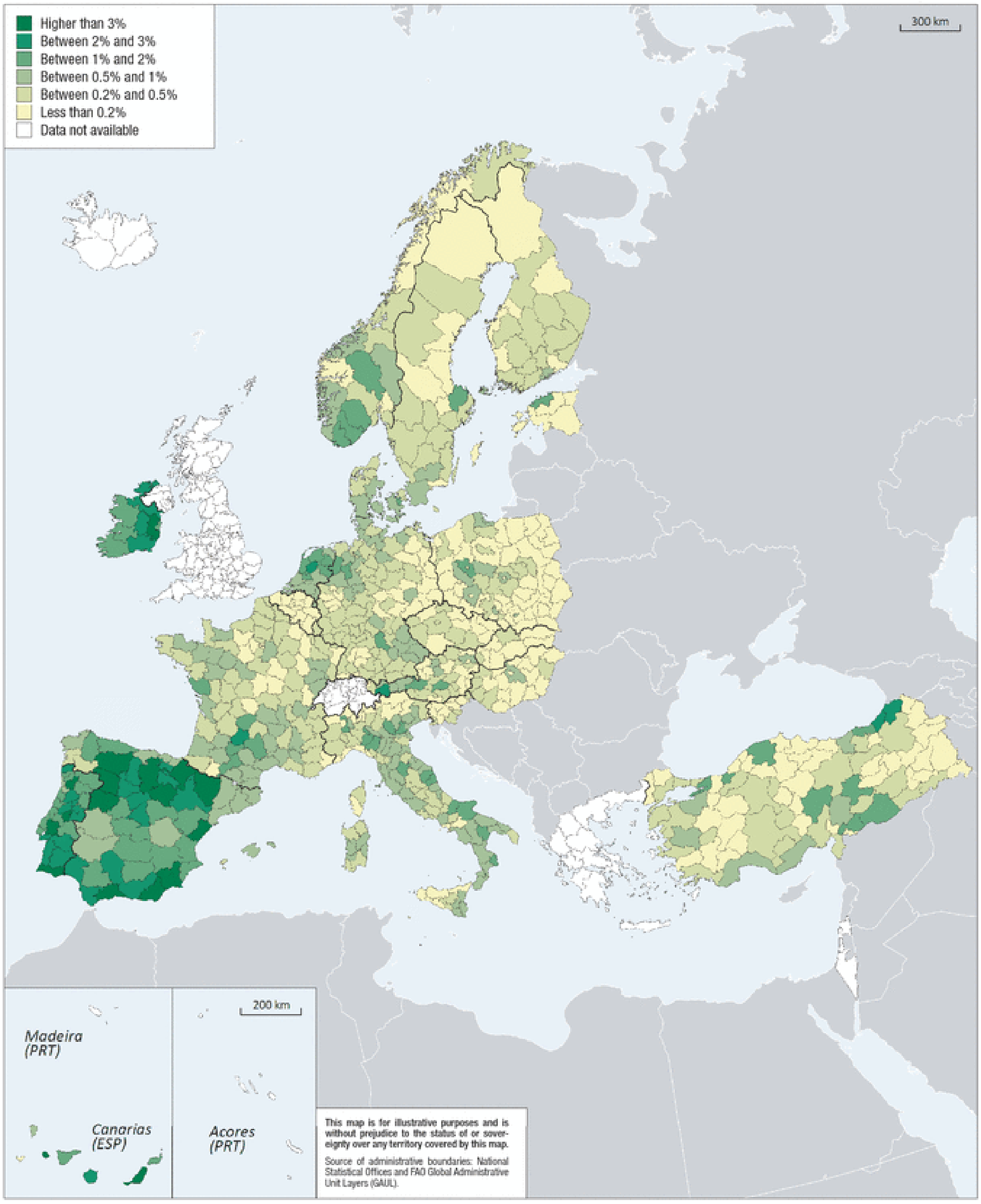


Figure 24. Annual average growth of urban land in Europe's TL3 regions 2000-06.
Source: OECD.

The growth of urban land replaces primarily agricultural surface with artificial surface and it has continued through 2000-06. If more land becomes cultivate

The sharp distinction between land areas by single functions is, however, not necessarily the most appropriate analytical approach. Multi-functionality of land areas is often a more adequate approach to understand the impacts of land-use and the balances between economic activities and nature.

14.5. Nature areas

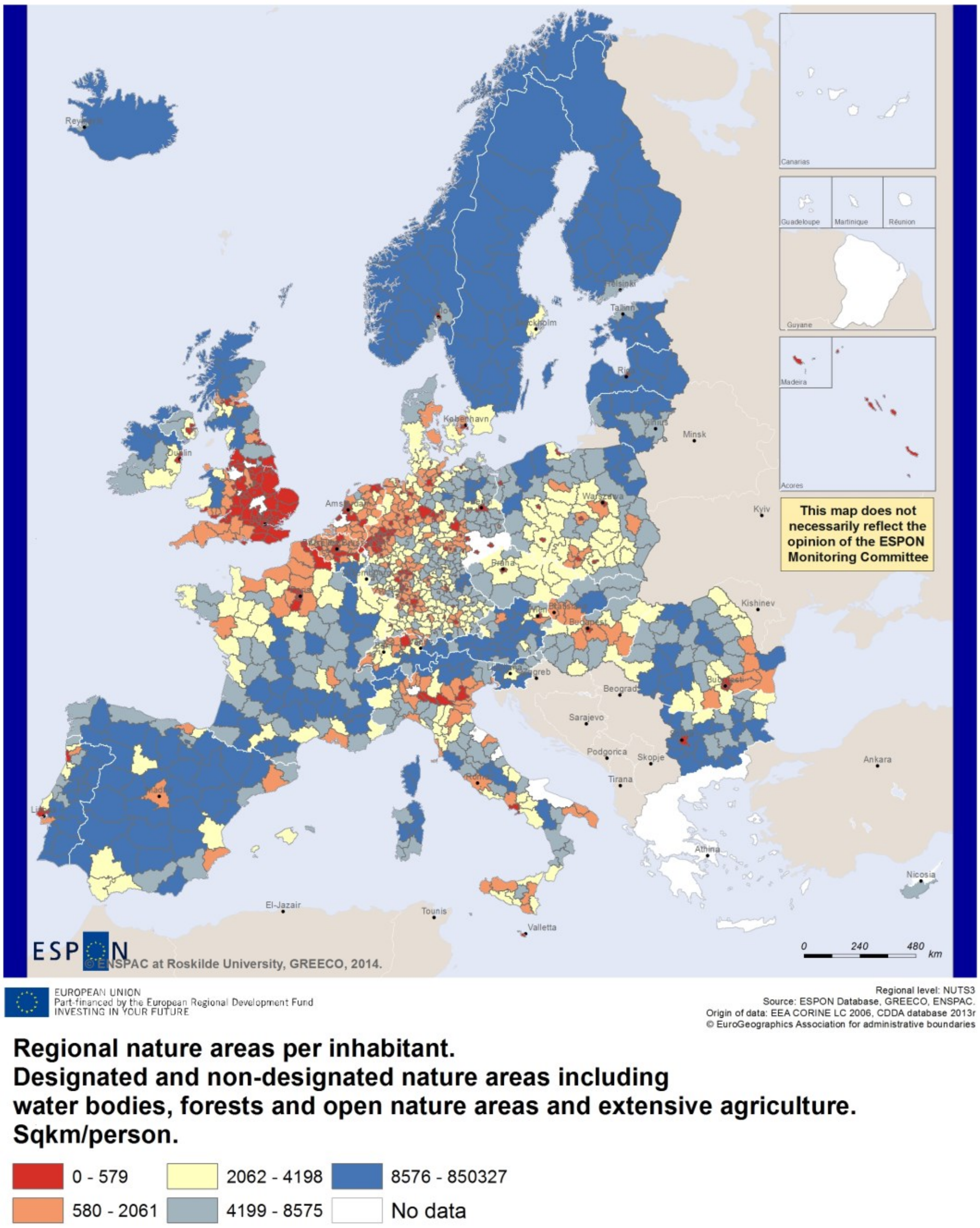
The ecosystem services available to the European citizens include the biodiversity, the cultural values of access to nature of high quality, the regulatory services such as the cleaning function in the hydrological cycle and the provision of materials and energy to the economy. With the present allocation of land between nature and the economy, additional land use for economic purposes (whether provision of materials and energy or urban purposes) is typically at the cost of the former three ecosystem services.

The ratio of the regional nature area to the regional population - "per capita nature" – is rough indicator of the regional availability of ecosystem services that is explored in the following.

The biodiversity strategy is supplemented by other legislation related to nature protection, integrated management of river basins and the common agricultural policy. The Natura 2000 network based on the birds and habitats directives provides instruments for reserving areas for nature purposes (EC, 2010c, 1992). This is because habitat area is an essential condition for the species and ecosystems we want to preserve.

The member-states protect far larger areas than Natura 2000. In the following we consider any form of protection as "protection" regardless of it only protect some aspect of nature and allows some economic activity to take place in balance with the ecosystems in the same area.

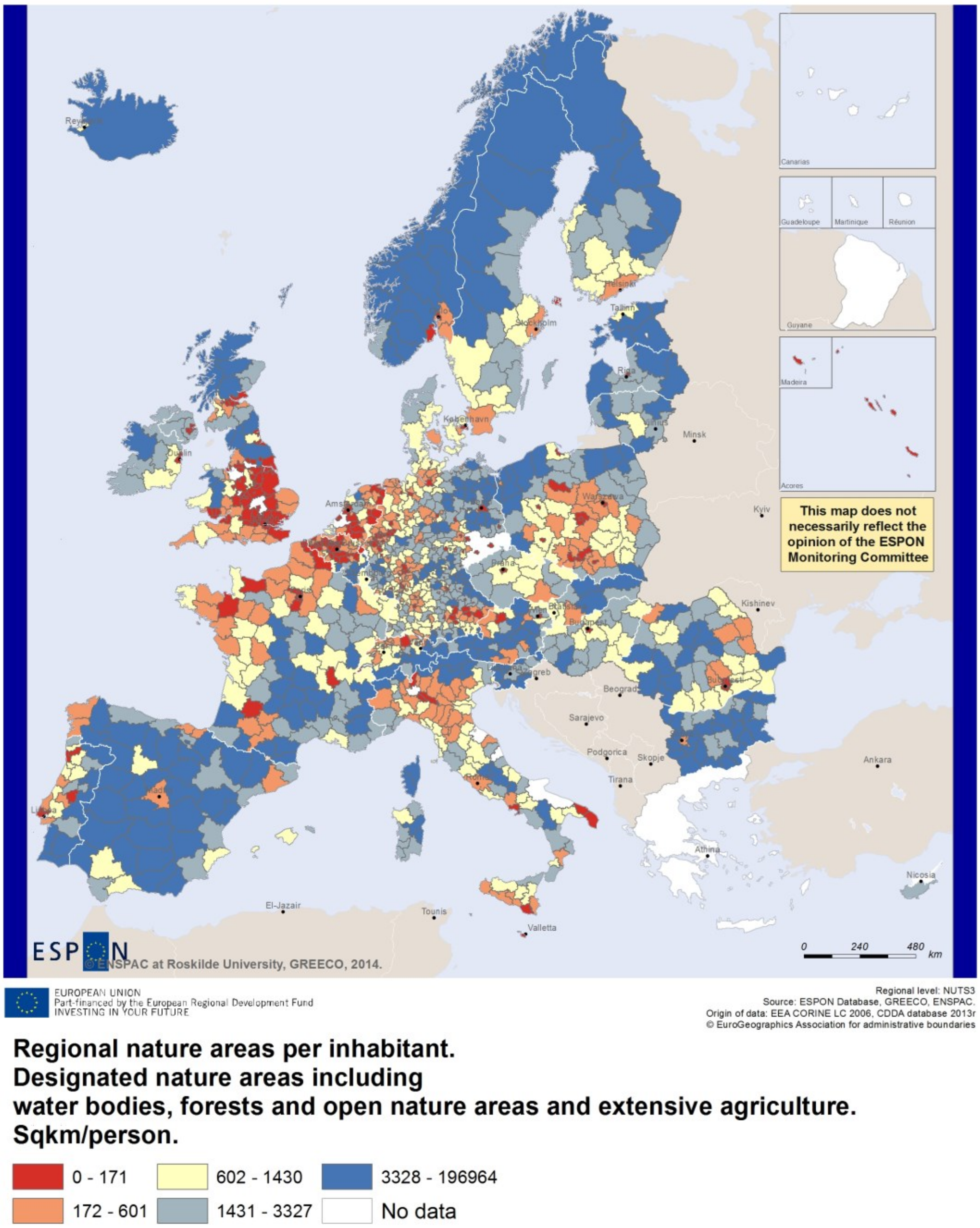
The European Environmental Agency (EEA) has merged the Natura 2000 database with a database of nationally designated nature areas. Based on the combined database the allocation of land between natural ecosystems and economic activities is studied below. "Nature" is defined as the corine land-cover classes of forest, water and extensive agriculture areas (pastures, meadows etc). These areas include areas that where economic activities have priority as well as areas where natural ecosystems have priority.



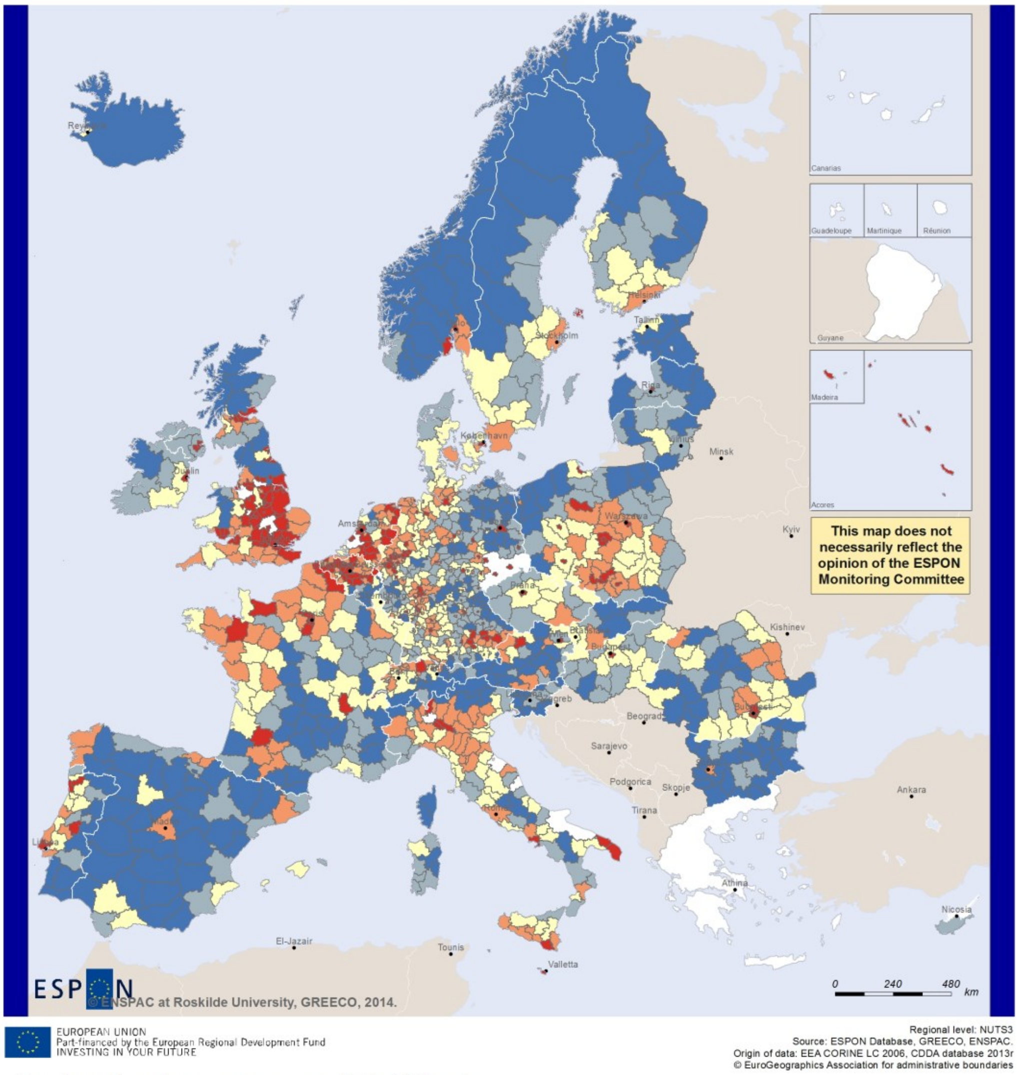
Map 31. Forest, water and extensive agricultural area per capita, 2011. Km^2/person.

Source: Author's calculations based on CLC and designated nature databases (see Hansen, 2013a).

The regional endowment of nature measured in area per person coincides with the population density.



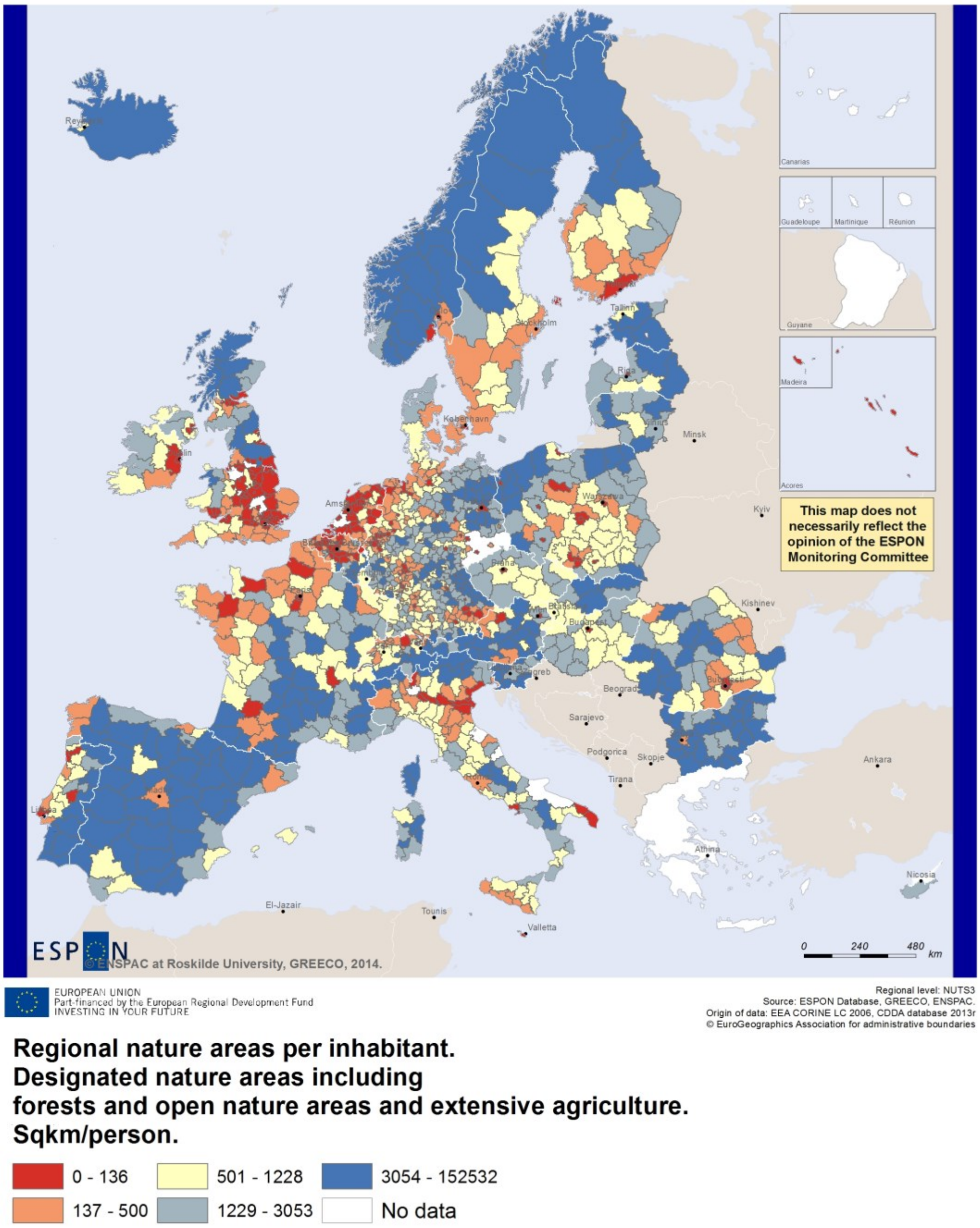
Map 32. Nature designated forest, water and extensive agricultural area per capita, 2011. Km^2/person.
Source: Author's calculations based on CLC and designated nature databases (see Hansen, 2013a).



Regional nature areas per inhabitant.
Designated nature areas including
water bodies, forests and open nature areas and extensive agriculture.
Sqkm/person.

0 - 171
172 - 601
602 - 1430
1431 - 3327
3328 - 196964
No data

Map 32 shows that when the concept of “nature” is delimited to areas that are designated for nature, that is, where natural ecosystems have precedence to economic activities, the areas with poor rates of nature per capita becomes larger.



Map 33. Nature designated forest and extensive agricultural area per capita, 2011. Km^2/person.
Source: Author's calculations based on CLC and designated nature databases (see Hansen, 2013a).

In map 33, the "nature" area has been reduced to include only terrestrial areas. This reduces the indicator value to 150,000 km^2/person in the most richly endowed region.

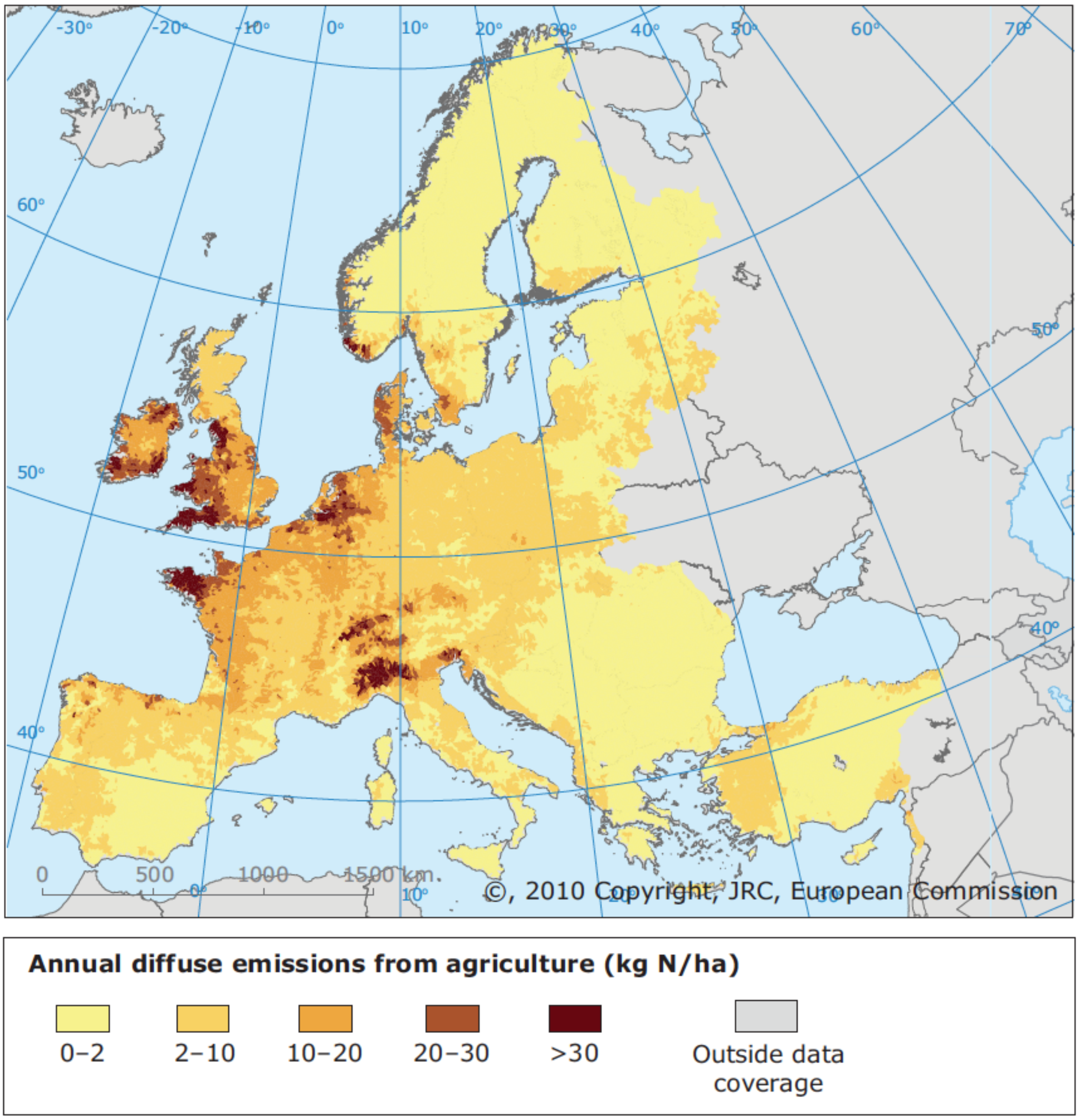
The weakness of this indicator is that many NUTS3 regions are delineated by urban morphology. Thus, the inhabitants of such regions may have access to lots of nature just outside the NUTS3 boundaries. On the other hand, the regions that are poorly endowed with nature areas seem to cluster and thus being neighbours to each other.

An alternative could be to calculate the indicator at NUTS2 level. This would, however, generate the same problem, just on a higher level and for spatially large regions the access to nature in one end of the region is of limited relevance to residents in the other end of the region. Consequently, the indicator should be developed using an accessibility approach to calculate measures of nature accessibility.

14.6. Nutrient cycle balances

The land (including water areas) left to natural ecosystems is also used as a sink for the materials flowing through the econosphere.

Diffuse sources of nitrogen from agriculture to freshwater represent a second important interference with the nitrogen cycle. The spatial patterns are shown in map 34.



Map 34. Annual diffuse nitrogen emissions from agriculture.
Source: (EEA, 2012).

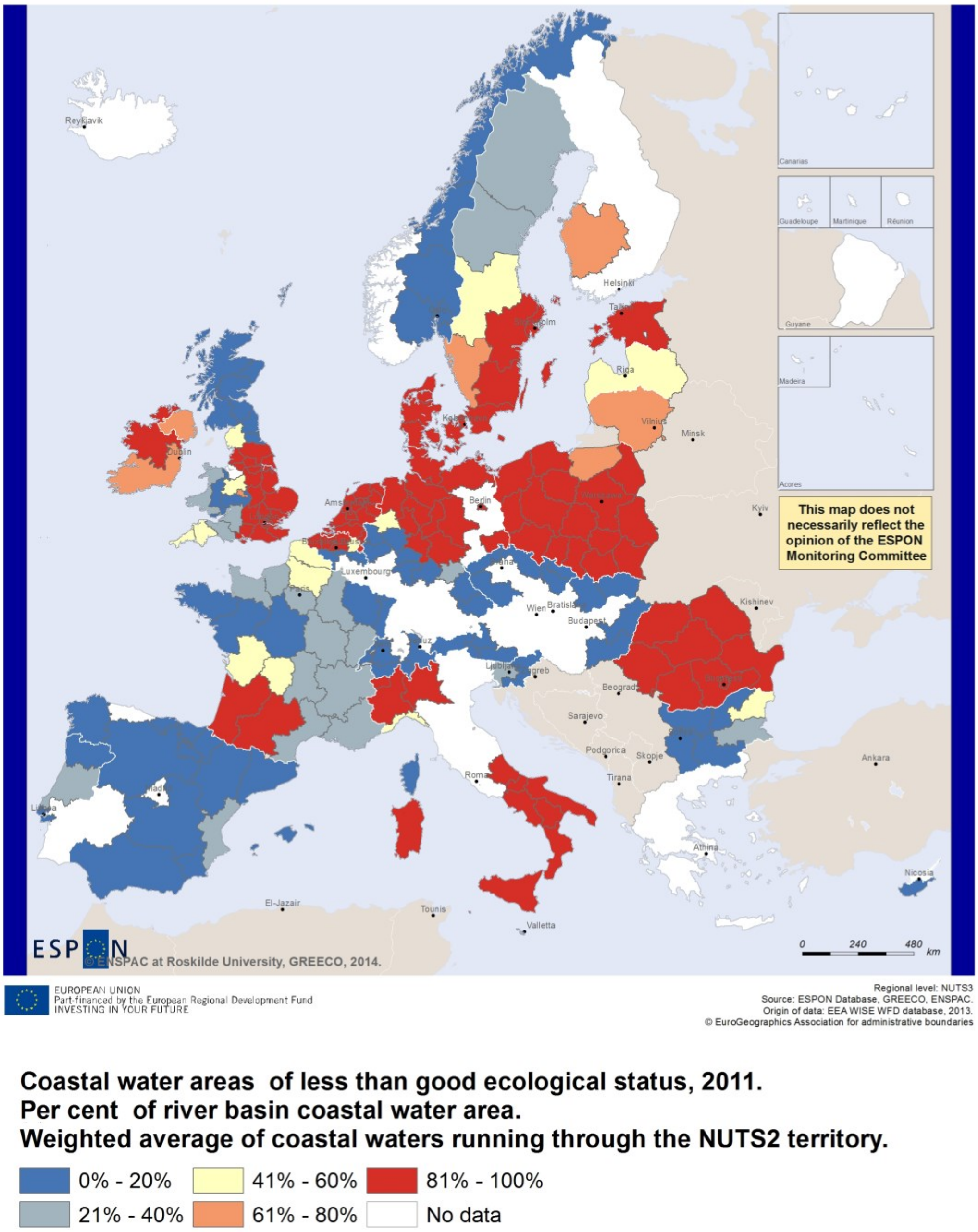
The diffuse nitrogen run-off from agriculture is not a severe problem to any agricultural area in Europe. Rather the high rates of emission are predominantly concentrated in areas with high livestock density. Such concentration may be desirable for economic reasons and it can be made sustainable by enclosing the flows of nitrogen in controllable circular chains. In this respect the industrialised animal production in agriculture does not differ from industrial production.

14.7. Water quality

The status of ecosystems related to freshwater areas is the primary purpose of the Water Framework Directive (EC, 2000). The Commission has developed a set of agri-environmental indicators that could form the basis of the post 2013 CAP, which will use agricultural subsidies as means to achieving environmental goals. These indicators are, however, not generally available at sub-national territorial levels.

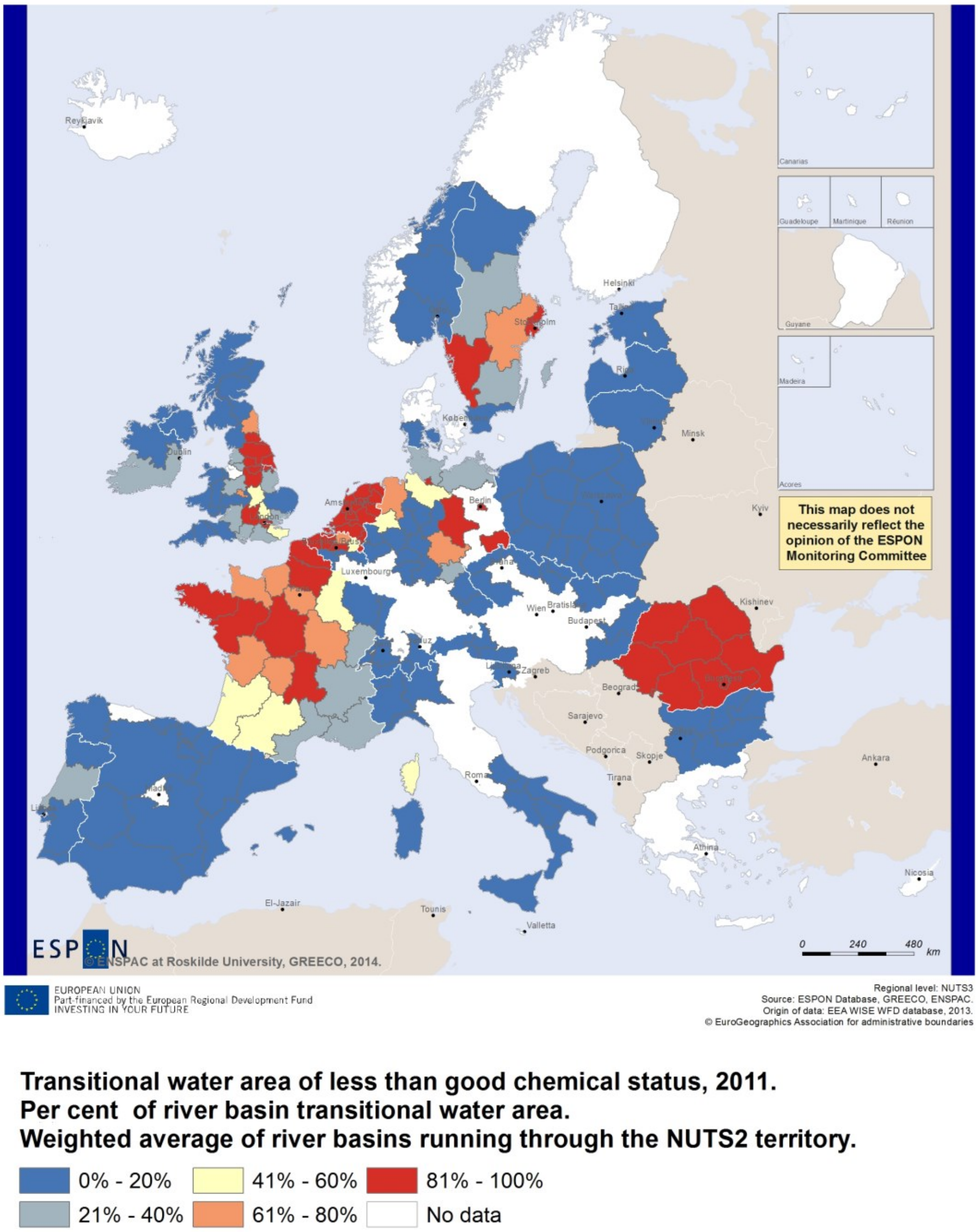
The target for water quality set by the water framework directive is at least a “good” chemical and ecological status of all water bodies in the EU. The scale for the status of water quality is high, good, moderate, poor and bad. The water bodies are classified in coastal, transitional, lakes and rivers. The ecological status depends on factors such as nutrient run-off from agriculture and household wastewater whereas the chemical status depends on discharge of heavy metals and other harmful substances. In some regions a naturally high background occurrence also plays a role.

It is not straightforward to assign water bodies to the individual regions. The firms and households of the region may be polluters (upstream) or pollutees (downstream) or both or neither. They may derive important services from the water bodies or no significant services. The indicator explored here builds upon the data on the share of the water bodies of the river basin that are classified as having less than good status. The value assigned to each region is then the average of the values for the river basins that run through the region, weighted by the area of the region, they occupy.



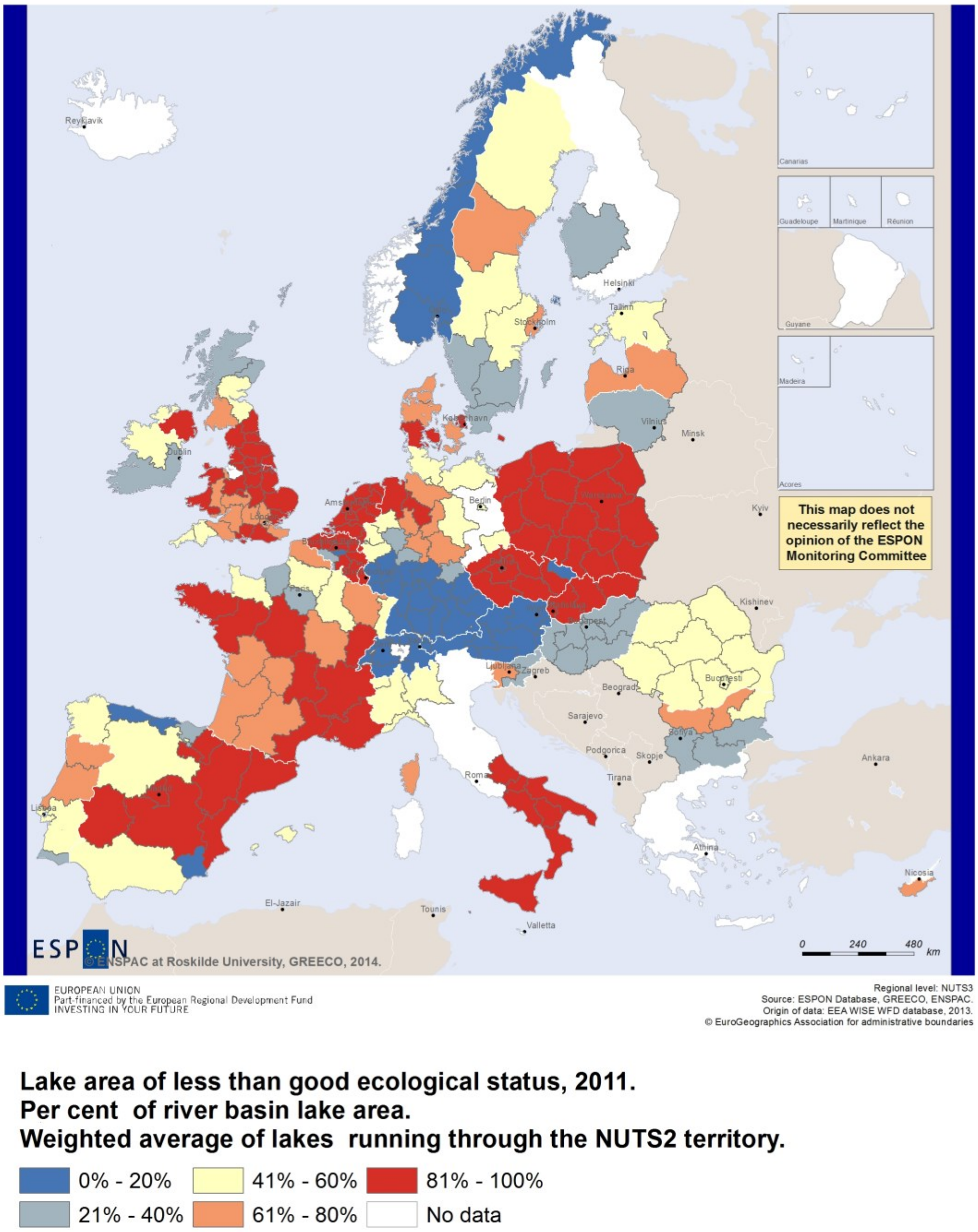
Map 35. Coastal water area of less than good ecological status by NUTS2 regions, 2011. Per cent.
Source: Author's calculations based on the EEA Waterbase (see Hansen, 2013a).

The method enables assigning the coastal water pollution caused by emissions upstream in the river basin to all upstream regions. As shown on map 35 coastal water pollution is a problem for many regions situated several 100 kilometres from the coast.

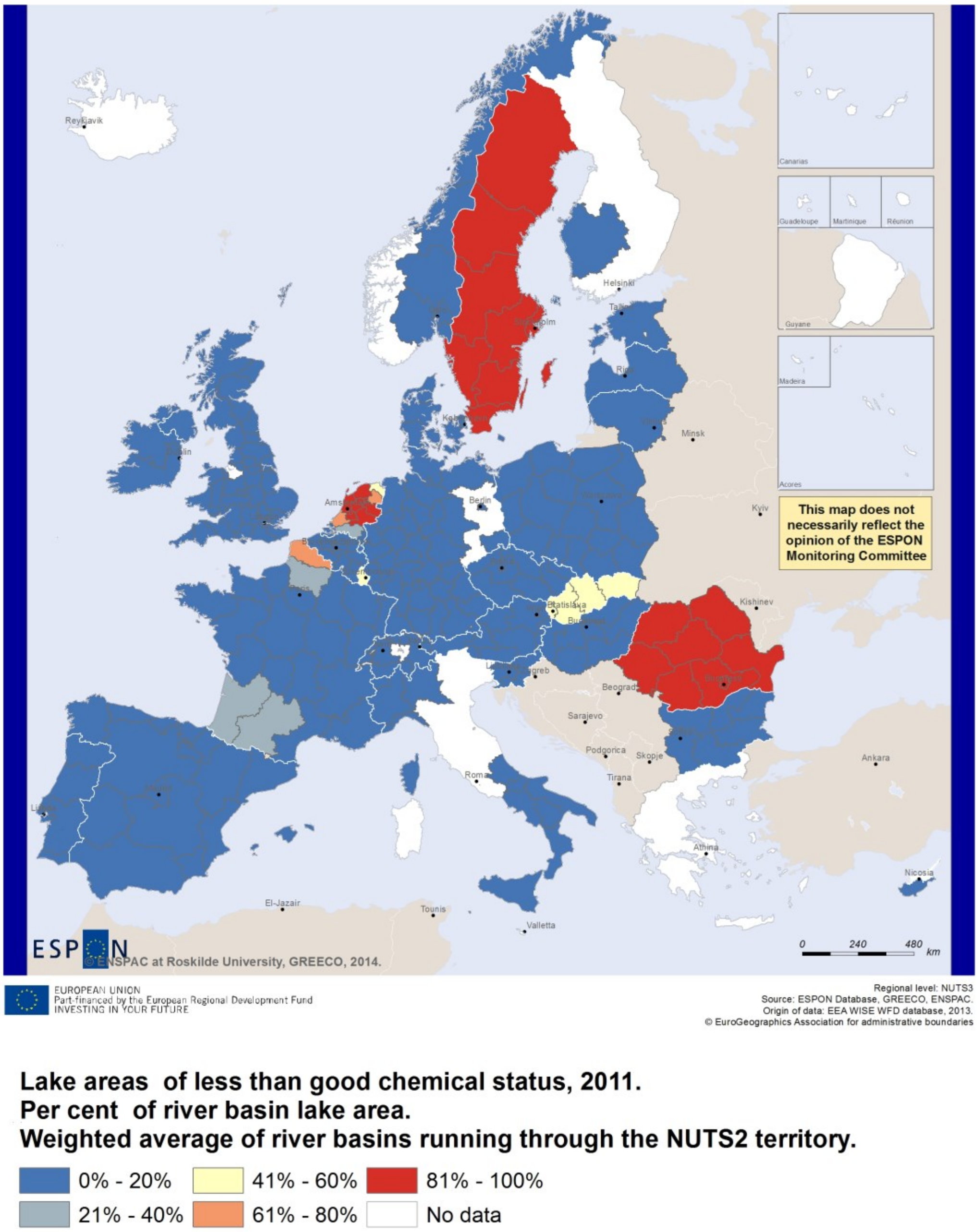


Map 36. Transitional water area of less than good chemical status by NUTS2 regions. Per cent.
Source: Author's calculations based on the EEA Waterbase (see Hansen, 2013a).

The chemical status of transitional waters is also a concern for upstream regions as it appears from map 36.

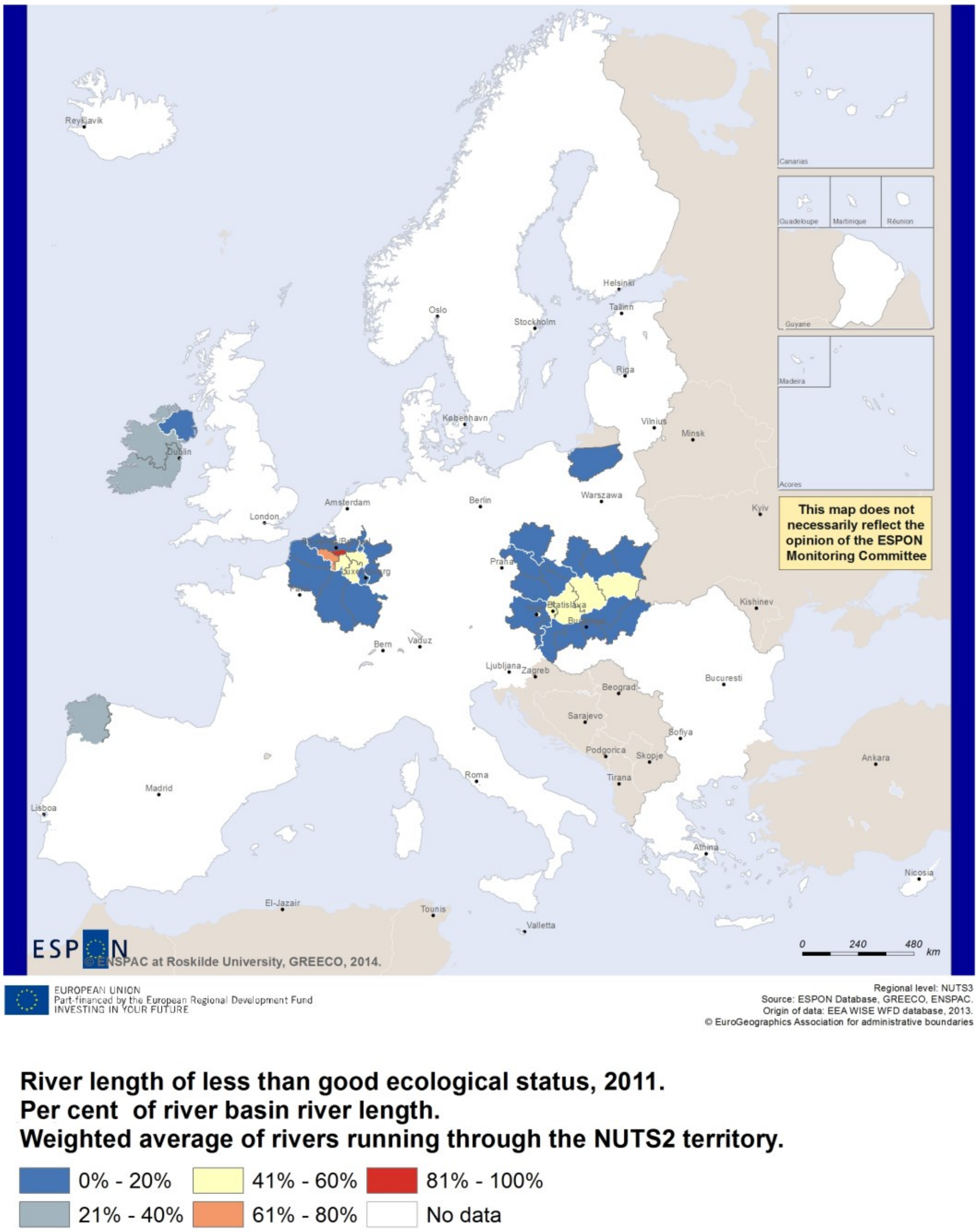


Map 37. Lake area of less than good ecological status by NUTS2 regions, 2011. Per cent.
Source: Author's calculations based on the EEA Waterbase (see Hansen, 2013a).

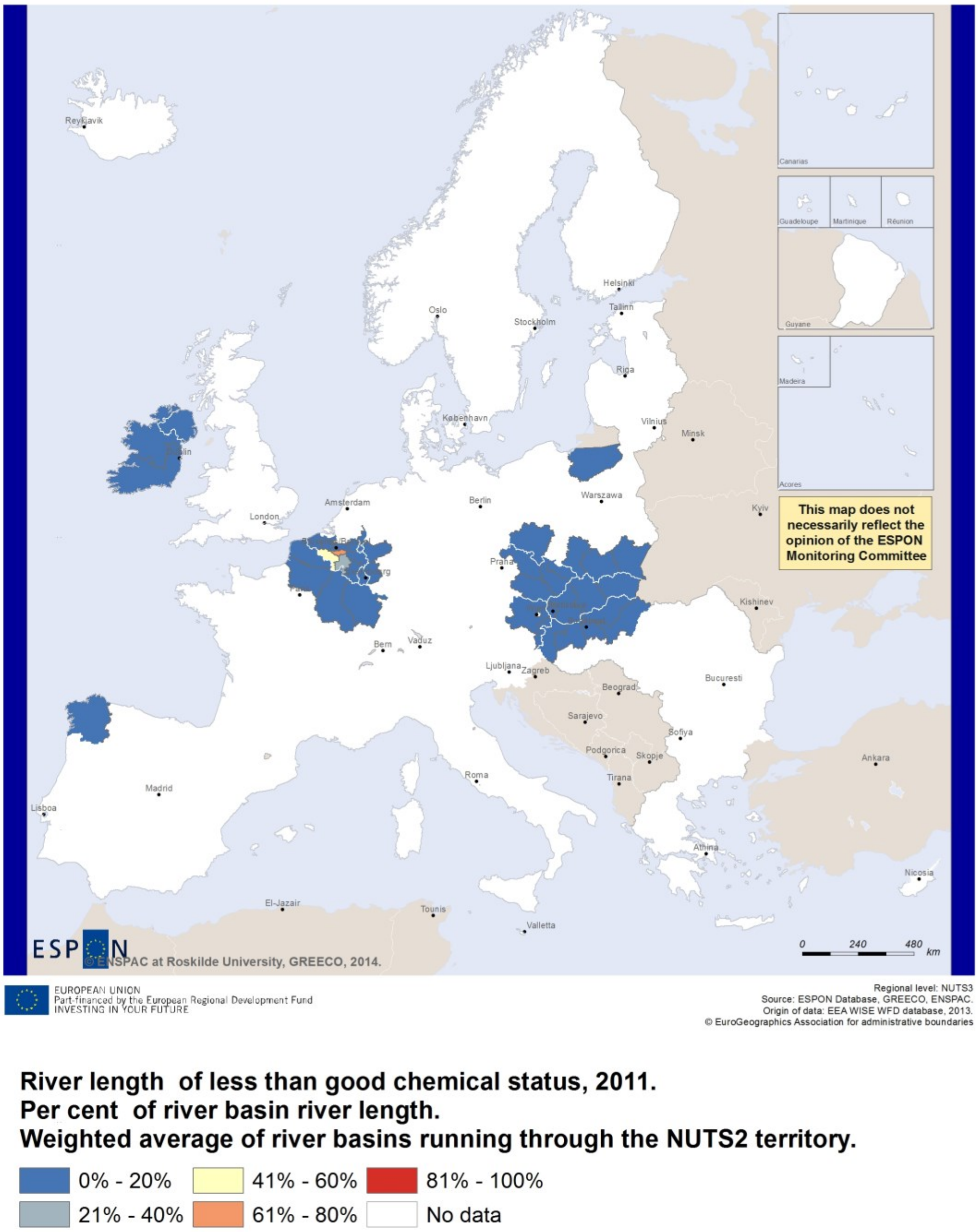


Map 38. Lake area of less than good chemical status by NUTS2 regions, 2011. Per cent.
Source: Author's calculations based on the EEA Waterbase (see Hansen, 2013a).

Map 37 and map 38 shows that a less than good ecological status is more pervasive than a less than good chemical status.



Map 39. River length of less than good ecological status by NUTS2 regions, 2011. Per cent.
Source: Author's calculations based on the EEA Waterbase (see Hansen, 2013a).



Map 40. River length of less than good chemical status by NUTS2 regions, 2011. Per cent.
Source: Author's calculations based on the EEA Waterbase (see Hansen, 2013a).

The data collected for rivers are not sufficient to calculate indicators for most regions as shown in map 40 and map 39. The few data that exists seem to confirm the finding for lakes that measured by area, the ecological status is more severe than the chemical. Measured by degree of environmental risk to humans, it may, of course, be different.

15. Green innovation and employment

The transformations of the econosphere depend on the innovation of green solutions. Innovation processes can be viewed as *product innovation* and *process innovation*. It is important to note that product and process innovation are two sides of the same coin although some firms profit from delivering the products and other firms from using them in processes. Indicators of green innovation are explored below.

Product innovation takes place in firms that produce investment goods for renewable energy, recycling, energy and materials efficient solutions etc. It also takes place in firms that produce green energy, organic food and other green products. Process innovation takes place in firms that use the above investment goods.

Process innovation indicated by the flow of resources and emissions required per employee or per produced value unit are analysed above. Wind and PV energy installations are also analysed from the process perspective. Below the process innovation perspective indicated by the expenditure for environmental protection and the product innovation perspective indicated by patent applications will be explored.

The employment of an economy – regional, national or EU level – depends on the demand relevant to the economy and the market shares of this demand supplied by the firms of the economy[2]. Consequently, the employment impact of the transformation to a green economy depends on the impact on demand and market shares.

Transforming the economy to an economy in ecological balance with its environment involves renewal of the fixed capital stock to a capital stock that is designed to deliver its services without the high throughputs of unsustainable materials and energy flows and without occupying more land than necessary and efficient.

The transformation processes – decarbonisation, dechemicalisation, recycling and ecosystem restoration – replace the inherited solutions by green solutions. The key decisions in this process concerns investment in innovation (including in organisation) and fixed capital.

Investment in green solutions does not *per se* bring about more demand and employment than investment in 20th century type solutions do. Investing in an oil boiler for house heating does not create less employment than investing in a less It is, however, the standard policy of European governments to advance government as well as private investment during recessions and to postpone them when the economy is over-heated. That is, governments can obtain macroeconomic stability by advancing and postponing investments (green or not) as an instrument of a counter-cyclical economic policy.

In addition to this, a high pace of renewal of the econosphere have created long periods of high economic growth in the past. During the three waves of

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[2] Tax financed ("government") demand is included in "demand" and public institutions such as hospitals and schools are included in the concept of "firm".

carbonisation through the 18th-20th centuries (first and second industrial revolution and the transformation to oil) the high rates of investment – not least in carbonised and energy demanding solutions – led to high rates of growth. Against this backdrop a similar high growth period could be the result of the processes of decarbonisation, dechemicalisation, recycling and ecosystem restoration.

Government innovation policies are important for supporting these processes. They include technological infrastructure such as research and education institutions and test facilities (push-measures) and a reliable future demand and supported access to relevant markets (pull-measures). Moreover, they include coordination-measures such as technical standards and competition measures such as public procurement and tendering rules.

Sometimes such measures may even be established with the hope that they will work as an autonomic pole attracting other activities that will attract other activities and so forth.

Against this backdrop, the regional government is an important player in government provision of such framework conditions for innovation, but national and EU level support is also indispensable. Industrial policies are typically centralised in the central or even EU level government bodies to ensure an even playing field for all competitors rather than competing on the support from regional or national government.

Regional and local government still have important roles to play in developing a technological and educational infrastructure that enables the labour force to respond to the demands of a growing industry. Test and demonstration facilities represent another factor of focus in many regions. Moreover, regional physical planning is necessary for making space for accessibility to the industries.

16. Environmental national accounts

16.1. The System of Environmental-Economic Accounts (SEEA)

Another set of statistical material on the process innovation side of the green transformation is provided by the efforts of integrating environmental and energy aspects in national accounting.

The development of this system was initiated in the 1970s based on a concern for environmental and other dimensions of our well-being that are not covered by the conventional System of National Accounts (SNA) statistics such as the GDP.

The early decisions on the development of such statistical frameworks followed recommendations from experts on developing separate physical and monetary accounts (United Nations, 1977).

These early efforts were in 1993 combined in a comprehensive framework, the System of Environmental-Economic Accounts (SEEA) as a response to the Agenda 21 recommendations of the UN Conference on Environment and Development (UNCED). The 2012 revision (United Nations, 2011) will describe the until now most comprehensive framework including definitions, classifications, accounting rules etc. The main components of the SEEA can be grouped as in Table 5.

Table 5. Environmental-economic flows in national accounting.

Physical/monetary accounts	**Ecological-economic category**	**Accounting methods**
Physical accounts: The throughputs linked to economic activities.	Natural resource requirements	Land use statistics
		Energy statistics
		Materials Flow Accounts
	Residuals to sinks	Emission statistics
		Solid waste statistics
Monetary accounts: The value of environmental goods and services (EGS)	Environmental Goods and Services (EGS) supply: Production value	Environmental Protection Activities (CEPA)
		Resource management activities (CREMA)
	EGS demand: Environmental protection expenditure	Investment costs
		Operational costs

The physical accounts are often referred to as satellite accounts. That is, changes in the use of nature as source or sink do not cause feedback effects on the economic accounts. Satellite accounts assumes no causal link from the "satellite" to the economy - the link of causation is one way.

The Classification of Environmental Protection Activities (CEPA) is composed of nine classes whereas the Classification of Resource Management Activities (CReMA) comprises seven classes. Together they form the 16 classes listed in table 6. This list is the result of discussions at a European level and represents a progress in comparison with the OECD/Eurostat 1999 manual.

Table 6. Environmental and resource activities defining the environmental goods and services sector

Classification of Environmental Protection Activities (CEPA):
1: Protection of ambient air and climate
2: Wastewater management
3: Waste management
4: Protection and remediation of soil, groundwater and surface water
5: Noise and vibration abatement
6: Protection of biodiversity and landscape
7: Protection against radiation
8: Research and development
9: Other environmental protection activities.
Classification of Resource Management Activities (CREMA):
10: Management of waters
11: Management of forest resources
11 A: Management of forest areas
11 B: Minimisation of the intake of forest resources
12: Management of wild flora and fauna
13: Management of energy resources
13 A: Production of energy from renewable sources
13 B: Heat/energy saving and management
13 C: Minimisation of the intake of fossil resources as raw material for uses other than energy production
14: Management of minerals
15: Research and development
16: Other natural resource management activities.

The statistics on green products follow the nomenclature-approach by using the CEPA and CREMA lists in table 6 to identify the codes in the Classification of Products by Activity (CPA) that are or could be used for environmental protection activities.

16.2. Monetary environmental accounts

In addition to the above physical accounts the system includes monetary accounts from the demand side as well as the supply side.

From the demand side, the Environmental-Protection-Expenditure-(EPE)-approach aims at measuring investment and operating expenditures that can be related to environmental purposes (Muthmann et al., 2005). The costs that can be associated with environmental purposes in the private as well as in the public sector are surveyed.

From the supply side, the Environmental-Goods-and-Services-(EGS) approach, however, aims at measuring the market turnover of commodities and services that can be characterised as "environmental" (EC, 2009e; Steenblik, 2005). The EGS statistics uses the nomenclature approach to identify the codes in the Classification of Products by Activity (CPA) that are or can be used for environmental protection activities.

This statistical material however only contains data at the national level and even at the national level there are large data gaps.

16.3. European environmental goods and services statistics

EUROSTAT conducted in 2009 a pilot data collection among the national statistical institutes of the relevant European countries and received 11 replies. The total environmental expenditures defrayed for the purpose of environmental protection in the EU amounted to more than 2 per cent of the GDP, cf. table 7.

Table 7. Environmental expenditure in the EU27, 2009. Per cent of GDP*).

Environmental expenditure, of which	**Total**	**Investment**	**Current expenditure**
Industry (except recycling) (CA10 to DN36 and E)	0.42	0.12	0.31
Private and public specialised producers of environmental protection services (DN37 and O90)	0.99	0.21	0.78
General government	0.60	0.15	0.45
Total	2.05	0.51	1.54

*) Provisional value, EUROSTAT estimate

Source: Author's calculations based on Eurostat data (EC, 2012b).

According to the results displayed in table 7 around a fourth of the environmental expenditures are investments whereas three fourths are current expenditures. These proportions are equal in industrial and government sectors alike. Apparently, these figures do not include environmental expenditure in agriculture, forestry and fisheries.

In addition to actual investment and operational expenditures, the data include fees and purchases and receipts from by-products minus subsidies/transfers and revenues. The fees included are only the earmarked fees, that is, fees that are dedicated to the finance of environmental expenditure. The actual use of these funds for financing of environmental expenditure should be covered by the subsidy/transfer accounts. This property makes it difficult to compare countries where environmental expenditure are financed by general taxes from countries where environmental expenditures are financed by ear-marked taxes.

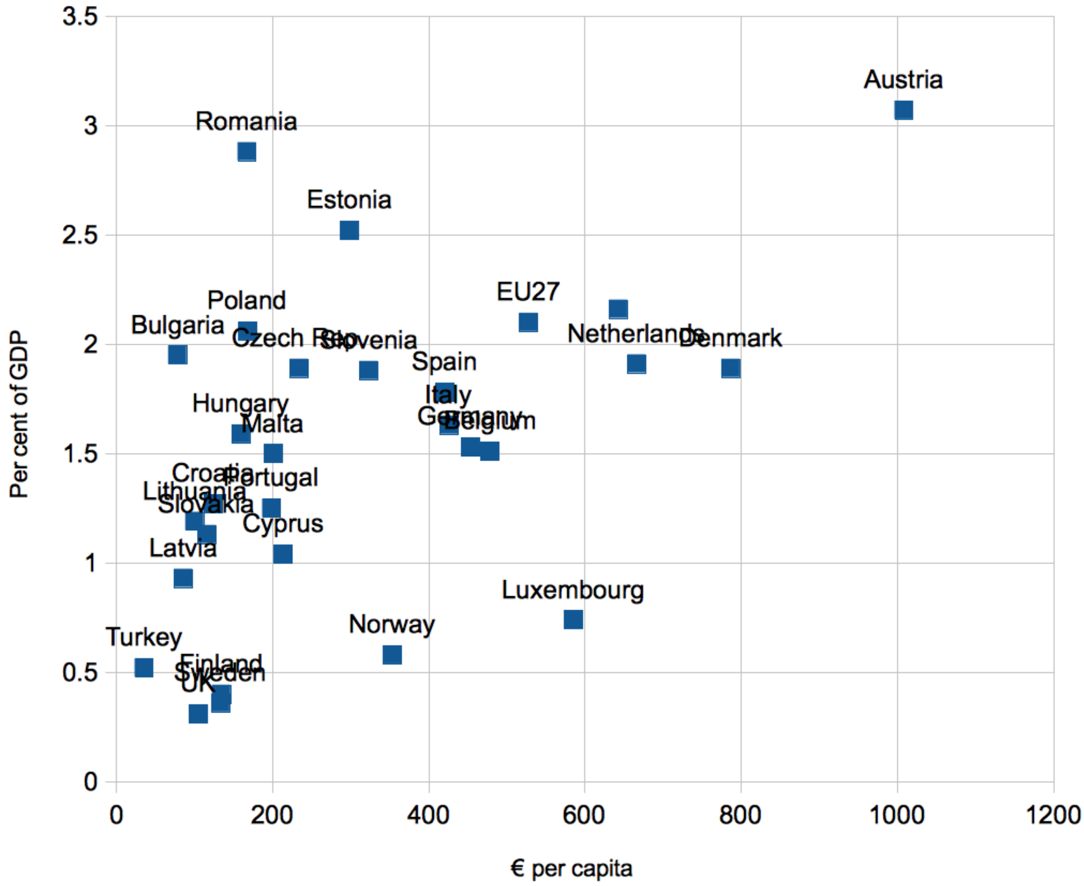


Figure 25. Environmental protection expenditure in the EU in 2007. Per cent of GDP and € per capita.
Source: Author's calculations based on Eurostat data (EC, 2012b).

The ranking of EU member states according to their environmental protection expenditure appears from figure 25. The highest share of environmental protection expenditure in GDP is found in Austria, Romania and Estonia, whereas the lowest shares are found in the UK, Sweden and Finland. The highest absolute environmental protection expenditure per capita was found in Austria, Denmark and the Netherlands, whereas the lowest absolute expenditures were found in Turkey, Bulgaria and Latvia.

The interpretation of expenditure statistics as an indicator of progress towards a greener economy is difficult. A high level of expenditure can be caused by a particularly high level of environmental pressure or a particularly high level in restoring ecosystems to an acceptable state.

Table 8. Employment share of the environmental goods and services sector in total employment. Per cent.

Netherlands	2007	0.1%
Germany	2007	0.3%
France	2007	1.2%
Sweden	2006	1.5%
Belgium	2004	1.5%
Poland	2007	2.2%
Romania	2006	2.5%
Austria	2008	3.5%

Source: Author's calculations based on Eurostat data (EC, 2012b).

The environmental expenditures – inside as well as outside the EU – lead to employment in the environmental goods and services sector. Few of the countries have supplied sufficient data for accounting for the employment in the environmental goods and services sector. The aggregate data available are shown in table 9 calculated as a share of total employment. The countries with the highest share of EGS employment are again Austria, Romania and Poland, whereas the countries with least EGS employment shares are Netherlands, Germany and France.

For some countries, detailed accounts are available. The employment data from France are shown in table 9.

Table 9. Employment in the environmental goods and services sector in France. 2007. Full time equivalent employment.

	Total environmental goods and services sector	An-cillary activi-ties	Market activities				
			Environ-mental specific and con-nected ser-vices	Con-nected goods	Adap-ted goods	End-of-pipe techno-logies	Inte-grated techno-logies
Total environmental protection activities	209,142	29,391	156,634	11,106	19,700	21,501	n/a
Protection of ambient air and climate	10,305	4,483	7,471	522	n/a	2,312	n/a
Wastewater management	75,317	9,062	55,085	5,998	n/a	14,333	n/a
Waste management	70,412	5,127	63,173	2,383	n/a	4,856	n/a
Protection and remediation of soil, groundwater and surface water	27,491	4,222	7,491	n/a	19,700	n/a	n/a
Noise and vibration abatement	12,931	n/a	11,398	1,533	n/a	n/a	n/a
Protection of biodiversity and landscapes	3,774	n/a	3,774	n/a	n/a	n/a	n/a
Protection against radiation	2,619	204	1,949	670	n/a	n/a	n/a
Research and development (R&D) for environmental protection activities	6,293	6,293	6,293	n/a	n/a	n/a	n/a
Total Resource management activities	103,710	n/a	63,244	10,019	23,825	n/a	7,265
Management of waters	6,430	n/a	5,497	1,576	n/a	n/a	n/a
Management of fossil energy resources	97,280	n/a	57,747	8,443	23,825	n/a	7,265
of which production of energy from renewable sources	38,571	n/a	9,462	2,406	22,968	n/a	3,735
of which Heat/Energy saving and management	28,275	n/a	19,144	5,601	n/a	n/a	3,530
resource as raw material	30,434	n/a	29,141	436	857	n/a	n/a

Source: Author's calculations based on Eurostat data (EC, 2012b).

The employment in the environmental goods and services sector as far as environmental protection is concerned is again dominated by employment in management of waste and wastewater. Resource management activities are similarly dominated by production of renewable energy, energy saving and other activities aiming at reducing the use of fossil fuels.

Table 10. Value added in environmental protection activities. Netherlands 2007. Pct. of total.

	Total environmental goods and services sector	Ancillary activities	Market activities: environmental specific and connected services	adapted goods	end-of-pipe technologies
Total Environmental protection activities	**100%**	**9%**	**91%**	**3%**	**n/a**
Protection of ambient air and climate	4%	4%	n/a	n/a	n/a
Wastewater management	19%	2%	16%	n/a	n/a
Waste management	63%	1%	61%	n/a	n/a
Protection and remediation of soil, groundwater and surface water	7%	1%	2%	3%	n/a
Noise and vibration abatement	0%	0%	0%	n/a	n/a
Protection of biodiversity and landscapes	1%	0%	n/a	n/a	n/a
Other environmental protection activities	5%	1%	12%	n/a	n/a
Protection against radiation	0%	n/a	n/a	n/a	n/a
Research and development (R&D) for environmental protection activities	1%	0%	n/a	n/a	n/a
Total Resource management activities	**100%**	**n/a**	**17%**	**27%**	**63%**
Management of waters	1%	n/a	n/a	n/a	n/a
Management of forest resources	0%	n/a	n/a	n/a	n/a
of which management of forest areas	*0%*	*n/a*	*n/a*	*n/a*	*n/a*
Management of wild flora and fauna	n/a	n/a	n/a	n/a	n/a
Management of fossil energy resources	85%	n/a	n/a	15%	63%
of which production of energy from renewable sources	*16%*	*n/a*	*n/a*	*15%*	*n/a*
of which Heat/Energy saving and management	*69%*	*n/a*	*n/a*	*n/a*	*63%*
Management of minerals	12%	n/a	n/a	12%	n/a
Research and development (R&D) for resource management activities	1%	n/a	n/a	n/a	n/a
Other resource management activities	1%	n/a	0%	n/a	n/a

Source: Author's calculations based on Eurostat data (EC, 2012b).

The data from Netherlands in table 10 shows that the economically most important environmental protection activities are waste and waste-water management. The economically most important activities related to resource management are activities directed towards energy savings and production of renewable energy.
It must be emphasised that the above data are collected in pilot exercise and that the national statistical institutes have applied different methods in obtaining them.

16.4. The potentials of the environmental accounts statistics

Most of the environmental protection expenditures and the related employment and value added are spent on waste and wastewater treatment. Increasing expenditures for these purposes are, however, not necessarily indications on progress towards a green economy. If unsustainable waste treatment such as landfilling or incineration of recyclable materials due to larger flows of waste increases, it may result in higher expenditure without transformation to sustainable flows. The economic activities of these sectors are also covered by the general economic statistics.

17. Green product innovation

17.1. Green products in international trade agreements

The process towards assigning the label "environmental" to a set of commodity (and service) code numbers has been driven partly by the need for tools for analysis of an expanding sector of the economy and partly by trade policy.

The WTO decided in 2001 to include negotiations on "the reduction or, as appropriate, elimination of tariff and non-tariff barriers to environmental goods and services" in the Doha agenda.

The ensuing negotiations were complicated by the fact that the WTO members have different trade interests and still, in 2013, a conclusion has not been reached. The national accounts branches of OECD, UNSTAT and EUROSTAT, however, have developed and refined definitions and manuals since 1992.

The issue has also been raised in the negotiations on the Transatlantic Trade and investment Partnership (TTIP). The tariffs in transatlantic trade are low and eliminating them will probably not have radical impact on trade. It may, however, lead to a "green nomenclature" that can be interesting from a statistical point of view.

There is a growing interest in the The growth of industrial branches that are innovative in, e.g., components of renewable energy plants or building insulation materials are much easier to assign to a demand derived from the transformation of the economy to a green economy. Turnover and jobs in the solid waste collection and disposal industry is not as strategically interesting as turnover and jobs in a firm taking an international lead on the technology in question. Statistical analysis of the growth and location of jobs in the latter industries, however, can be very useful for analysing territorial dimensions of the progress towards a green economy.

The environmental industries identified to be used for the purpose of accounting for turnover and employment of the green industries in Europe comprise 27 industrial branches that are fully "environmental" and 300 branches that are partly "environmental". How to estimate the degree of being "environmental" is up to the discretion of the national statistical institutes. This property of the EGS approach assigns the data with a methodological uncertainty that makes comparisons doubtful.

Environmental activities identified in the CPA - and thus the EGSS - does not include important processes in the transformation towards a green economy, e.g., public transport. There is little doubt that a modal shift from individual car transport to public transport will be part of a green economy in the congestion and air pollution prone cities of Europe. Yet such products are not identified as environmental activities. Thus, it is clear that "environmental goods and services" are not identical with "processes towards a green economy".

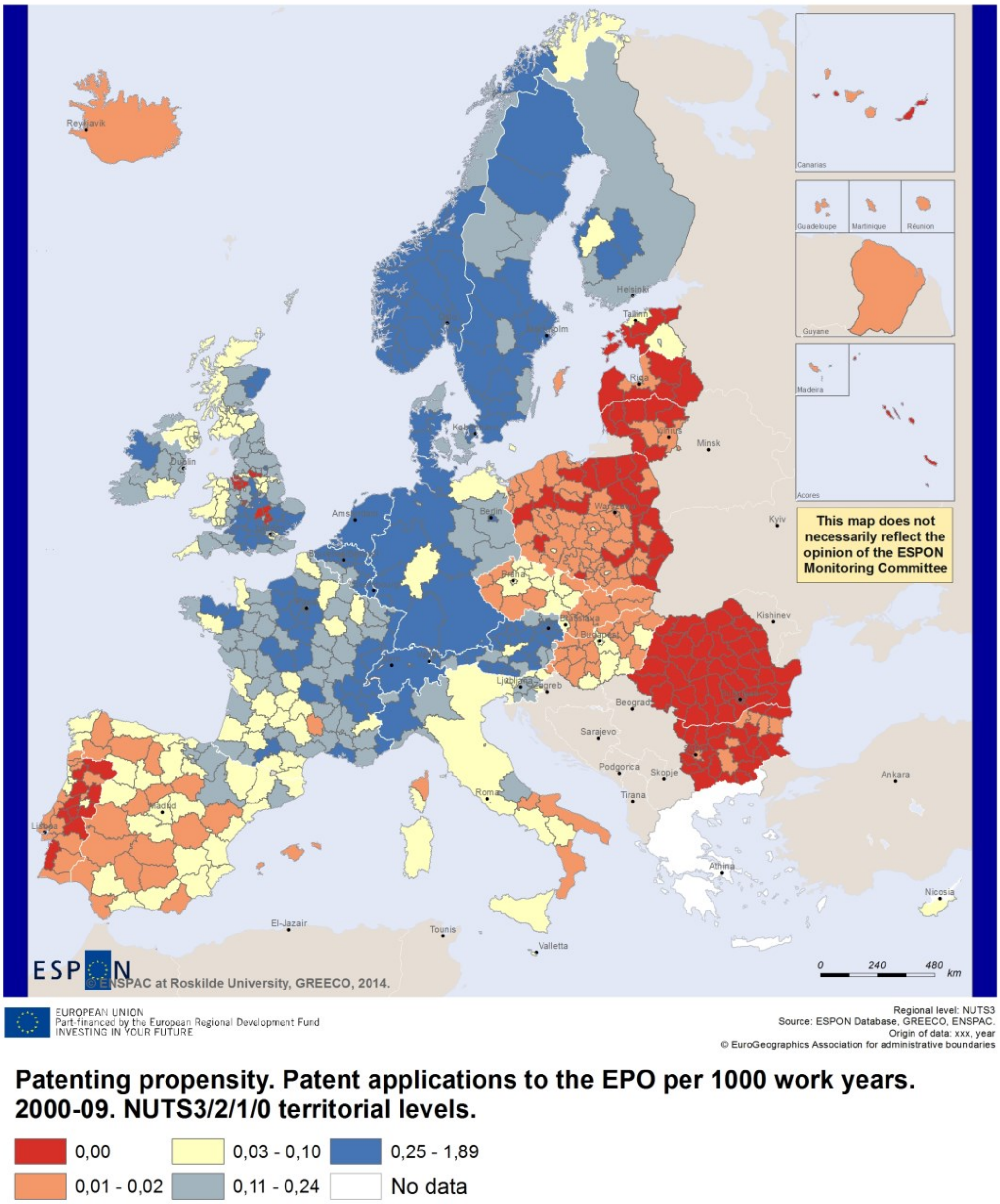
17.2. Green patent applications

Innovation of the green solutions that replace the conventional resource intensive econosphere is difficult to quantify. Patent statistics is a widely used source of data on innovation. The weakness is that they comprise small and large innovations, very valuable and close to valueless patents alike. On the other hand the patent statistics provide consistent data will full coverage over long periods.

The OECD has processed the patent application data from the European Patent Office (EPO) and has succeeded in categorising them according to green and other applications. The data also contain applications filed under the Patent Cooperation Treaty (PCT), but many these never become real patent applications and they are excluded from the analysis.

In the analysis of the regional patterns of the innovation of green solutions, two main problems are of interest. First, the propensity of a regional economy to apply for patents. Second, the share of patent applications that can be classified as green.

The regional patterns of propensity to apply for patents can be measured as the ratio of the number of patent applications filed in a period to the number of work years performed in the period. The period chosen is the 10 years 2000-09 as the detailed NUTS3 statistics otherwise would be too thin.

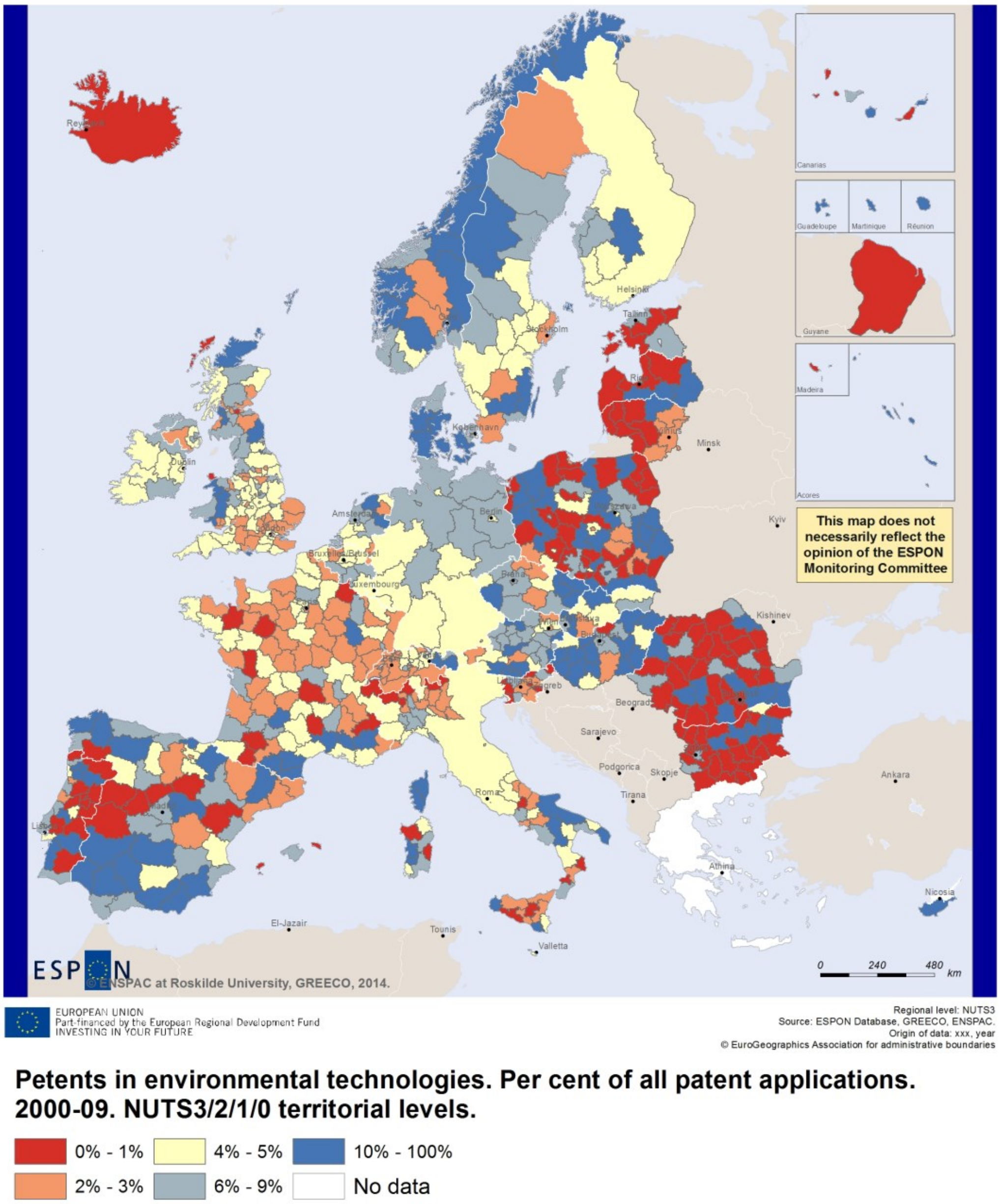


Map 41. Patenting propensity 2000-09. Patent applications per 1000 work years.
Source: Authors calculations based on the GREECO datasets (Hansen, 2013a).

Map 41 reveals a clear divide between the "old" EU15 and the new member-states (NMS10) and also differences between the South of Europe and the North. The innovative capacity of the economy is an indispensible prerequisite for progress in the transformation of the econosphere. Thus, unless the regions and countries with low patenting propensity specialise in green innovation, the map reveals serious disparities in the ability of the regional economies to deliver green solutions.

The OECD has used the International Patent Classification (IPC) to identify the patent applications that concern green technologies. Green technologies can be classified in general environmental management technologies (water, air, waste) and energy efficiency and non-fossil energy technologies. The latter comprises 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 and energy generation from renewable and non-fossil sources.

The regional patterns of specialisation in green innovation appears from map Map 42.



Map 42. Share of green innovations in patent applications to the EPO. 2000-09. Per cent.

One of the interesting patterns in Map 42 is that many of the regions with a relatively low patenting propensity have a high share of innovations in the green technology fields.

18. Is simultaneous progress possible?

18.1. Delinking and rebound effects

The energy consumption – and fossil energy consumption in particular – closely related to economic growth of the developed or industrialised economies in most of the 20th century. In the last two decades of the century, however, the growth of fossil fuel use and energy consumption seems to have been less closely linked to GDP growth. This delinking is interpreted partly as a response to the oil crises in 1973-74 and 1979-80, but not necessarily a response led by government.

The nature of the mechanisms behind linking and delinking has been debated in the scientific literature under the headlines of "rebound effect" and "Environmental Kuznets Curves (EKC)".

The rebound effect is a type of market mechanism based on the fact that more resource efficient solutions in production and consumption do not necessarily lead to less resource use. Firms and households buy technical solutions to provide the services they need for their production and wellbeing. When such solutions become more resource efficient, they can deliver the same or more services with less resource use.

It is also called *Jevons' paradox* referring to the observation of the 19th century economist William Stanley Jevons in his inquiry on the coal question. He noted that the progress in the energy efficiency of steam machines did not lead to lower coal demand, but instead to investment in more and more powerful steam machines (Jevons, 2001, 1965).

When combustion engines in cars, for instance, has become more fuel efficient due to improved injection technology, it enables the car owners to reduce their purchase of petrol for a given amount of transport services. But it also enables car owners to buy larger and heavier cars with larger engines without increasing the petrol bill. Or to increase their consumption of transport services without increasing their petrol expenditures.

In typical cases, where the cost of technological progress are not included in the resource flow itself such responses are even what must be expected as illustrated below.

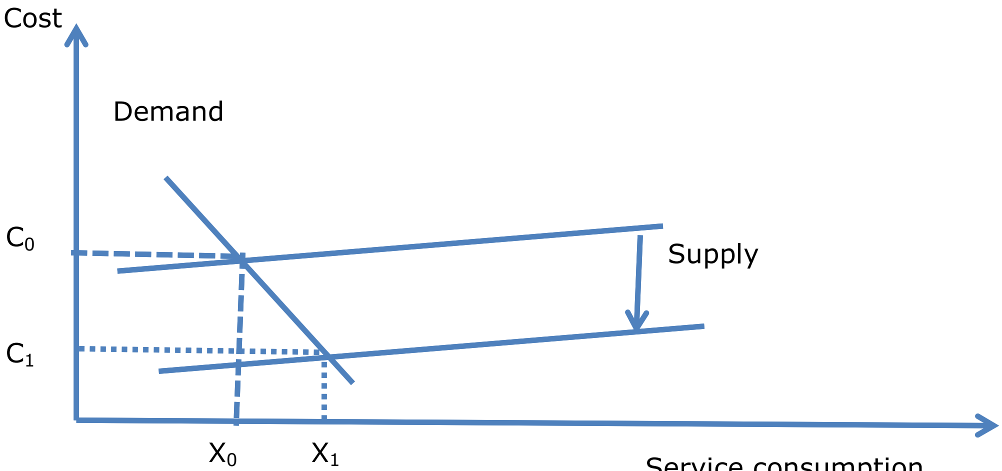


Figure 26. Direct rebound effect.

The figure shows the market for services such as transport (measured vehicle kilometres, passenger kilometres or ton kilometres). For simplicity we assume that there are no maintenance costs depending on the amount of transport. The new technology shifts the fuel cost per kilometre (C_0) downward to C_1 enabling the car fleet to reduce the petrol bill from the area of the C_0X_0 rectangle to the area of the C_1X_0 rectangle. At the lower costs, however, the users of the vehicle fleet want to consume more kilometres or transport heavier loads or more passengers. The result is more kilometres and a fuel bill of C_1X_1. The market strikes back and the final impact on the fuel demand is uncertain.

The literature on rebound effects distinguish between direct and indirect effects (Sorrell and Dimitropoulos, 2008; Sorrell et al., 2009). The effect shown in **¡Error! No se encuentra el origen de la referencia.** is the *direct* rebound ffect.

Indirect rebound effects can occur to the extent demand responses do not convert all of the potential gain to a higher demand for the energy services. If the demand for car transport is saturated – that is, the relevant section of the demand curve is close to vertical -, then the users will spend the budget, they otherwise would have spent on petrol, on other goods that also may entail unsustainable use of sources, sinks or areas.

Another indirect effect can occur though the specific supply chain behind green solutions. When a significant share of the car fleet of an economy consists of electric cars, the energy efficiency of car transport will be dramatically improved because most of the energy in petrol is lost to the surroundings as waste heat from the combustion process. Electric vehicles eliminate this loss because they don't combust anything. However, they do also generate a demand for electricity. If that electricity is supplied by, e.g., coal power plants as it often was in the 20th century, this demand will generate a similar loss of waste heat from coal combustion in the electricity sector. Then, the final impact on the gross inland energy consumption will be uncertain.

The direct rebound effect shown in **¡Error! No se encuentra el origen de la eferencia.** can be neutralised by raising the cost of resource consumption and introduce technical standards for the capital equipment using the new technology. In Europe and Japan, for instance, the fuel taxes were raised significantly in the last decades of the century whereas in the US they were not. This difference is often seen as a major explanation for the different ways the same car technologies were used in Europe and in the United States. In Europe smaller fuel efficient cars became more popular, whereas in the United States heavier cars with more horsepower became more popular in the 1990s.

The market price itself also plays a role here. The oil price increased from the lowest level in the 1990s of about $10 per barrel to around $100 per barrel through the 2000s. This increase, of course, has the same effect of neutralising rebound effects.

In general, price as well as tax increases induce innovation in fuel and other resource efficiency. This is also a clear objective of the above strategy of fuel taxing in Europe and Japan. It is, however, important to note that the price increase of fossil fuels due to the increasing global competition for steadily diminishing reserves is neither sufficient nor timely enough to ensure the transformation to a renewable based and efficient energy econosphere within our carbon budget. First these are two different ecological problems and second the fossil fuel prices tend to fluctuate around an increasing trend rather than follow a straight line upwards.

It must also be noted that as the world leaves fossil fuel combustion as the primary energy source for the economy, the demand will go down pressing the world market prices down and lead to a type of rebound effects also referred to as macroeconomic price effects or carbon leakage.

Two conclusions can be inferred from this.

First, due to the rebound effects, it is difficult to envisage the transformation to a green economy without an intensive use of green taxes, tradable quotas and other economic instruments along with technical standards. Otherwise the market will strike back in the form of direct rebound effects and bring the transformation process to a standstill.

Second, indirect effects along the supply chain call for a government *coordinated transformation* of the energy conversion sector in parallel with the final energy use sectors. Transforming transport and heating from fossil fuels to electricity and piped heat requires a parallel transformation of the energy conversion sector from refineries and fossil fuel power plants to renewable energy based electricity and heat. Policies for transforming the economy cannot accomplish significant decarbonisation goals without such a supply chain perspective.

The Environmental Kuznets Curve (EKC) debate is related to this as it is based on observations of some pollution problems describing an inverse U shaped curve over the history of industrialisation and urbanisation of economies. The observation is similar to an observation made by the economist Simon Kuznets on measures of inequality, thus the name (Kutznets, 1955).

The questions debated are whether the EKC really is a regularity according to standard criteria of statistics and, more generally, how we can understand the variation of environmental pollution in the course of economic development.

The original and subsequent empirical findings have been criticised for not meeting standard statistical criteria. Few curves do, but the general pattern is that the growth of emissions and polluted environment follows the growth of income in an economy. There are, for instance, patterns of development of urban air pollution that are common to European economies, but they can be explained by the uniform use of regulation, urban planning concepts with heavy industry relocated from centre to periphery and that kind of government responses (Stern, 2005, 2004).

The conclusion is that the available evidence does not support that economic development requires high rates of environmental pollution in the beginning and automatically evolves into a greener economy as it matures. This curve is definitely a strategy that a developing country can choose, but it can also choose a sustainable development strategy implementing the green solutions already developed in other countries.

The relative delinking of energy and fossil fuel consumption in the recent decades in European economies is not seen as a has been explained by many factors including the specialisation of the European economies away from energy intensive industries and towards knowledge intensive products. Re-specialisation of the economy does not change the carbon footprint of the economy. The CO_2-emissions caused by European consumption is just emitted from other countries.

Against this backdrop, the following analyses of delinking processes are formed within a view that they do not evolve automatically from the maturity of European economies or from the technological development in general. They require long term government policies with the use of a palette of technical standards, economic incentives, information and innovation supportive frameworks. Regional administrative bodies are usually not entrusted with government authorities that enable them to do make such instruments, but central governments can establish an institutional framework, that is useful for regions in furthering green transformations of the regional economy.

18.2. Economic progress without ecological decline?

The real challenge of the transformation to a green economy is to achieve progress in all three dimensions simultaneously. In the great debate on environment and growth in the 1970s it was a widely distributed premise that it was impossible. It was a choice between growth as in the industrialised economies with massive ecological losses or no growth. The concept of sustainable development and now the green economy is also a statement of its feasibility. Economic prosperity in ecological balance is possible.

In the European economies energy use is closely linked to economic growth and energy is to a high degree carbonised, that is, fossil. This is because the fixed capital stock was and is designed to use fossil flows to produce its services such as transport. This carbonised system of fixed capital and supply chains (the econosphere) effectively links economic growth to growing flows of fossil fuels.

A green economy is characterised by a different design of the econosphere. As the fixed capital stock of oil-, gas, and coal boilers, combustion engines, heat wasting buildings etc are replaced by wind turbines, photovoltaics, heat pumps, electro-motors, near-zero-energy buildings etc, the econosphere reduces the energy required to deliver energy services ("energy delinking", "energy efficiency") and reduce the carbon content of the energy used ("decarbonisation"). A decarbonised and energy efficient econosphere enables even an expanded provision of energy services such as measured by heated square-meters of floor area or vehicle-kilometres without overconsuming natural resources and sinks. Economic growth becomes delinked from growing CO_2-emissions. The EU has agreed on policies in this direction, but the pace of the transformation is debated.

Similar transformations of the sets of material flows and capital equipment designed to handle them take place in, for instance, the flows of nutrients through agriculture and food consumption, the flows of chemicals implying environmental risks and the flows through products to municipal waste. Enclosing substances in circular supply chains, redesigning the dosage and substituting hazardous with safe substances are key green innovations. As the sets of capital equipment and material flows are replaced by green solutions, it is possible to deliver a high level of production without overconsuming natural resources and sinks.

18.3. Ecological progress without economic decline?

The level of production and employment of an economy depends on the demand at relevant markets and its market share of this demand. The latter depends on the competitiveness of the industries. Thus, the question can be split in the demand-impact and the competitiveness-impact of green transformations.

The competitiveness of industries depends on the cost level of inputs, the efficiency with which they are used and the performance of the products relative to those of the competitors.

Progress in resource efficiency in the production and use of energy – decarbonisation and delinking of energy – will be a key condition for employment growth in the rest of the 2010s and the 2020s because of changes in the cost level of inputs.

The natural gas and electricity prices in North America in the next 20 years are expected to be between a third and half the prices paid by European industries (Organisation for Economic Co-operation and Development (OECD), 2013b). Thus, it will be economically optimal for European economies to leave more of the energy intensive production to North American producers and specialise in less energy intensive products. Energy intensive production with that is radically more energy efficient than the North American counterparts can also be competitive. The sooner the European economies close deficit generating energy intensive industries and invest in green solutions, the better the prospects for economic growth. These changes are particularly challenging for the regional economies where these energy intensive industries play a dominating role.

The learning costs associated with driving renewable energy technologies forward by using them have to be shared by all energy users. Industries that carry a disproportionally large share of these costs risk their competitiveness. The cause of this is, however, not the progress in the ecological dimension, but the distribution of costs on industries. It is important to use the full potential of the ETS and other economic instruments for sharing the costs of transformation to a more resource efficient econosphere.

The aggregate demand relevant to an economy consists of consumption and investment expenditure (private and public) and exports. Each of these aggregate demand components can be decomposed in sub-groups of products. In a period with idle production capacity, higher investments in green fixed capital means higher demand and thus higher production and employment.

The transition to a green economy depends critically on the transformation of the econosphere towards more capital and less flows of materials and energy. This implies a structural change in the economy with more investments – and more fixed capital consumption – and less expenditures for materials and energy.

I many cases, the "own" economy may have or can acquire a capacity to provide the investment goods and their installation, but not the flows of materials and energy. This is the often case in European economies. They are, for instance, generally poorly endowed with fossil energy resources, but have or can build capacity to deliver components for renewable energy solutions as well as installation and operation services.

A green new deal was suggested as a response to the cascading crises after 2008. Advancing green investments that would otherwise take place later on would be an effective instrument to restore the investment demand in the economy (Edward B. Barbier, 2009; United Nations Environmental Programme (UNEP), 2009). The EU Commission shared some of these views in its recovery plan from 2008 (EC, 2008a), but did and does not control the government budgets required for realising the green new deal. The fiscal consolidation strategy from 2011 pulled in the opposite direction, but was relaxed in 2013.

The OECD also presented the transformation to a green economy as a more long-term growth strategy in "Towards Green Growth". The strategy addresses the "twin challenges: expanding economic opportunities for a growing global population, and addressing environmental pressures that, if left unaddressed, could undermine our ability to seize these opportunities" (OECD, 2011a).

Thus, in the field of energy, the progress in the ecological dimension has the important impact on economic growth, that it restores employment lost due to energy cost competition by employment driven by investment in the green energy solutions.

In the longer run, it replaces the flows of income set apart for import of fossil fuels with flows to pay returns to investment in renewable energy solutions. This will have negative impact on economic growth in the oil, coal and gas exporting countries, but potentially a positive impact on growth in the oil, coal and gas importing economies.

18.4. Green growth without green economy?

It is, however, possible that the production of green investment goods such as wind-turbines and e-cars in an economy can increase without bringing the economy closer to being a green economy.

All technological innovation is product innovation as well as process innovation at the same time. In a closed economy without foreign trade any product innovation would also be a process innovation in the same economy. However, the European economies interact in globalised markets. The investment products of one economy are invested in another economy – even more so when it comes to regional economies. Successful innovation of green solutions leads to green production in one region and substitution, efficiency or recycling in some region, but not necessarily the producing region. Thus, a region aspiring to become a green economy cannot concentrate on developing green products, but needs also to support the transformation of the econosphere at its territory to comply with the regional ecological budgets. This transformation can even lead to a local market supporting the product innovation of the regional economy.

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