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Abstract

Governments around the world seek for strategies to overcome the reliance on fossil resources and provide solutions for the most challenging contemporary global issues: food shortage, depletion of natural resources, environmental degradation and climate change. A very recent and widely diffused proposition is to transform economic systems into bio-based economies, which are based on new ways of intelligent and efficient use of biological resources and processes. If taken seriously, such endeavour calls for the creation and diffusion of new knowledge as basis for innovation and behavioural change on various levels and therefore often is referred to as knowledge-based bioeconomy. In the current debate, the requirement for innovation is mostly seen in the advance of the biotechnology sector. However, in order to fulfil the requirement of sustainability, which implicitly is connected with the bio-based economy, the transformation towards a bioeconomy requires a fundamental socio-economic transition and must comprise changes in technology as well as in markets, user practices, policy, culture and institutions. To illustrate a nation's capability for this transition, we refer to the concept of national innovation systems in its broad approach. With the help of an indicator-based multivariate analysis we detect similarities and dissimilarities of differ-

ent national systems within the European Union as basis for a transition towards a knowledge-based bioeconomy. The analysis allows to compare the different strategies and to identify bottlenecks as well as success factors and promising approaches in order to design policy instruments to foster this imperative transformation.

1. Introduction

Based on the European Commission's (2012b) understanding of the bioeconomy and the OECD's (1996) definition of a knowledge-based economy combined with considerations taken from Schmid et al. (2012) we define the knowledge-based bioeconomy as:

> *An economy that is based on the production and dissemination of new knowledge about renewable biological resources and their potential to be sustainably converted into food, feed, bio-based products and bioenergy with the aim to overcome the wastefulness of production and consumption in its full dependency on fossil resources*.

Formally, there is a global agreement for the imperativeness of such transformation of our current economic systems explicitly highlighted in policy agendas and strategies for the bioeconomy on global (OECD, 2009), regional (EC, 2012a), national (US Government, 2012; BMELV, 2013) and sub-national (MWK, 2013) levels. However, the responses of the specific national systems to the above mentioned global challenges and their capability to innovate by developing new policy strategies and institutional reforms vary. In their reflection on innovation systems in the learning economy, Lundvall et al. (2002) conjecture that "some national systems may, for historical reasons, be better prepared to cope up with the new context than others" (p. 234). Without doubt this conjecture holds for the transformation towards a knowledge-based bioeconomy as well.

To examine the various national conditions for innovation towards a knowledge-based bioeconomy within the 28 member states of the European Union (EU), we empirically analyse and compare the specific national innovation systems. The section 2 illustrates the theoretical foundation of our analysis. Section 3 describes the analytical approach by specifying the variables (indicators) measured and the methodology deployed. This is followed by the presentation of the resulting clusters and some carefully deduced implications of these results in section 4. The concluding section 5 closes with an outlook and some critical remarks.

2. Theoretical background

The comparison of different political economies has occupied scholars and political actors for many years. Politicians and scientists seek to understand how differences in the organisation of national systems are responsible for certain economic outcomes and why there is more than one model that delivers economic success (Hall & Gingerich, 2009). Different theoretical frameworks have been applied for comparative analyses between nations. One of them is the concept of national innovation systems (NIS) (Lundvall, 1992; Patel & Pavitt, 1994). It emerged during the 1990ies and illustrates the underlying structure and processes of the interdependent evolution of technologies, industries and institutions in an economy. The basic assumption of the broad approach of NIS is that those institutions that directly promote the acquisition and diffusion of new knowledge are embedded in a specific socio-economic system (Lundvall, 1992). Within this system, "political and cultural influences as well as economic policies help to determine the scale, direction and relative success of innovation" (Freeman, 2002; p. 194). The NIS framework has been the basis for many theoretical as well as empirical studies and was subject to refinement and further elaboration in many ways during the last two decades. Such comparative studies have been undergone at the level of national economies (e.g. the comparison of the Danish and the Swedish innovation systems undertaken by Edquist and Lundvall, 1993), sectors (Malerba, 2005) or individual parameters (e.g. the future-orientation of innovation systems of Central and Eastern European countries analysed by Hanusch et al., 2010). Some of these undertakings have not only served for describing dissimilarities between systems, but also to uncover cross-national similarities in the structure and innovation performance (Balzat and Pyka, 2006). By identifying the extent and the areas of such structural similarities within empirically determined groups or clusters of national innovation systems, such research can have an impact on the efficiency of mutual learning processes for policy planning. Just as the differences between path-dependent NIS prohibit a one-fits-all political solution for a common problem, structural similarities in certain fields allow for sectorial policy learning across national borders (Lundvall and Tomlinson, 2002). This holds especially for the countries of the EU which are embraced by common European institutions and share certain cultural characteristics.

The special challenge of examining the national systems regarding their capability to move towards a knowledge-based bioeconomy is emerging from the overarching and yet quite specific nature of the bioeconomy. While a mere analysis of innovativeness within e.g. the biotechnology sector or the agricultural sector would not allow for drawing conclusions on the state of the bioeconomy in a country, the examination of the entire economic system of a nation would fall short of the specific requirements for a development towards the bioeconomy. The connection between the concept of NIS and the bioeconomy has recently been endeavoured by Roberto Eposti (2012). He proposes the creation of an EU-wide knowledge and innovation system for bioeconomy (KISB) with the aim to overcome the sectorial boundaries, improve agricultural innovations, acknowledge the heterogeneity of involved actors and adapt the EU research policy to the emerging structures of the bioeconomy. This proposal entails important challenges of the transition towards the bioeconomy (namely transdisciplinarity, innovativeness, governance and policy convergence) and describes a process still "largely in progress, incomplete and country-specific" (Eposti, 2012, p.253). We will step back and try to assess the grounds for such concept by a comparative analysis of the underlying national systems on a broad empirical basis.

One of the latest adaptations of the NIS approach for innovations towards higher resource productivity and lower environmental impact has been coined by Stamm et al. (2009) and further refined by Altenburg and Pegels (2012): the sustainability-oriented innovation systems (SoIS). They are defined as to comprise the network of those institutions that foster innovations "to reduce environmental impacts and resource intensity to a level commensurate with the earth's carrying capacity" (Altenburg & Pegels, 2012; p. 10, based on Freeman 1987). Many of the implications that comprise such SoIS also apply to our endeavour undertaken in this study and have found their expression in the identification of measured indicators. Another implication of NIS for bioeconomy is expected to be the impact of public attitudes towards the environment, technological progress and the consumers' willingness to change[1] (USDA, 2012).

3. Analytical approach

The factors that shape a national system's capacity to adopt a knowledge-based bio-economy are unknown and highly complex. The varieties of historical, geographical, political and socio-economic conditions across the European countries (i.e. the "given factors") as well as the multitude of potential expressions of a well-functioning knowledge-based bioeconomy (i.e. the "desirables") mark the grounds of our analysis. We can at best try to approximate reality by subjectively defining relevant indicators for measurement. In a theoretical comparative analysis of the evolution of bio-industrial complexes as building block of an emerging bioeconomy in five different OECD countries, Mats Benner and Hans Löfgren (2007) focussed on the degree of state intervention as characteristic difference between countries. Since the scope of our understanding of the knowledge-based bioeconomy goes beyond the emergence of bio-industrial complexes (see our definition above), we extend the frame of analysis by including indicators that describe the "relevant institutions and economic structures affecting the rate and direction of technological change [in the field of bioeconomy (the authors)] in the society" (Edquist & Lundvall, 1993).

3.1 Indicators

Indicators for monitoring innovation towards the bioeconomy have not yet been defined. For the purpose of this study, the indicators proposed by the OECD to monitor green growth (OECD, 2011) as well as the goals defined within the European Bioeconomy Strategy (EC, 2012a and 2012b) and the implications of SoIS (Altenburg & Pegels, 2012) have served as a basis for an eclectic identification of relevant units of measurement.

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[1] "Public attitudes toward and understanding of biobased products are important for the growth of the bioeconomy for at least two reasons. First, the government's commitment and ability to financially support the growth of the bioeconomy relies on a willing public. Second, public attitudes toward and understanding of biobased products will influence the demand for these products, which ultimately will determine the future of the bioeconomy. Measuring public attitude could be used as a leading indicator." (USDA, 2012; p.49)

The following six categories of data for the empirical assessment of the potential to introduce the bioeconomy are covered by our selection:

1. The **environmental and resource productivity** of production and consumption: Indicating an economy's ability to minimize non-renewable resource consumption per unit of output (i.e. decoupling production from non-renewable resources).
2. The base of relevant **scientific, applied and public knowledge**: Indicating a nation's potential to tackle future challenges in the field of the bioeconomy with the help of education on different levels. The European Commission (2012) states that innovation in bioeconomic sectors requires a workforce that has the right mix of skills including experienced workers with new qualifications and professionals for interdisciplinary tasks who understand "the economic and societal impact of their activities, fostering cross-talk between sectors" and across society. At the same time, public understanding about the ethical, environmental, health and safety implications of the bioeconomy affects the acceptance and the economic success of new products and processes (EC, 2009 and USDA, 2012).
3. **Policy responses and bio-economic opportunities**: Indicating a nation's potential and will to innovate and proceed in technological and institutional terms. This becomes evident by assessing activities that foster innovation in general and specifically in environmental science and technology (Global Innovation Index, R&D expenditures, research personnel etc.). In addition, these indicators shall measure political efforts and social acceptance to support a move towards a resource-efficient and environmentally-friendly economy.
4. The **natural asset base**: Indicating an economy's capability to maintain the quantity of their natural assets. This measure takes account of the fact that naturally regrowing resources are not infinite and must be sustainably managed.
5. The environmental dimension of **quality of life**: Indicating the social well-being in terms of access to an intact environment (including clean air, intact nature etc.). The desired increase in utilisation of biological resources must not be achieved at the expense of a loss in environmental quality – an asset hardly measurable in economic terms and to be kept separate from the natural asset base measured quantitatively (indicator group no. 4).

6. General **socio-economic structure**: Indicating the socio-economic context in which the different economies act. Even among the EU member states, structural and socio-economic differences exist that may influence their overall performance of their development towards the bioeconomy, including differing attitudes of the population.

To examine the disposition of the 28 nations to move towards a knowledge-based bioeconomy, indicators for each of the above introduced groups have been identified, amounting to a total of 47 variables (see annex 1).

3.2 Methodology

Cluster analysis is a multivariate statistical technique which is used to group objects (in this case: countries) based on the characteristics they possess (Hair et al., 2010). In the context of this paper, the grouping emerges from the specific national values for each of the indicators identified to characterise the individual NIS with respect to their capacity for a transformation towards a knowledge-based bioeconomy. Maximum homogeneity within a cluster and maximum heterogeneity between the clusters allow for better handling and easier interpretation of the large amount of data. However, the main advantage of such classification is to reveal relationships among the observed innovation systems that are hard to detect on the basis of the individual national data (Hair et al., 2010). At the same time, our analysis indicates the degree and the areas of structural similarities between the countries, which are analysed and can potentially provide guidance to the improvement of mutual learning (Lundvall and Tomlinson, 2002 in Balzat and Pyka, 2006). Clusters are formed on a global data level (i.e. comprising all 47 variables) as well as on each of the six category levels introduced above.

We determine the coherence of a cluster and the diversity between clusters by calculating the distance values between the countries based on their measured characteristics. Of the various methods to calculate such distances, we apply the Euclidian distance. To measure similarity between clusters, we use the average-linkage method, since this procedure measures the averages of clusters and is therefore only to a small extent affected by extreme values. Furthermore, its main aspiration is to produce clusters with small within-group variation rather than seeking to form necessarily equally sized clusters. Because of the differing scales and magnitudes of the variables, original data has been standardised by converting the variables to standard scores (also known as Z-scores) before clustering the countries.

Since the number of clusters is not known beforehand, we apply an agglomerative hierarchical clustering process. The rationale behind this approach is to repetitively merge similar objects in groups and then similar groups together in bigger groups until you reach the maximum amount of heterogeneity between the groups while at the same time remaining at an acceptable level of homogeneity within each group. There is no strict method to determine the optimal number of clusters. One way to achieve a suitable number of clusters is to plot the heterogeneity coefficient against the number of steps taken along the agglomerative clustering process (Eckstein, 2008). The step, within which the rising line of the graph suddenly steepens, i.e. where heterogeneity within the cluster strongly increases, is considered one-step “too far” (see red arrow in fig. 1). The number of recommended clusters c is calculated as:

$$c = n - f$$

where n is the number of cases and f is the order of fusion step along the agglomerative clustering process, which produces the sudden increase in heterogeneity.

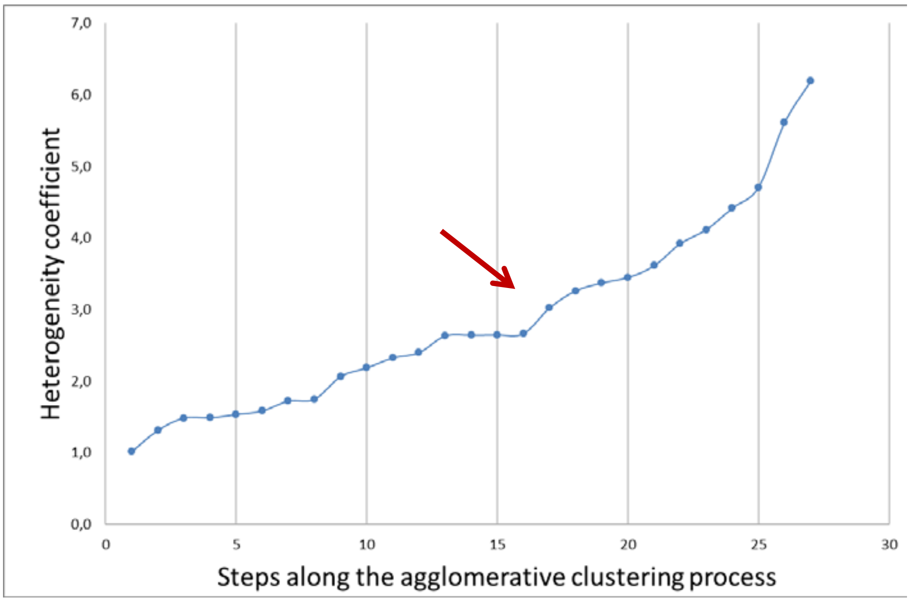

Figure 1 Heterogeneity coefficient plotted against the orders of steps along the agglomerative clustering process. (Note: the case displayed here would call for c = n-f = 28-17=11 clusters).

The clusters emerging from this calculated number of clusters are thus formed by countries that are relatively similar in terms of the measured indicators. We will present the results of the cluster analysis in the following section and carefully interpret them thereafter, not without considering possible biases deriving from the indicators chosen, imperfect data and uncertain causalities.

3.3 Interpretation

Comparison and benchmarking of different national innovation systems is difficult and must be undertaken with care. As suggested by Lundvall and Tomlinson (2000), it should not focus too much on the comparison of quantitative data, but on the efficiency of a system in achieving the goal in question. Only this way, the results of our analysis will be able to stimulate reflection and support learning among the countries examined. Quantitative comparisons will therefore be restricted to structurally similar countries, i.e. within detected clusters and to the illustration of differences between clusters regarding indicator values explicitly describing the efficiency of a system towards a bioeconomy transformation (e.g. CO_2 emission per capita).

How efficient are the European NIS in achieving the goal of a knowledge-based bioeconomy? The paths towards an economy "based on the production and dissemination of new knowledge about renewable biological resources and their potential to be sustainably converted into food, feed, bio-based products and bioenergy with the aim to overcome the wastefulness of production and consumption in its full dependency on fossil resources" (see above) are expected to be manifold and hard to measure and to compare. Well aware of the shortcomings of the underlying measurements, including the restrictions in data access and indicator relevance, statistical imperfection of the method of cluster analysis as well as the general uncertainty and path dependency of strategies towards a less wasteful and sustainable way of production and consumption, we take a chance to offer some interpretations and derive some implications of the results after they have been presented in the following.

4. Results

The clusters emerging from the global analysis and the analyses according to the different categories are presented in different shades on maps (fig. 2 to 8). In addition, the clusters are presented numerically in a table (annex 2).

When calculating the distances of all variables across the European Union in a global analysis, seven groups of countries with similar structures can be identified (fig. 2). The similarities partly show a geographical distribution with a Northern cluster (Sweden and Finland), a North Sea cluster (Denmark, Ireland, Netherlands and United Kingdom), a central cluster (Austria, Belgium, France, Germany and Slovenia) and a South-and-East cluster (Bulgaria, Croatia, Cyprus, Czech Republic, Greece, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia and Spain). The remaining countries form single-country clusters indicating a special profile in the indicators measured (Estonia, Luxembourg and Malta respectively). The North cluster countries Finland and Sweden are wealthy nations with outstanding environmental quality and a very strong focus on education and training (strong knowledge base). They range among the most innovative countries in the EU and rely on a wealth of natural assets. This is accompanied by a high environmental awareness of the population. The countries forming the North Sea cluster are also relatively wealthy, build upon a very strong knowledge base and show high innovative capacity. Their natural assets are scarcer than in the North, but the environmental quality of life is above average. A high proportion of the countries' surface is used agriculturally and forest is scarce. The agricultural sector (including forestry, hunting and fishing) does not contribute much to the total domestic value added. The countries belonging to the central cluster form an average throughout the complete set of variables.

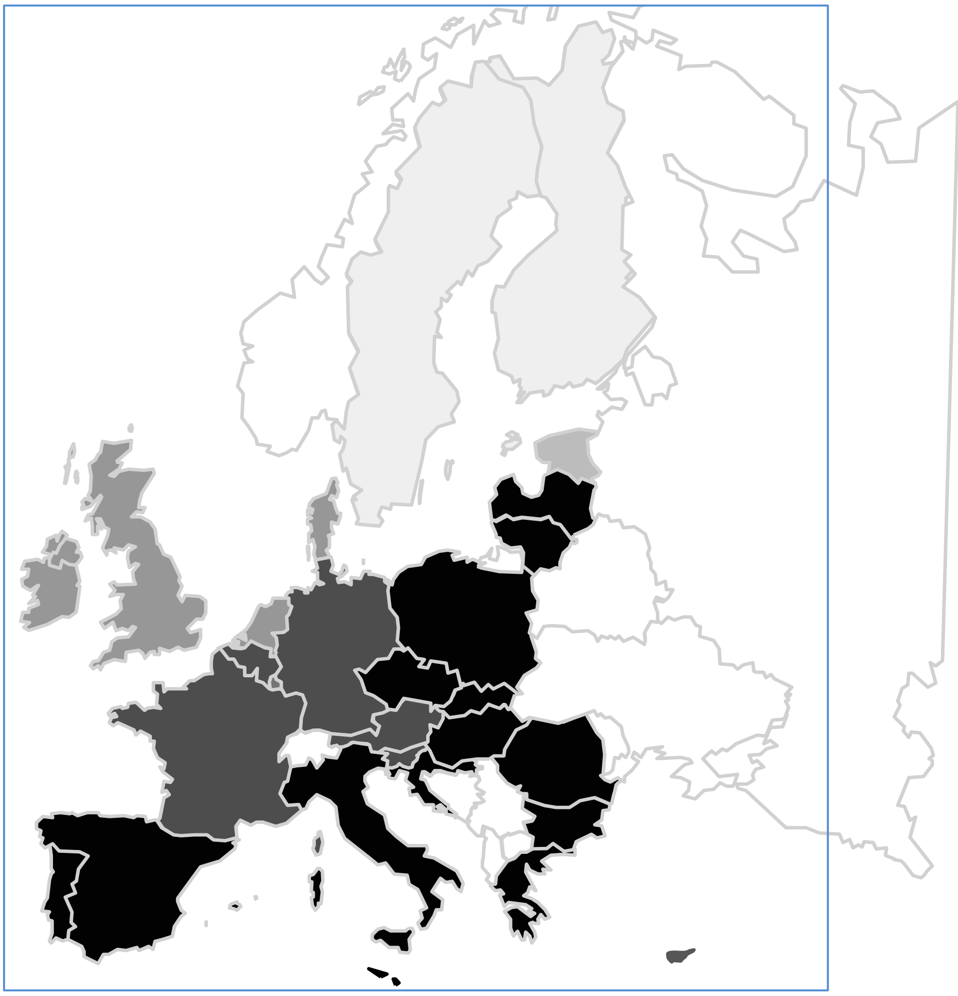

Figure 2 The seven clusters according to the global analysis.

The extensive South-and-East cluster consists of the least wealthy countries of the EU with the largest agricultural sectors, comparably low innovation activity and a small proportion of employment in science and technology. The governments are less dedicated to education and training and the population is not so much concerned about the environment which is partially very healthy and partially heavily polluted. However, because of the relatively low income per head and the correlation to economic activities their overall CO_2 emissions per capita are relatively low.

Estonia's innovation system is very different from the other EU countries' and thus forming its own cluster. As a country with the seventh lowest GDP in the EU and a very carbon intensive economy, it possesses a remarkably strong knowledge base and the highest number of biotechnology patents per million inhabitants. The nation with a strong natural asset base and relatively unpolluted environment is home to an optimistic and environmentally aware population. Luxembourg is probably the most exceptional country in the EU. With the highest GDP and largest proportion of researchers in the active population it emits the most CO_2 per capita. It has a population with a very high environmental awareness and very little trust in science and technology. The third one-country cluster is formed by Malta. The Mediterranean island of medium economic wealth and very limited natural space and resources produces at a highly resource efficient, but carbon intensive scale. The high governmental expenditures on education have not shown effect on the knowledge base of the country. Environmental awareness is very high, pollution partially very strong.

4.1 Environmental and resource productivity

Since the category of environmental and resource productivity obviously encompasses those indicators that are most directly connected to the achievement of the goals formulated in our definition of a knowledge-based bioeconomy, the similarities and dissimilarities of NIS in this category deserve special consideration. Here, again seven clusters emerge, however in a somewhat different distribution than in the global analysis (fig. 3).

While the North cluster of Finland and Sweden remains to form a group, parts of the central cluster (except France and Slovenia) and Cyprus merge with the North Sea cluster. Both clusters produce a relatively high amount of CO_2 emissions. The North cluster is less dependent on fossil energy and excels in the share of renewable energy in gross final energy consumption, whereas the central/ North Sea/ Cyprus cluster proves to be more energy and resource efficient. The largest cluster comprises Bulgaria, Croatia, Czech Republic, France, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia and Spain. These countries produce on average less CO_2 and waste, have a low recycling rate of municipal waste and for all other resource productivity indicators range between the superior North and the less efficient central/ North Sea/ Cyprus clusters.

The two single-country clusters of Estonia and Luxembourg both produce very CO_2 intensively. Luxembourg is very resource productive and also uses its energy relatively efficiently – both indicators where Estonia performs very poorly. On the other hand, Estonia produces the least amount of waste per capita and deploys a high share of renewable energy – both indicators where Luxembourg performs very poorly. The single-country cluster of Malta uses its energy and resources highly efficiently and uses little fertilizer, but ranges lowest in the share of renewable energies. Greece, the last individual cluster, produces relatively resource and energy efficiently, but CO_2 intensively. Here, the highest amount of fertilizer is consumed within the EU.

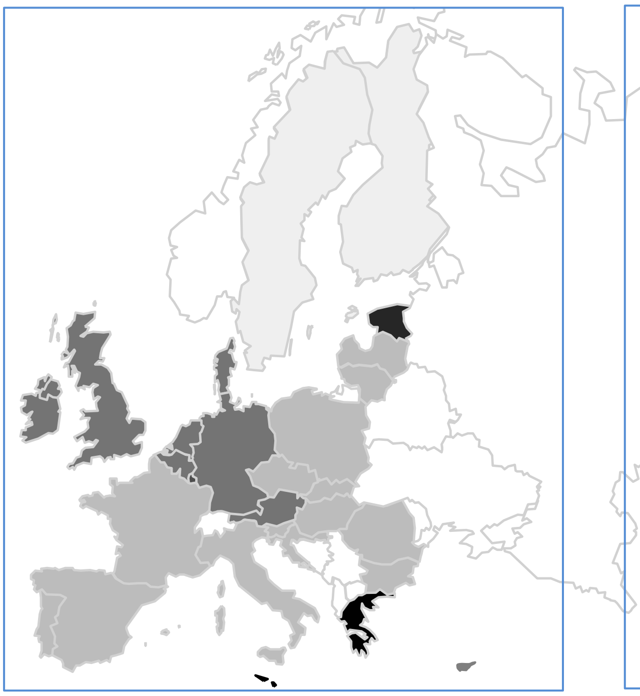

Figure 3 The seven clusters according to environmental and resource productivity indicators.

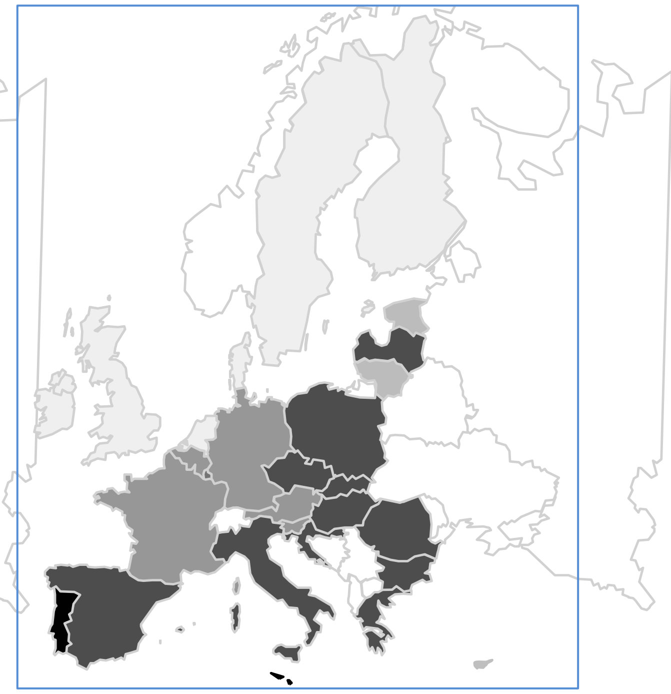

Figure 4 The six clusters according to knowledge base indicators

4.2 Knowledge base

The indicators describing the knowledge base of the countries assessed give a picture of the future capability of the different NIS and show how well nations are prepared to learn and innovate (Balzat and Pyka, 2006). We identified six clusters of relatively similar countries (fig. 4). The North cluster (Sweden and Finland) now merges with the North Sea cluster (Denmark, Ireland, Netherlands and the UK) to the best performing systems in terms of knowledge production and support. Also relatively keen in this respect are the following three clusters, formed by Cyprus, Estonia and Lithuania (high education level of the population and most positive attitudes towards the influence of science and technology on their respective countries), by Austria, Belgium, France, Germany and Slovenia (relatively high proportion of researchers and scientific articles, but only average education level of the population and quite negative attitudes towards the influence of science and technology on their respective countries) and by the single-country cluster of Luxemburg with the highest employment share in science and technology but relatively few scientific publications and very little trust of the population in science and technology. The last two clusters, the South-and-East cluster (comprising the rest of Eastern Europe and Greece, Italy and Spain) and the far-South cluster (Portugal and Malta) do not show a strong knowledge base.

4.3 Policy and bioeconomic opportunities

This category produces eight clusters (fig. 5). The Northern cluster – here excluding Sweden and the United Kingdom – proves to be very innovative in general and shows a strong political commitment to environmental issues and the bioeconomy at the national level: all countries belonging to this cluster (Denmark, Finland, Ireland and Netherlands) have a bioeconomy strategy in place, raise high environmental taxes and rank high in biotechnology patenting; but they are not very fast in signing international environmental agreements and do not invest much in environmental development assistance. The cluster is closely followed by the single-country cluster United Kingdom. Despite of ranking even higher on the innovation index, the UK produces fewer biotechnology patents and invests less in research and development (R&D). Of all clusters, however, the population of the UK shows the most positive attitudes towards genetic engineering. The two European countries with the highest number of biotechnology patents per million inhabitants form the small-country cluster: Estonia and Luxembourg. The green party has a good share among their EU parliament representatives and their population is very critical when it comes to genetic engineering. Most money is spent for R&D in general and for environmental development projects by the cluster made up of France, Germany and Sweden. These three countries also top all other clusters in the share of green party representatives in the EU parliament. Genetic engineering is not valued positively here. The cluster of the two small economies Austria and Belgium spends quite a lot in R&D, does not raise high environmental and energy taxes and is very slow in notifying EU legislation. The East-and-South cluster (Czech Republic, Hungary, Italy, Malta, Portugal, Slovakia and Spain) and the East cluster (Bulgaria, Croatia, Cyprus, Greece, Latvia, Lithuania, Romania and Slovenia) are comparable in most of their political and innovation indicators, but fundamentally different in their attitudes towards genetically modified food and genetic engineering in crops: The population of the East cluster does not support such technology, whereas the East-and-South cluster regards it very positively. Within the category of policy and bioeconomic opportunities, Poland forms a single-country cluster. Compared to the rest of the EU, it does not focus much on innovation and environmental policy, but Polish people show remarkably positive attitudes towards genetic engineering above the EU average.

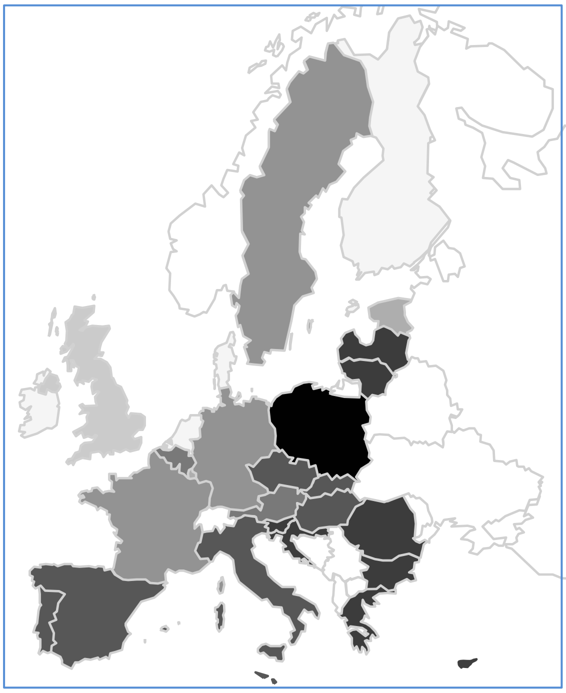

Figure 5 The eight clusters according to policy and bioeconomic opportunities indicators.

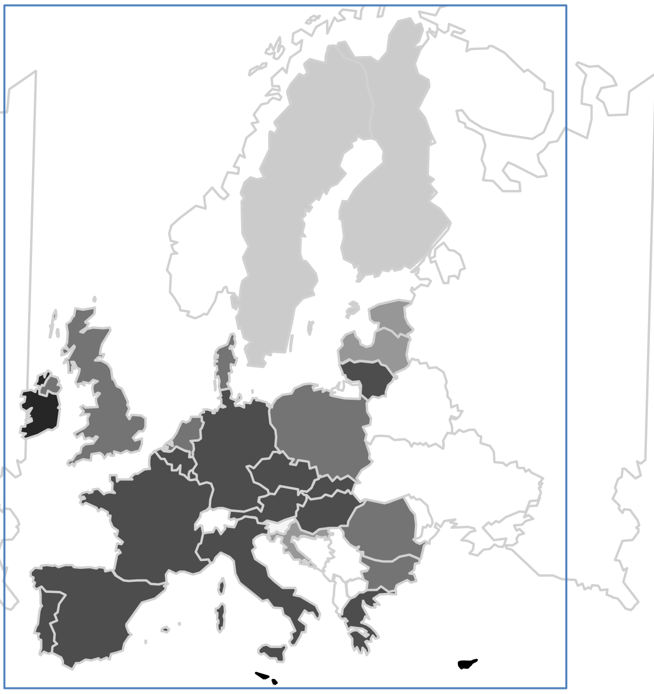

Figure 6 The seven clusters according to natural asset base indicators.

4.4 Natural asset base

When applying the indicators of the natural asset base of the EU countries, seven clusters emerge (fig. 6). The single-country cluster of Slovenia has the highest share of protected area and is very rich in freshwater resources as well as in forest cover and standing volume of wood. The North cluster (Finland and Sweden) has even richer forest resources and slightly larger wealth in non-renewable minerals, but the least amount of agricultural land and very few protected areas. With a lot of forest, little agricultural area and medium mineral resource wealth, the East cluster (Croatia, Estonia and Latvia) shows a similar pattern as the North cluster, only a little less wealthy than the same. The cluster formed by the

North-Southeast-embracing economies (Bulgaria, Denmark, Netherlands, Poland, Romania and the United Kingdom) comprises the countries with the highest share of agricultural land, the largest mineral wealth and an above average share of protected areas. Water resources and forest are scarcer. Not surprisingly, the islands (the single-country cluster of Ireland and the Southern islands cluster of Cyprus and Malta) are not competitive when it comes to natural wealth with Ireland having the slight geographical advantage of abundant water resources and better conditions for agriculture. The large central cluster comprising the remaining countries takes a medium position between the agriculturally strong the North-Southeast-embracing and the weaker islands.

4.5 Environmental quality of life

For the indicators describing the environmental quality of life within the 28 nations, the seven emerging clusters roughly follow a new geographic pattern: in addition to the North-South distribution revealed within the other categories to different degrees, this category shows a West-East distribution (fig. 7). Next to the North cluster with the by far lowest environmental impairment, the population of the Western cluster enjoys a relatively intact environment. The Baltic economies follow in two clusters (Estonia and Latvia forming one cluster, Lithuania the other one) with some pollution and considerably less access to improved drinking water. The single-country clusters Malta and Romania show the least environmental quality of life, while nevertheless Malta shows the least air pollution by particulate matter and provides its population access to sufficient improved drinking water. The large Central-East cluster with the remaining countries shows average pollution values, provides relatively much improved drinking water, but is strongly polluted by particulate matter in the air.

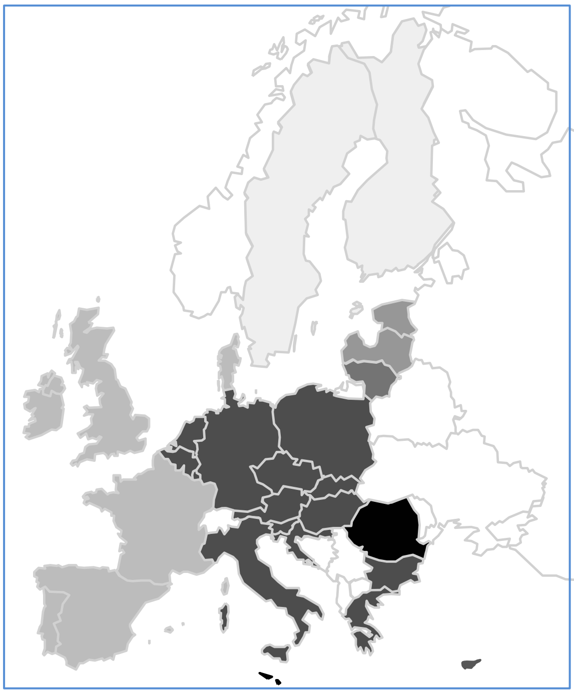

Figure 7 The seven clusters according to environmental quality of life indicators.

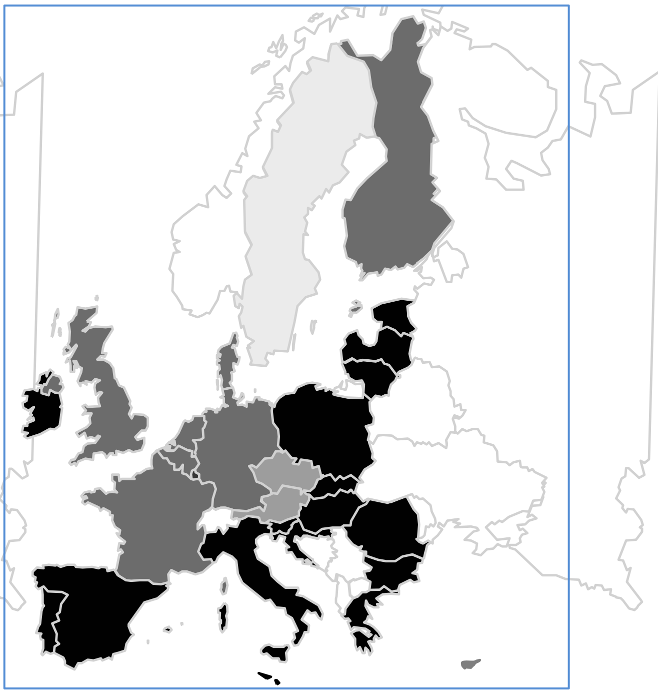

Figure 8 The five clusters according to socio-economic context indicators.

4.6 Socio-economic context

Measuring the socio-economic environments of the national innovation systems leads to the emergence of five clusters (fig. 8). Sweden and Luxembourg are so different from the other EU countries in this respect that the form their own two clusters: Both countries are very wealthy (Luxembourg's GDP is number one in the EU) and home to a mostly urban and environmentally concerned population with a high employment rate (Sweden's employment rate is the highest in the EU), but little trust in the future. The other three clusters are formed by Austria and Czech Republic, by the central countries Belgium, Cyprus, Denmark, Finland, France, Germany, Malta, Netherland and the United Kingdom and by the rest (Southern and Eastern states plus Ireland), respectively. All clusters except the South-and-East+Ireland cluster produce an above average GDP, have high income equality, environmental awareness and employment rate, relatively little contribution of the agricultural sector to the total GDP and comparably negative attitudes towards the future. In all these aspects, the South-and-East+Ireland cluster shows opposite figures (with important exceptions, such as high GDP in Ireland, very negative attitudes towards the future in Greece and top position of Slovenia in income equality).

4.7 Implications of the analyses

According to the global analysis and to the six categories defined above, we find some countries to be part of the same clusters over and over again. Such countries usually share geographical, historical, structural, political and/ or cultural characteristics and thus have the potential to learn from each other more effectively than countries with differing systems.

Finland and Sweden are one such example. They share geographical and structural as well as cultural characteristics. With their high shares of renewable energies, their strong knowledge base and their wealth in natural resources, they are certainly on a good way towards a knowledge-based bioeconomy. However, their potential and will to innovate and to proceed in technological and institutional terms (as measured in category 3) seems to differ slightly: While Finland was among the first countries to publish a bioeconomy strategy, Sweden has just recently (2012) brought forward a strategy, but nevertheless produces more biotechnology patents and spends more on total R&D. Sweden also emits far less CO_2 than Finland and taxes energy highly compared to general environmental taxes. One last remarkable difference is the population's attitudes towards the future: Of all EU citizens, the Finnish have the strongest trust in the future development, whereas the population of the highly innovative and wealthy Sweden rank at the bottom in their attitudes towards the future and also distrusts genetic engineering quite strongly.

Another pair of countries with quite similar patterns is Denmark and the United Kingdom. Both have extensive agricultural land areas that contribute little to the GDP (but consume a lot of artificial fertilizer, especially in the case of the UK). The population of both countries regards environmental protection as very important and attitudes towards genetically modified food are generally positive. In the share of renewable energy in gross final energy consumption, the United Kingdom strongly lags behind, but it produces more resource efficiently and generates less waste per capita than Denmark.

Bulgaria and Poland are two countries found within the same cluster throughout almost all analyses. Those two countries are strongly dependent on their agricultural sectors, produce quite energy and resource intensively, have a relatively low level of education and little focus on research and development. They are wealthy in non-renewable natural resources and have comparably large and productive forests. Poland is very inefficient in the implementation and enforcement of EU legislation and the governments of both countries are failing to implement sufficient environmental policies, e.g. to halt air pollution and guarantee better access to improved drinking water. Unemployment rates are relatively high, but the attitudes towards the future are positive.

This list of comparable bioeconomic innovation systems could easily be extended by discussing similarities between countries as a basis to stimulate reflection and improve the potential to learn from one another (Lundvall and Tomlinson, 2000). The mentioned examples shall suffice in the context of this paper. One last example of particular interest, however, is worth mentioning. Two countries that have great similarities in their historical and geographical background, but have proved to be quite distinctive in the variables measured in the context of our analysis are Estonia and Latvia. The former Soviet states show quite similar systemic patterns in respect to their natural assets, their environmental quality of life and their socio-economic context – three categories most strongly connected to geographical and historical conditions. The dissimilarities become evident when looking at the knowledge base and the policy and bioeconomic opportunities of the two countries. It becomes evident that Estonia has invested much more in those two future-orientated areas than Latvia has: The results are more researchers and human resources in science and technology, a higher level of education among the population and higher expenditures on education (all levels). Estonia has produced the most biotechnology patents per inhabitant, ranks above the EU average on the innovation index and the Estonians have more positive attitudes towards genetic engineering. However, areas of improvement for Estonia remain with regards to its environmental and resource productivity: Across the EU, Estonia's CO_2 emissions are only topped by Luxembourg and it ranks lowest in energy and resource efficiency of production.

For policy planning, the comparisons of innovation systems within the detected clusters can be of use in two respects of different time scales: short-term policy adaptations and long-term policy planning. In the short run, it will surely be beneficial for economies to improve on single areas using benchmark values of individual indicators reached by economies within the same cluster. Sweden, for example, should endeavour to take its population on board of the bioeconomy movement to improve their attitudes towards future technologies and new products by learning how Finland has achieved such positive attitudes. The United Kingdom should be able to create incentives for the industry to put more effort in the development of renewable energies by examining the experiences made by Denmark. In the long run, however, it will not be sufficient for national policies to be geared to structurally similar economies. Long-term policy planning must aim for qualitative and structural change (across current clusters) towards the three focal aims of the knowledge-based bioeconomy: independency from fossil resources, sustainable production and conversion of biological resources and efficient production and dissemination of knowledge. As argued by Kemp et al. (1998), such change will not be achieved by the promotion of certain (new) technologies, but by the inducement of a change towards an integrated system of technologies and social practices. Policy's task is to support such regime-shift by modulating the dynamics of socio-technical change into a desirable direction and thus manage processes instead of defined goals.

5. Conclusions and outlook

The aim of this study is to analyse the varieties of national innovation systems in their capability to undergo the transition towards a knowledge-based bioeconomy. The underlying empirical variables are chosen to illustrate six areas of national innovation systems: the environmental and resource productivity, the knowledge base, policy and bioeconomic opportunities, the natural asset base, the environmental quality of life and the specific socio-economic context within the 28 countries. With the help of a multivariate cluster analysis we are able to detect similarities and dissimilarities among the countries of the EU. The similarities are of particular interest since similar patterns of bioeconomic innovation systems allow for improved comparability of the outcomes and stimulate mutual learning from experience. In the same vein, the divergence of national innovation systems does not imply that the examined countries are situated on different stages on one defined path towards a functioning knowledge-based bioeconomy. The dissimilarities rather take account of the multitude of approaches towards this goal in their dependence on geographical, historical, structural, political and cultural conditions.

Given the large national differences within the EU, the necessity of a supra-national policy planning becomes evident: It might be wise to geographically separate the production of the biomass and research on this production from various fields of refinement or to create centres of specialisation across the EU, thus building a European Innovation System for the knowledge-based bioeconomy. This is not to suggest a political consolidation of the differences between more traditional and agriculturally orientated economies and highly innovative knowledge-based economies, but to take account of the varying natural conditions like climate, space and water availability to name a few that matter when biological production is involved.

Whoever expected a national ranking on bioeconomic performance among the members of the EU from this study has been severely disappointed. The reasons why we cannot provide this are twofold: Firstly, we lack a benchmark. Our definition of the knowledge-based bioeconomy describes an ideal that is not measurable in numbers and figures. Secondly, even if indicators for a well-functioning bioeconomy were defined, they would hardly be assessable empirically due to a lack of data and what is more, they would be subject to continuous change since the nature of innovation is uncertain and path-dependent and benchmarks would have to be adapted based on the innovations introduced during the course of time. This also implies that there are no winners or losers in our comparative analysis, only a variety of innovation systems that are currently more efficient in certain aspects of the bioeconomy and systems that could improve their efficiency by short-term policy learning from other, structurally similar, systems and by a long-term policy-driven adaptation of their innovation systems. Such structural transformations could eventually also serve as models for the transition of less developed economies towards knowledge-based bioeconomies.

To create incentives for the introduction and implementation of political strategies towards knowledge-based bioeconomies and to enable an evaluation of measures and outcomes, it would nevertheless be desirable to develop a theoretical construct of regionally specific indicator values for ideal performance according to which the clusters could be ranked based on their goal realisation level.

6. Annex

6.1 Annex 1

Table 1: Indicators for the analysis of bioeconomic innovation systems.

Category	No	Code	Indicator	Year	Source
1. Environmental and resource productivity	1.1	101	CO2 emissions (metric tons per capita)	2010	World Bank
	1.2	102	CO2 intensity (kg per kg oil equivalent energy use)	2010	World Bank
	1.3	103	Resource productivity (GDP in PPS/ kg consumed material)	2011	Eurostat
	1.4	104	Energy use (kg of oil equivalent) per $1,000 GDP (constant 2005	2011	Eurostat
	1.5	105	Share of renewable energy in gross final energy consumption (%)	2012	Eurostat
	1.6	106	Waste generation (kg/capita)	2012	Eurostat
	1.7	107	Recycling rate of municipal waste	2012	Eurostat
	1.8	108	Artificial fertilizer consumption (kilograms per hectare of arable land)	2010	World Bank
2. Knowledge base	2.1	201	Human Resources in Science and Technology (% of active population)	2012	Eurostat
	2.2	202	Researchers FTE (per million inhabitants)	2011	UNESCO
	2.3	203	Scientific and technical journal articles (per thousand capita)	2009	World Bank
	2.4	204	Population with tertiary education attainment (%)	2013	Eurostat
	2.5	205	Population with at least secondary education attainment (%)	2013	Eurostat
	2.6	206	Total public expenditure on education, all levels (% of GDP)	2010	Eurostat
	2.7	207	Attitudes towards the influence of science and technology on the country (% very positive answers)	2013	GESIS/ Eurobarometer
3. Policy and economic opportunities	3.1	301	Global Innovation Index	2013	GII 2014
	3.2	302	Number of biotechnology patents (per million inhabitants)	2008	Eurostat
	3.3	303	Total R&D expenditures (PPS per inhabitant at constant 2005 prices)	2011	Eurostat
	3.4	304	Official Development assistance dedicated to environmental issues (% of GNI)	2011	OECD
	3.5	305	Environmentally related taxes (% of GDP)	2012	Eurostat
	3.6	306	Implicit tax rate on energy (Euro per tonne of oil equivalent)	2012	Eurostat
	3.7	307	Years since publication of bioeconomy strategy	2013	BioPro BW
	3.8	308	Years of participation in selected International Environmental Agreements	2010	UNStats
	3.9	309	Transposition deficit of EU legislation (% of directives not yet notified)	2012	Eurostat
	3.10	310	New infringement cases in EU legislation (total number)	2012	Eurostat
	3.11	311	Number of representatives of the green party in EU parliament (share of total national seats)	2013	European Parliament
	3.12	312	Attitudes towards genetically modified food (% agreeing that it should be encouraged)	2010	GESIS/ Eurobarometer
	3.13	313	Attitudes towards genetic engineering on crops (% agreeing that it should be encouraged)	2010	GESIS/ Eurobarometer
4. Natural asset base	4.1	401	Renewable internal freshwater resources (m3 per inhabitant)	2011	World Bank
	4.2	402	Forest total growing stock (m3 per inhabitant)	2010	FAO
	4.3	403	Share of agricultural land cover (% of total land area)	2011	FAO
	4.4	404	Share of forest land cover (% of total land area)	2011	FAO
	4.5	405	Terrestrial and marine protected areas (% of total territorial area)	2012	FAO
	4.6	406	Non-renewable natural resources (oil, gas, coal, mineral) rents (% of GDP)	2011	World Bank
5. Environmental quality of life	5.1	501	Population exposed to particulate matter above WHO thresholds 2011 (%)	2011	Environmental Performance Index
	5.2	502	People suffering from pollution, grime or other environmental problems (%)	2011	Eurostat
	5.3	503	People suffering from noise (%)	2011	Eurostat
	5.4	504	Population with access to improved drinking water (%)	2012	Environmental Performance Index
	5.5	505	Forest and other wooded land per capita (ha/inhabitant)	2010	FAO
6. Socio-economic context	6.1	601	GDP per capita in PPS (EU 28=100)	2012	Eurostat
	6.2	602	GINI coefficient of equivalised disposable income (0-100)	2011	Eurostat
	6.3	603	Urban population (%)	2012	World Bank
	6.4	604	Positive attitudes towards future (%)	2012	GESIS/ Eurobarometer
	6.5	605	Attitudes towards importance of environmental protection (%)	2012	GESIS/ Eurobarometer
	6.6	606	Employment rate (% of age 20-64)	2012	Eurostat
	6.7	607	Value added from agricultural sector (% of GDP)	2009	World Bank
	6.8	608	Share of total organic crop area (% of total agricultural area)	2012	Eurostat

6.2 Annex 2

Table 2 Cluster overview (note: the values do not represent weightings and close numbers do not indicate close clusters).

	Global analysis	Environmental andresource productivity	Knowledge base	Policy and bio-economic opportunities	Natural asset base	Environmental quality of life	Socio-economic context
Austria	1	1	1	1	1	1	1
Belgium	1	1	1	1	1	1	2
Bulgaria	2	2	2	2	2	1	3
Croatia	2	2	2	2	3	1	3
Cyprus	2	1	3	2	4	1	2
Czech Republic	2	2	2	3	1	1	1
Denmark	3	1	4	4	2	2	2
Estonia	4	3	3	5	3	3	3
Finland	5	4	4	4	5	4	2
France	1	2	1	6	1	2	2
Germany	1	1	1	6	1	1	2
Greece	2	5	2	2	1	1	3
Hungary	2	2	2	3	1	1	3
Ireland	3	1	4	4	6	2	3
Italy	2	2	2	3	1	1	3
Latvia	2	2	2	2	3	3	3
Lithuania	2	2	3	2	1	5	3
Luxembourg	6	6	5	5	1	1	4
Malta	7	7	6	3	4	6	2
Netherlands	3	1	4	4	2	1	2
Poland	2	2	2	7	2	1	3
Portugal	2	2	6	3	1	2	3
Romania	2	2	2	2	2	7	3
Slovakia	2	2	2	3	1	1	3
Slovenia	1	2	1	2	7	1	3
Spain	2	2	2	3	1	2	3
Sweden	5	4	4	6	5	4	5
United Kingdom	3	1	4	8	2	2	2

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