Agriculture in the context of ecosystem services and

Green Infrastructure

Discussion paper - synthesis

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1. Introduction

Agricultural land is the largest land use in the EU in terms of surface, covering almost 50% of the total land surface, therefore decisions on its management taken in the policy arena affect great part of the continent. This is true especially for the Common Agricultural Policy (CAP), but also for biodiversity and regional policies, for the Europe 2020 Strategy Flagship initiative on a resource-efficient Europe. This document aims at making the point on the role that agricultural areas play in the context of the provision of ecosystem services, and how its contribution to the establishment of the Green Infrastructure for Europe can be identified.

2. Agriculture as provider of ecosystem services

Agro-ecosystems provide provisioning, regulating and cultural services to human society. The provisioning services of agriculture relate to the provision of crops and livestock, which are considered as agricultural production.

There is significant evidence that most intensively managed agricultural systems produce services in an unsustainable way, in which the natural capital resources are progressively depleted at a high rate and not restored.

Crops and livestock are listed among the benefits derived by men from nature (CICES classification version 4). The main difference between these and the other provisioning services (i.e. fish, water, timber) is that they require a deep modification of the natural environment in order to being produced (especially crops). While fish, water and timber would be available without human intervention, crops and livestock would not. Regulation and maintenance services as well can be maximized by human intervention, but at least to some extent are available also without human labour.

Therefore human intervention is a crucial factor and is also the main difference between crops and livestock production and the rest of regulating and provisioning ecosystem services. Crops and livestock as ecosystem service are dealt with in terms of production (UK NEA, 2011, Costanza et al., 2007), but since they are provided by a necessary alteration of the natural state, that can be very deep, an approach is proposed to quantify not only the agricultural output, but the input as well necessary to obtain such output. At this stage the analysis focuses on the ecosystems in the strict sense, therefore on crops and grassland, and does not include "derived" products such as cattle, milk, butter etc.

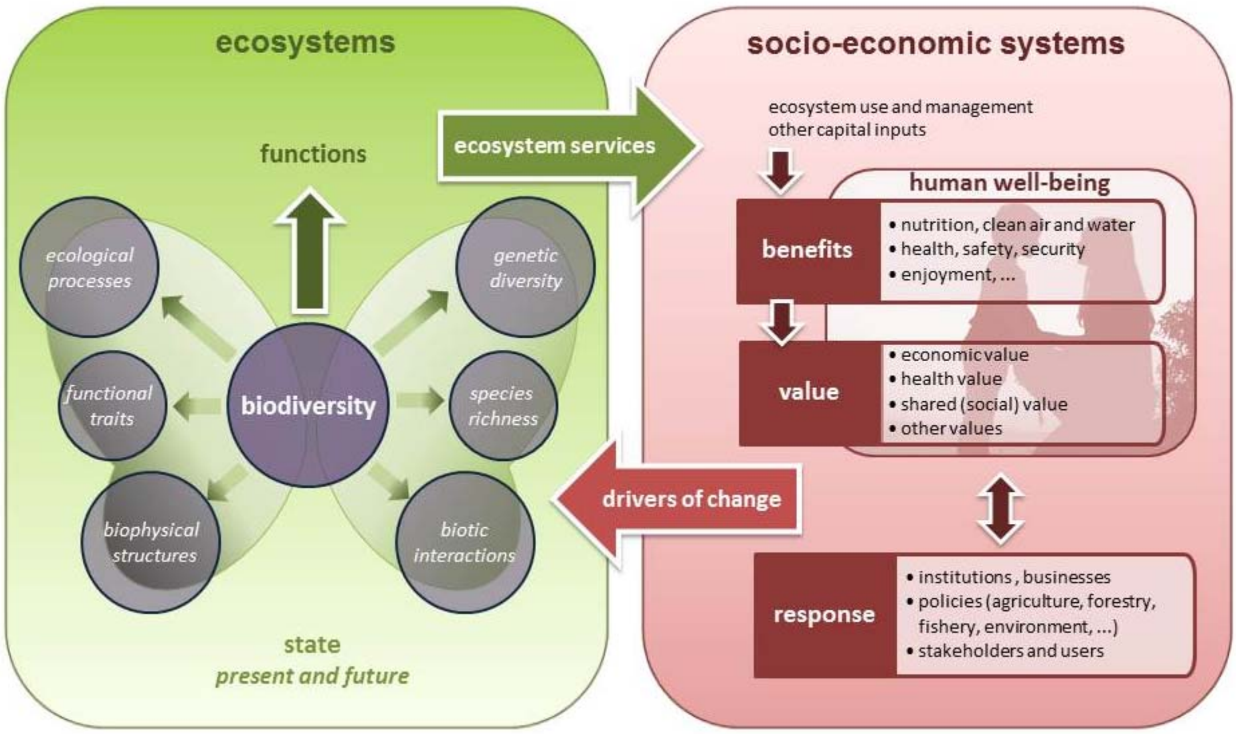


Figure 1: Conceptual framework for EU wide ecosystem assessments (WG MAES working Paper version 9.6)

From this perspective, when referring to the conceptual frame proposed by WG MAES (Figure 1), which links socio-economic systems with ecosystems via the flow of ecosystem services, and through the drivers of change that affect ecosystems either as consequence of using the services or as indirect impacts due to human activities in general, it should be underlined that in the case of agricultural activities the socio-economic system is not only a driver of chance but also the main driver for the ecosystem service provision per se. In this case, also, the ecosystem function and service coincide, since agriculture is by default an activity performed when there is a (human) need.

2.1.1 The Energy Return on Investment as a possible measure to describe provisioning services provided by agro-ecosystems

Ecosystem services can be viewed as the flows of energy from ecological systems to human or social-economic systems (H.T. Odum, 1984 a.o.). In the agro-ecosystems there may be energy embodied in biomass (e.g. food, fibre) or in water streams; i.e. provisioning services), in the work by ecosystems influencing environmental conditions (e.g. climate, water levels; i.e. regulating services), or in generating information (e.g. the diversity of genes and species in ecosystems and landscapes; i.e. cultural services).

The energy flows involved in (food/feed) biomass production from agro-ecosystems are very complex as it is shown in Figure 2.

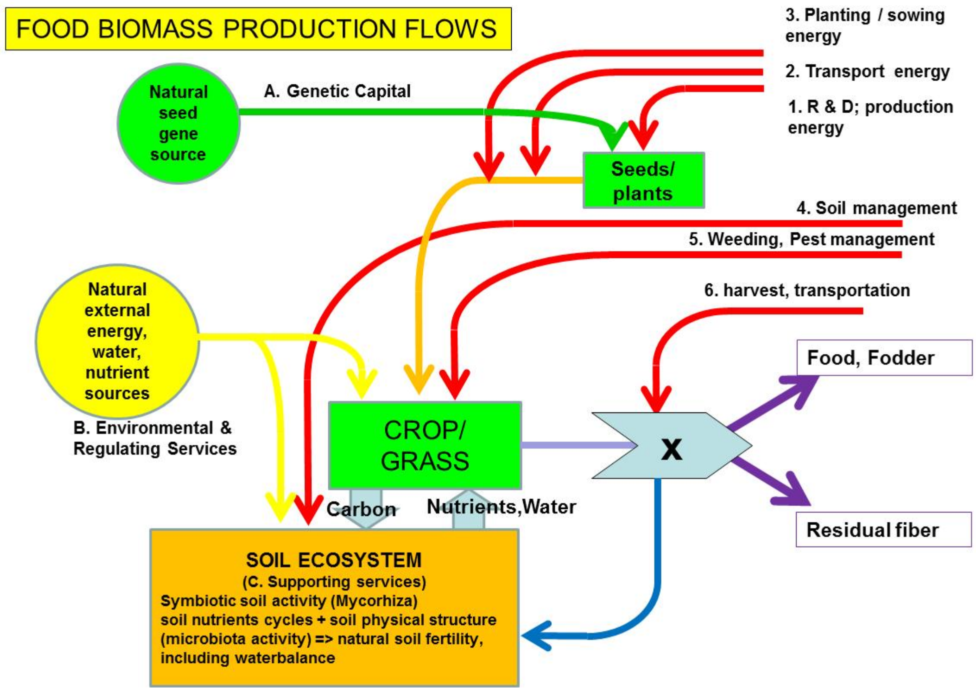


Figure 2: The energy flows involved in food / feed biomass production. Solid lines indicate energy flows. Red lines = human activity; yellow lines = environmental / ecosystem processes; other colours: energy flows resulting from interaction of (natural) ecosystem & human flows.

When analysing the energy flow from the perspective of ecosystem services, it was decided to limit the analysis to the exchange of energy through the soil, since the soil is the natural resource for plant production, and to exclude all the indirect input (see production) and output processes (e.g. animal production). In practice, the analysis focuses on that part of the energy flow that man can control through the Energy Return on Investment (EROI) approach (Schramski et al., 2011; Murdoch et al., 2007), therefore the energy input will include labour, machinery, fertilisers (including nitrogen from manure), seeds and irrigation, the output the yields and the remaining biomass after harvest used for fibre or fuel.

It is clear then, that not all the energy flows shown in Figure 2 are considered. Figure 3 shows the major energy flows from agro-ecosystems to society in the provisioning ecosystem services, which are the objective of this study.

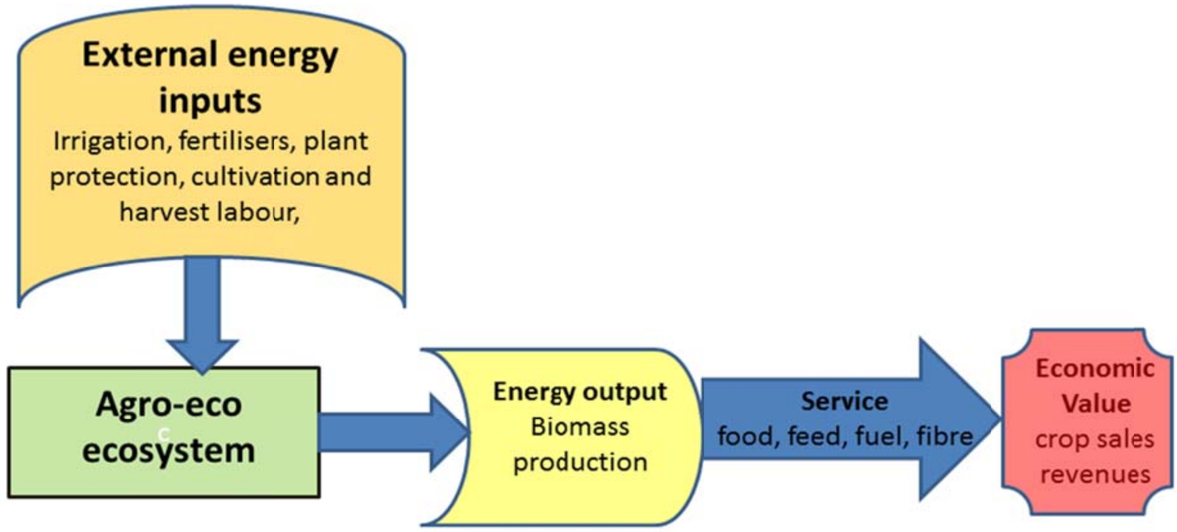


Figure 3: Energy flows in provisioning services from agriculture

The EROI approach can easily be applied to provisioning ecosystem services in a broad sense, as biomass produced for energy consumption is directly captured by humans building on the support of biological processes (photosynthesis and other). The harvest of the amount of biomass planned, can only be ensured by manipulation of the ecosystem, e.g. in the selection of particular (crop) species, minimisation of nutrient shortages, optimisation of water availability etc. All of these activities can be expressed in energy units as well as the output gained in biomass.

The proposed approach focuses on the assessment of the degree of human intervention in the agro-ecosystem for provisioning services compared to natural ecosystems. Therefore it does not quantify the also required (natural) external energy inputs, (e.g. sun, rain and wind), nor internal inputs within the ecosystem, (e.g. nutrient and water flows, microbial activity in root systems). In addition to the desired types of biomass (for food, feed, fibre, fuels), production processes also deliver plant components that are not always used in consumptive processes, but nonetheless contain energy that goes somewhere and has to be included in an overall energy balance system. It has also to be kept in mind that the caloric (Joule) content of the agricultural product is not reflecting the whole level of embodied energy within the product, as heat energy has been lost in processing activities in relation to the output energy.

Another advantage of using an energy balance is that it enables a quantified assessment of many different human influenced and natural ecosystems which are all characterised by flows of energy. In addition to the flows of energy and the net energy gains it will also be assessed to which extent the net energy production of an agricultural system is valued in terms of economic value.

In brief, the approach needs to take into consideration that:

- agro-ecosystems result from strongly modified habitats;
- the focus is on the direct use of the soil, as natural resource for plant production, and therefore excludes the indirect animal production;
- it excludes as well crop production in greenhouses, which have a small share of the UAA (Utilised Agricultural Area), use mainly artificial soil and have a very negative net energy balance.

- the way to express the provisioning ecosystem services provided by agriculture should be as net energy balance, and therefore the energy input and output in the production agro-ecosystem need to be expressed in energy and biomass. The input includes labour, machinery, fertilisers, seeds and irrigation as far as data are available. The output is measured as the biomass related to the different crops yields;
- the comparison baseline against which actual food provision can be compared, takes into account the full productive capacity of the soil including food and feed, but also additional biomass production not necessarily being used by humans at this moment, such as biomass for fibre and fuel production, as far as data are available;
- the approach targets the EU in terms of its practical implementation, but conceptually should have a more general applicability.

The EROI is calculated using the CAPRI (http://www.capri-model.org/) energy balance model, and the provisioning service is analysed through two indicators:

1) MJout/MJin per ha.

2) Net MJ per output per ha=MJout-MJin

The two units are calculated per crop type and per crop group type.

The calculation of the EROI is made at the scale of regions (CAPRI regions) and at a more detailed scale (CAPRI Homogenous Spatial Mapping Units (HSMUs)).

The soil energy balance calculations were made per crop and were then aggregated to total area averages and total crop group averages to make them presentable and analyse the overall patterns and trends. Overall, we see that there are very large differences in input and output levels between crops, but also within crop groups between EU regions.

In Figure 4 an overview is given of the average per hectare input per category. Overall it becomes clear that input levels are generally lower in EU-10 then in EU-15 countries. This particularly applies to Romania, Bulgaria, Estonia, Lithuania and Latvia. In the EU-15 group the UK jumps out as a country with a relatively low input level per hectare.

High average input levels per hectare in the EU-15 are particularly found in the Netherlands and Belgium, Italy, Spain and Germany. In the EU-10 Slovenia jumps out with a very high input per hectare.

The categories taking the largest part of the input are mostly energy for cultivation and fertilisers. In the Mediterranean countries irrigation also adds significantly to the input side.

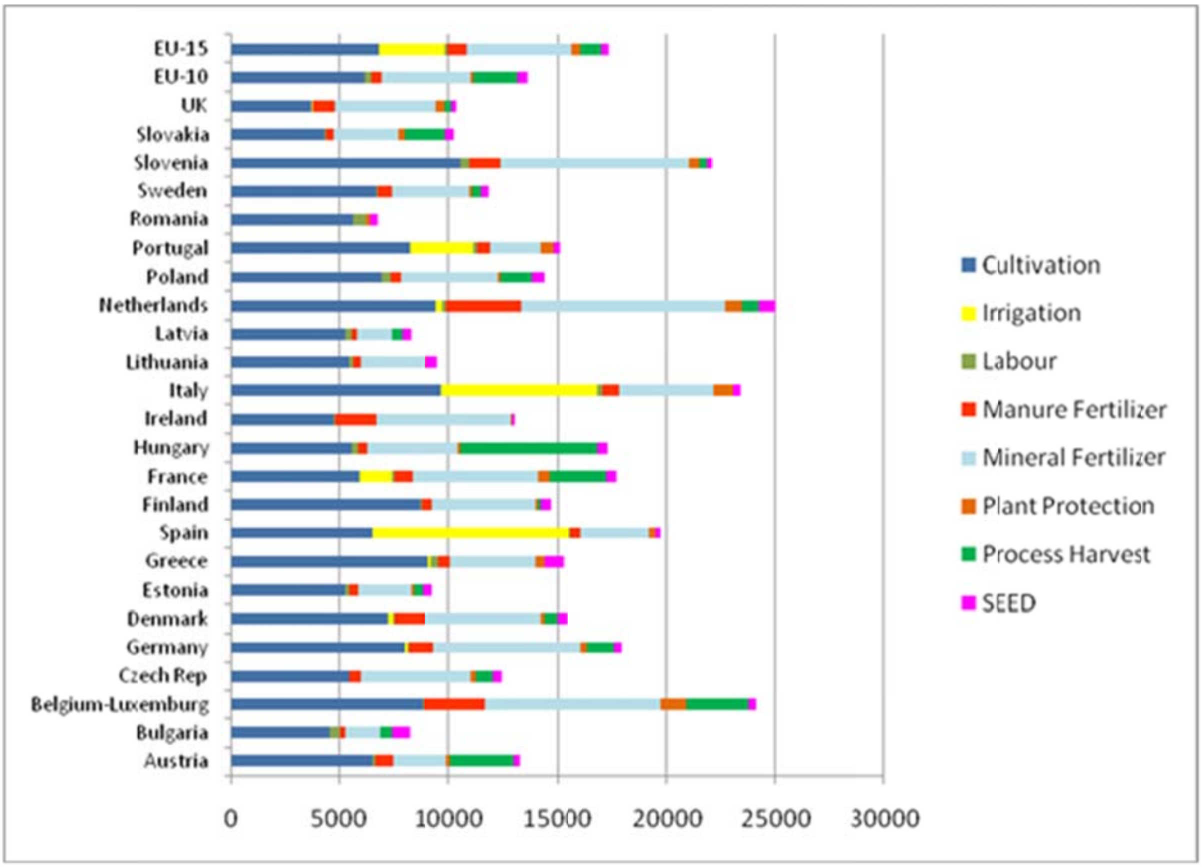


Figure 4: Composition of input (MJ/ha) for all crops

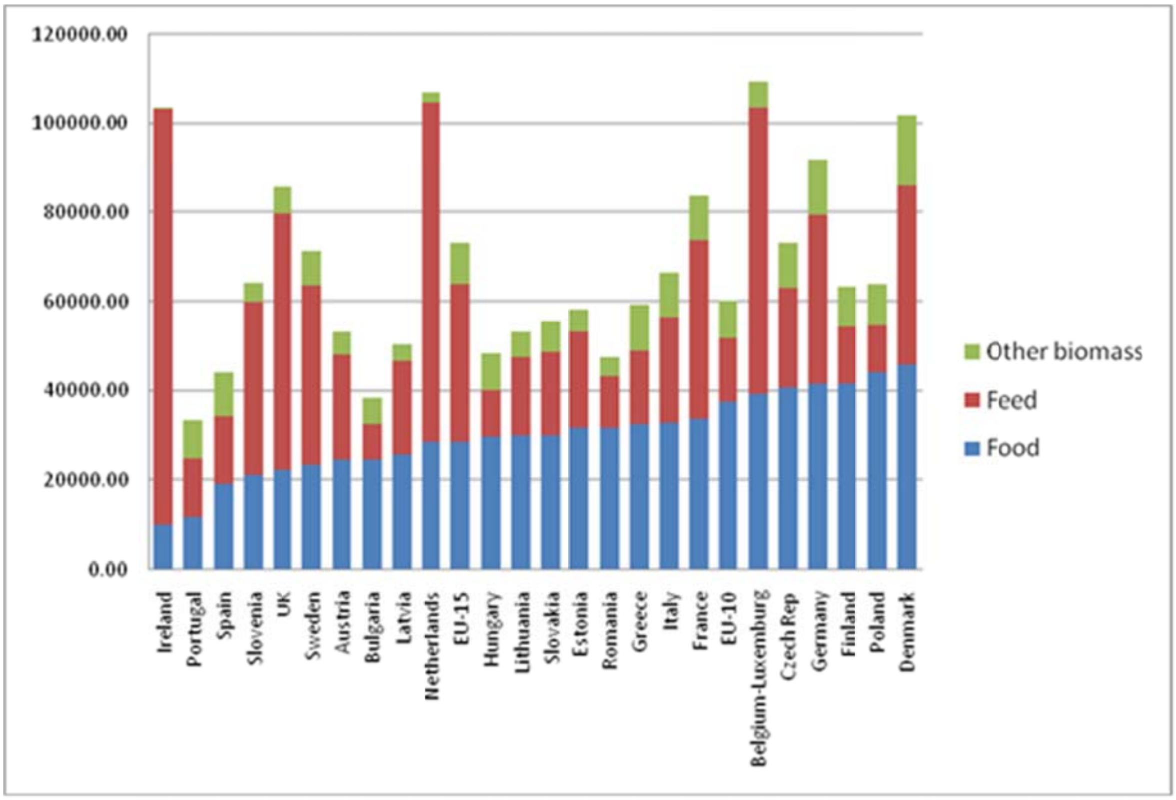


Figure 5: Average output (MJ/ha) for all crops in terms of food, feed and other biomass

On the output side a distinction was made between output in food, feed and other biomass. The latter category includes biomass such as straw and cuttings not necessarily harvested from the field at this moment. The results in Figure 5 show that highest output levels in food are found in countries like Denmark, Poland, Finland, Germany, Czech Republic and Belgium. The EU-10 who have generally a lower input level, have a higher output level than the EU-15, at last when looking at the food output. The comparison of the input and the output already shows that high input levels often go together with high output levels and vice versa especially in relation to total biomass output, but not necessarily in relation to food output. This is also confirmed when looking at the net energy balance in Figure 6.

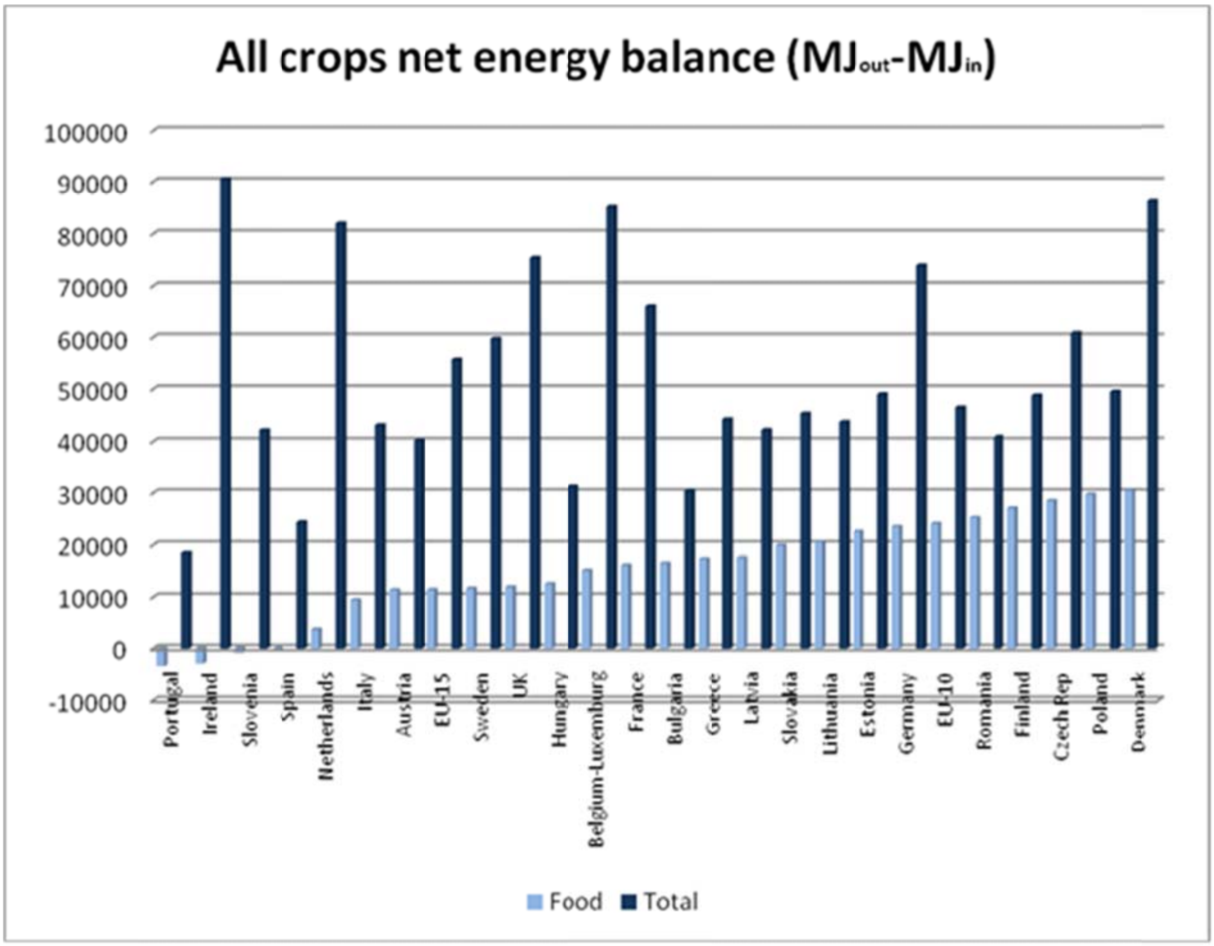


Figure 6: Average net energy balance per hectare (MJ/ha) for all crops

The highest net output in terms of total biomass is reached in Ireland, Belgium, Denmark, Netherlands, UK and Germany which were countries showing both relatively high and low input levels. Explanatory factors should clearly be sought in a combination of factors, but location in the Atlantic zone having a temperate climate could be one of them. The other explanatory factors are of course the land use composition and the farming management practices.

Land use patterns in the EU countries differ significantly. Countries with a very high share in the arable land category are Denmark, Finland, Hungary, Czech Republic and Sweden. These high arable land shares often go together with high to very high output levels, particularly in relation to food output. The countries with the highest grassland area shares, e.g. Ireland, UK, Slovenia and Netherlands, are also among the countries with the higher output levels particularly in total biomass. Countries with a more mixed land use pattern, like is seen in most southern EU countries, generally show a lower output level, particularly when it goes together with high fallow land areas shares, like is the case for Portugal, Spain and Bulgaria.

Although part of the energy ratios per country can be explained from the composition of the agricultural land use, differences in Europe's environmental zones are also an important driver of the EROI. For all crops the energy for fertilisers and cultivation on average make up the largest part of the input, but the largest variation in input levels per region is due to irrigation. Average input levels are lower in the Alpine, Boreal-Nemoral and Continental-Pannonian zones. In the Atlantic-Lusitanian zone and the Mediterranean the input levels are higher. In the Atlantic this is caused by an overall high input level as compared to other zones, but in the Mediterranean the extreme are larger with very low and very high input levels occurring at the same time. An important factor of influence on the final EROI in the latter zone is irrigation which can be extremely high in certain regions for certain crops. In the Atlantic high input levels are particularly caused by high level of energy input in cultivation and through mineral fertiliser application.

For cereals the mineral inputs generally make up the largest share of the input, followed by energy input for harvesting, but the largest regional variation is found in the irrigation level and the harvesting. The permanent crops show by far the highest average inputs and also the largest regional variation in input levels. This variation is caused by large variation in both cultivation and irrigation inputs. For grassland the variation is also enormous, with irrigation and fertiliser inputs as most regionally diverse.

Overall one can conclude that variations in input levels are very wide within crops, both for the whole EU as within environmental zones particularly in relation to irrigation, process harvesting and mineral fertiliser.

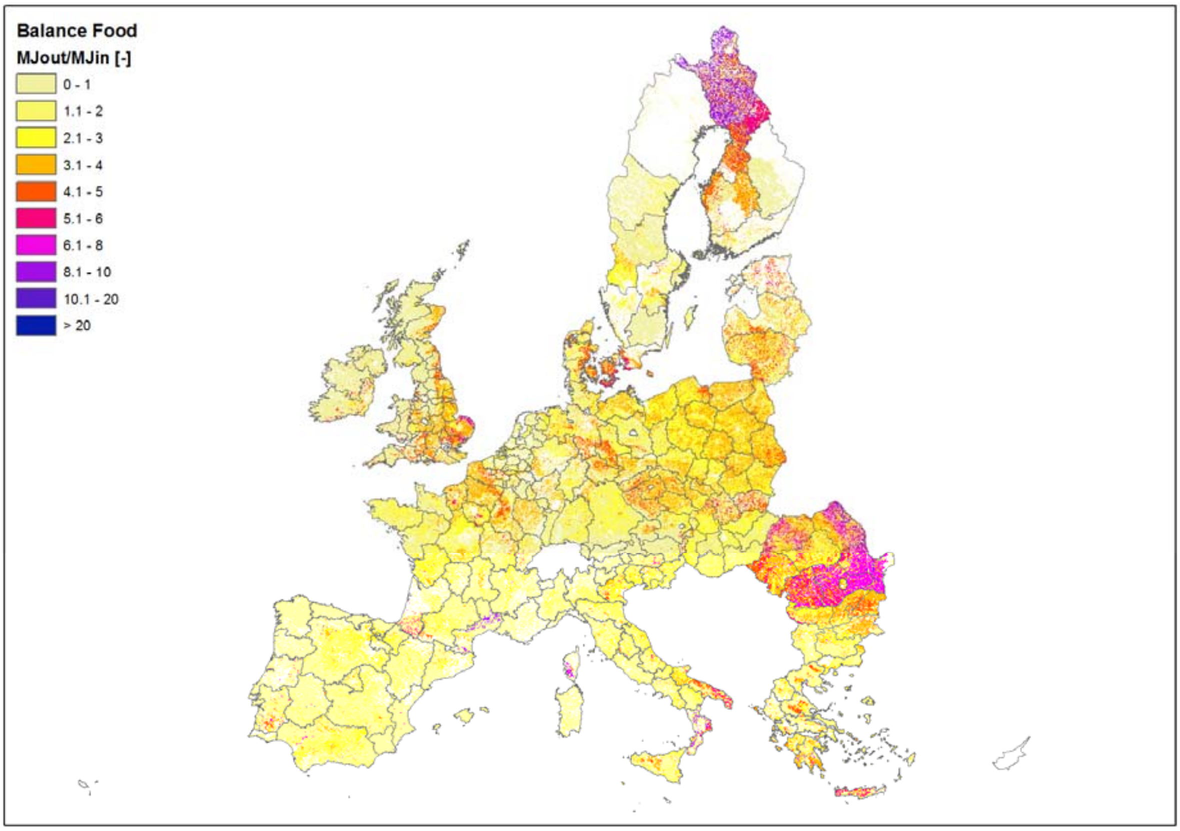


Figure 7: Energy balance per hectare (MJout/MJin) calculated for food at HSMU level

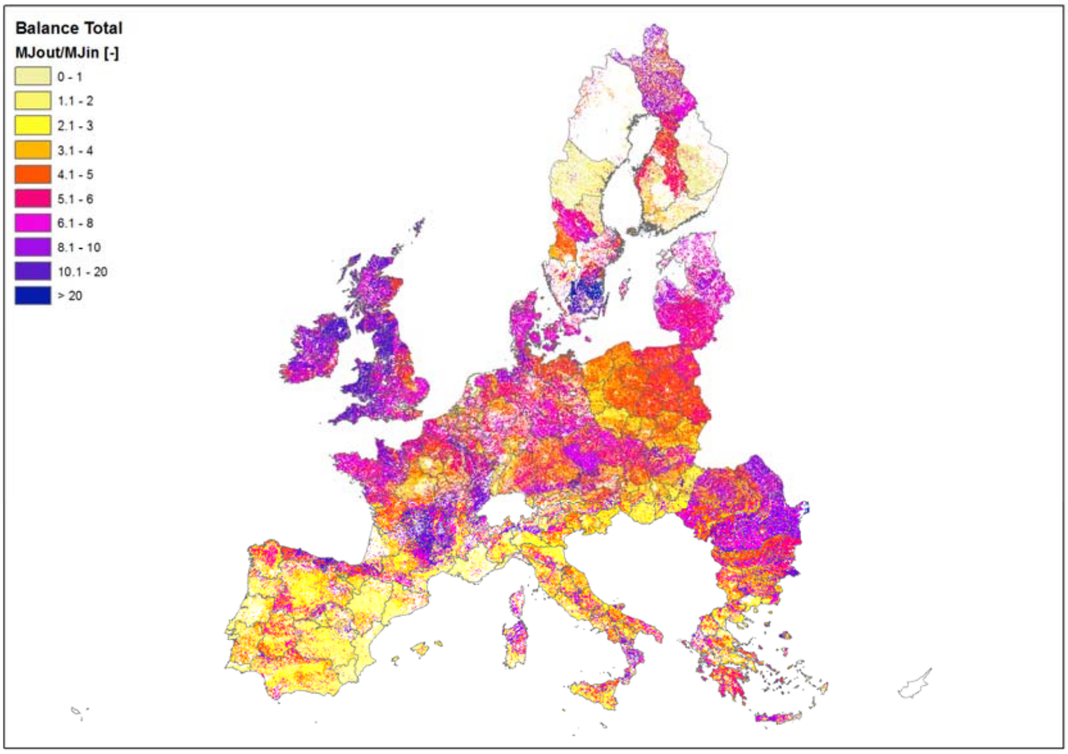


Figure 8: Energy balance per hectare (MJout/MJin) calculated for total biomass at HSMU level

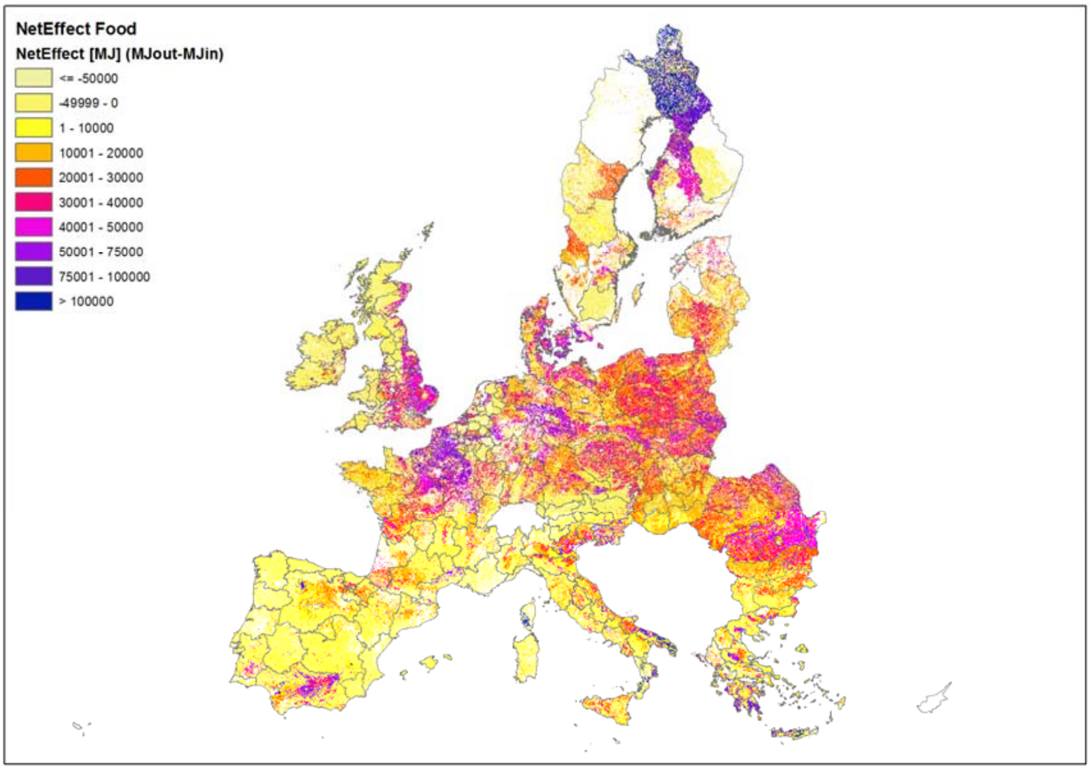


Figure 9: Net energy per hectare (MJout-MJin) calculated for food at HSMU level

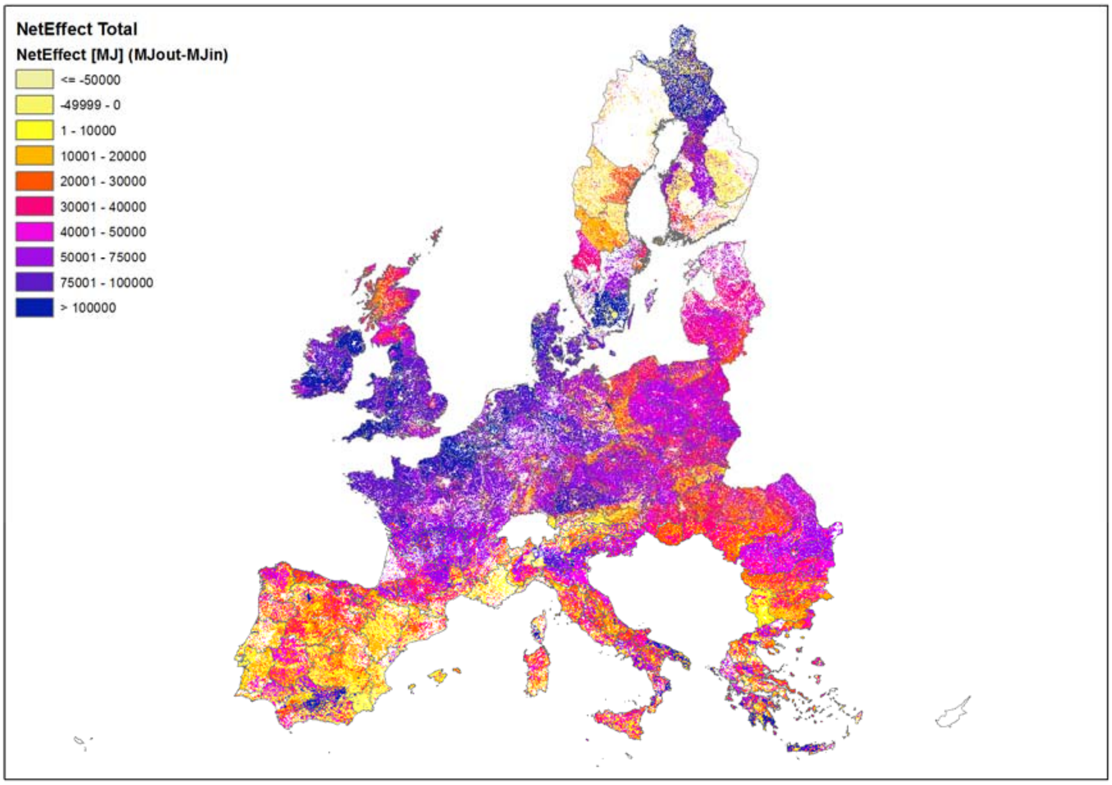


Figure 10: Net energy per hectare (MJout-MJin) calculated for total biomass at HSMU level

The variation in inputs and outputs shows strong differences in EROI results as can be seen from Figure 7, Figure 8, Figure 9 and Figure 10, certainly when total biomass output is taken into account. Overall the largest energy gains per hectare when only food output is taken is found mostly in the regions in North, west and central Europe and Italy and it concerns mainly arable land dominated regions. The highest energy gains per hectare when total biomass is taken as output are mostly in grassland areas in the Atlantic UK, Ireland, Sweden, western and central France, North-western Spain and Germany.

2.1.2 Relation between input and output

From the former it became clear that there is a large diversity in energy input and output levels between crops, between regions and even between similar crops in the same region. The energy gain that can be reached per crop differs therefore strongly but overall it is clear that the biggest energy gains are in arable and grassland systems in which generally high outputs are reached with generally lower input levels. This is confirmed in Figure 8 in which we see that grasslands show low input levels while their output levels vary from very low to very high. Arable crops, like cereals and oilseed, also cluster in the lower input levels. The output for oil crops is however also rather low, because their crop residues are not assumed to be used as biomass. For cereals the output ranges strongly from low to high, whereas the straw of cereals contributes significantly to the total output.

In fruits and olives the relation between input and output levels are relatively weak and show a large diversity. But overall input levels are clearly higher than in grassland and arables, while the output levels for fruits are even lower. The correlation of input and output over regions is generally rather low, for olives and oilseeds even almost zero. Cereals, oilseeds and fruits are aggregates of various crops. Following a low correlation can partly be explained by changing crop shares within these aggregates. Only grassland, which is a pure class, shows is a medium, positive correlation of input and output.

In fruits and olives overall input levels are clearly higher than in grassland and arable, while the output levels are generally also lower, with some exceptions to the high side. The optimal level of inputs is difficult to establish, but in grassland it is clear that high output gains can be reached at relatively low additional inputs.

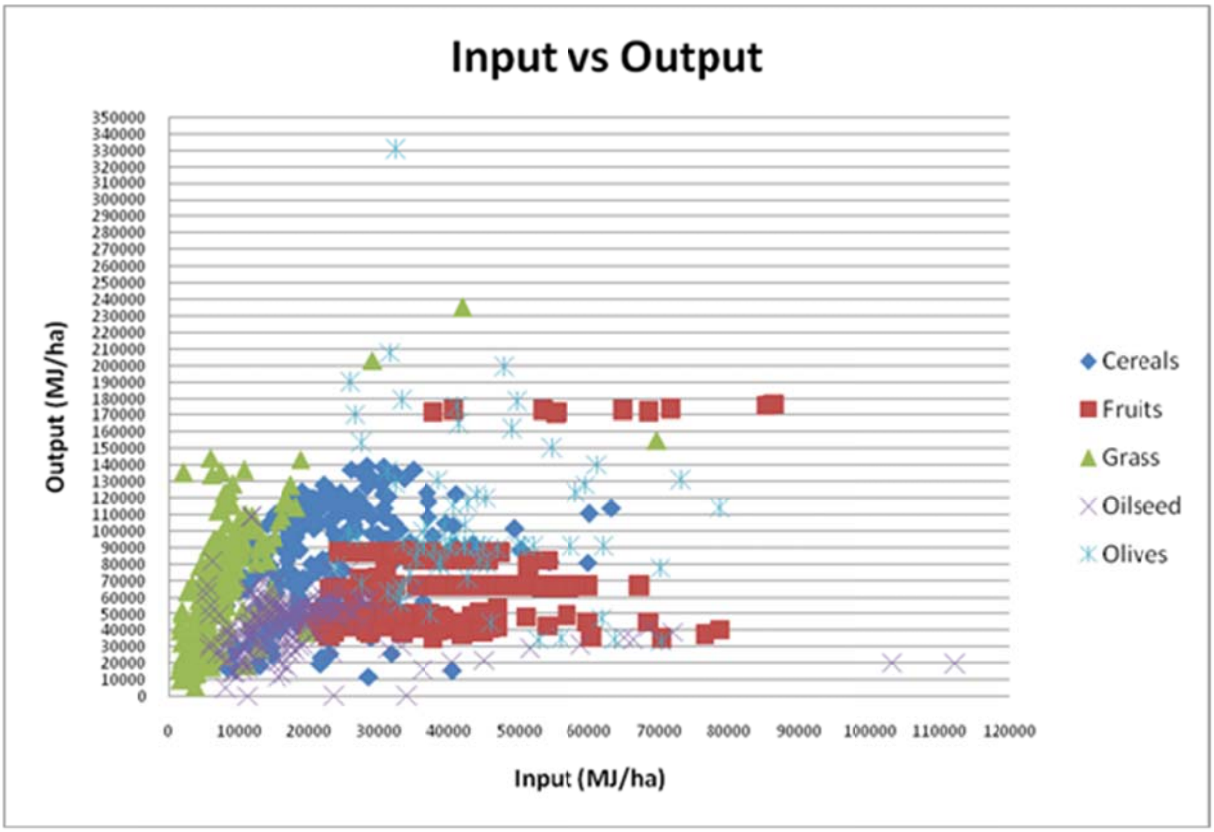


Figure 11: Input and output relation

Overall Figure 11 shows that though the general relation between inputs and outputs is very weak, within crops some interesting patterns can be distinguished.

3. Identification of semi-natural vegetation in agricultural lands as component of the Green Infrastructure

In a broad sense, the semi-natural vegetation likely to be found in agricultural lands can be grouped in semi-natural grasslands (i.e., permanent grasslands under extensive management practices) and woody vegetation elements, composed by tree vegetation (such as woodlots or tree-lines), shrub/scrub/brush communities (shrub-lands or hedgerows) or mixed formations (i.e., agro-forestry areas such as Spanish *dehesas* or Portuguese *montados*).

Mapping the network of semi-natural vegetation features that are present in agro-ecosystems is a crucial step for the final objective of identifying green infrastructures. The integration of this ecological network with the information on ecosystem services and biodiversity, serve as a base to define and assess the green infrastructures that already exist in agricultural lands. Moreover, it provides a framework for spatial planning and, more specifically, for zoning and setting ecosystem restoration priorities. On the other hand, it may be a valuable input for introducing the "greening measures" that the new CAP requires.

Given the importance of the delineation of this network in the context of green infrastructures and ecosystem services, a map of abundance of semi-natural vegetation features within the EU agricultural lands has been elaborated. The methodological process was structured in two consecutive stages that respectively focused on these tasks: 1) mapping permanent vegetation with a distinction between permanent grasslands and woody elements; 2) mapping semi-natural vegetation after a delimitation of extensively and intensively managed grasslands.

As a base for mapping, the identification of permanent vegetation was undertaken only in those areas delimited by classes 12 to 22 ("agricultural areas", class 2 of level 1) and class 26 ("natural grasslands") of Corine Land Cover 2006.

This mapping exercise needed recent fine-resolution land data at EU scale. Given these requirements, the 2006 SRC mosaic of classified satellite images (Baraldi *et al.*, 2006) was selected as the most suitable source currently available. The spatial resolution of this mosaic is 25 m. It is classified in 59 spectral classes defined by their distinctive spectral response in terms of vegetation type and strength. It must be noted though that this spectral classes do not necessarily correspond to determined land uses or covers. The mosaic covers the majority of Europe (only the images belonging to IRS-P6 LISS III satellite were used for this exercise) but, to the date, it is not completed for certain areas. As a substitutive data source for these missing areas, the 2000 SRC mosaic of classified satellite images (Baraldi *et al.*, 2006) was used. Its spatial resolution is the same as the 2006 mosaic but it only represents 20 spectral classes where types of vegetation are more aggregated.

The high heterogeneity of dates made necessary the delimitation of zones where distinctive patterns could be found. In order to comprise the availability of data and introduce environmental conditions as a factor, three criteria were established for the definition of zones: source data (mosaic 2006/mosaic 2000), time of capture of the image (vegetative period, from May to July/non-vegetative period, rest of the months) and Environmental Zone (Metzger *et al.*, 2005), grouped in Mediterranean and Non-Mediterranean. As a result, 16 zones were drawn. An analysis was later made in order to select those spectral classes that are more likely to represent permanent vegetation within each homogeneous zone, distinguishing between permanent grasslands and woody vegetation.

On the other hand, as a source of additional information, a coarse (250m) ecological indicator based on vegetation dynamics and phenology was calculated throughout Europe. The resulting map was used to refine the identification of permanent vegetation.

To complete the mapping of woody vegetation, two pre-existing maps were incorporated: the European Forest Map 2006 (Kempeneers *et al.*, 2011) and the Riparian Vegetation Map 2006 (Clerici *et al.*, 2013), both with a spatial resolution of 25 m.

Figure 12: shows an example of the permanent vegetation mapping.

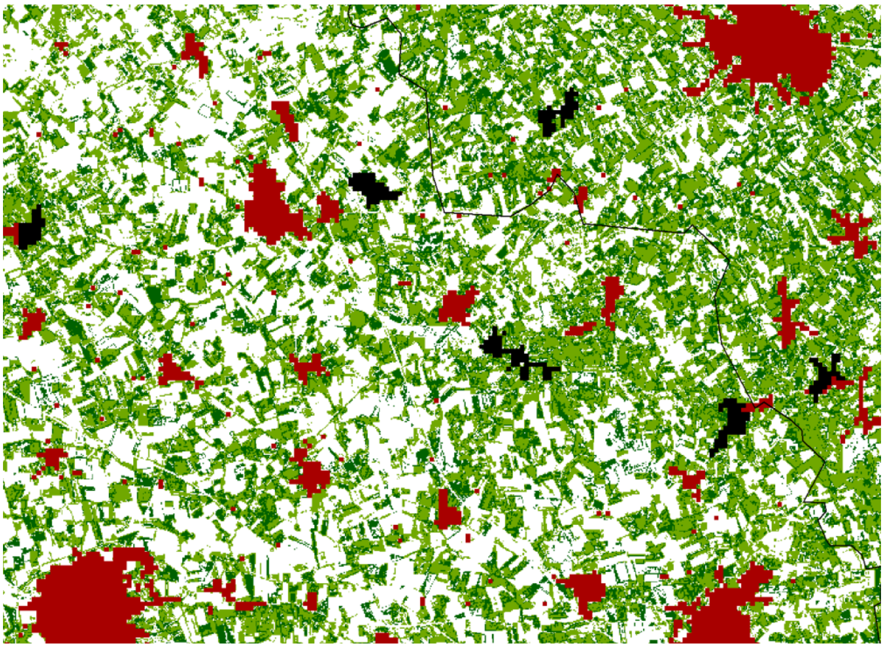
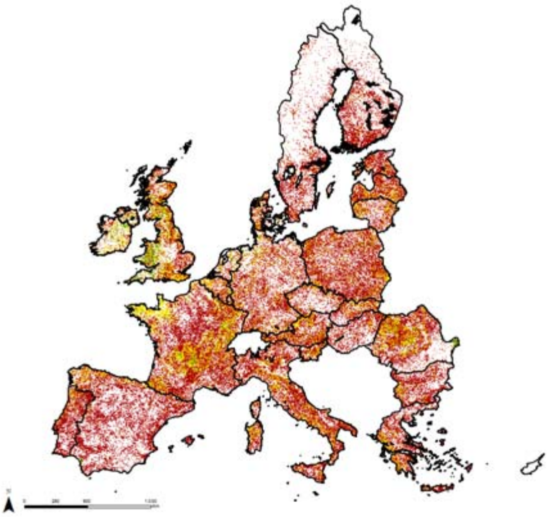


Figure 12: Permanent vegetation at 25 m resolution, distinguishing between permanent grasslands (light green) and woody vegetation (darker green). Example extracted from Northern France

Once the permanent vegetation was mapped, the next step of the process was the selection of the permanent grasslands that can be considered as semi-natural, i.e., that are not intensively managed. In this way, a map of agricultural areas managed under extensive practices was created on-purpose. Two sources of information were additionally used: the CAPRI model (Britz, 2008) and the map of High Nature Value (HNV) farmland (Paracchini *et al.*, 2008).

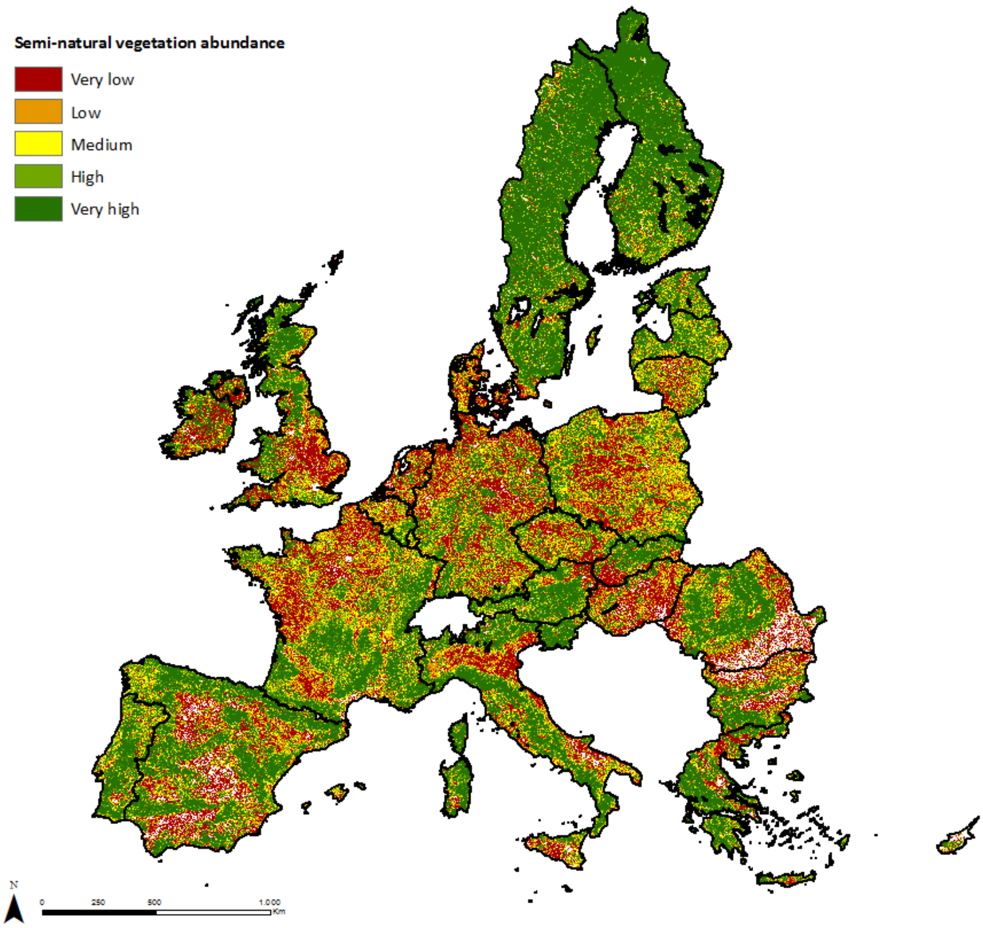
In addition, to generate a map that comprises the entire territory of the EU and not only the "agricultural areas" and "natural grasslands", the classes 35 and 37 of CLC 2006 ("inland marshes" and "salt marshes") were also incorporated as semi-natural grasslands with the highest value of abundance. With the same purpose as in the map of semi-natural grasslands, the following classes of CLC 2006 were incorporated as semi-natural woody vegetation: 23 to 25 ("forests"), 27 to 29 ("scrub and/or herbaceous vegetation association" excluding "natural grasslands"), 32 ("sparsely vegetated areas") and 36 ("peat bogs"). Both maps were later up-scaled to 1 km (Figure 13).

The final map of abundance of semi-natural vegetation at EU scale is the result of combining the semi-natural grasslands and woody elements maps, and summing up their values. Figure 13 shows the up-scaling of the resulting map to 1 km. In the generation of all of them, classes "artificial surfaces" and "water bodies" (1 and 5 of level 1 of CLC) were considered as "No data".



Semi-natural grasslands

Woody vegetation



Semi-natural vegetation (semi-natural grasslands + woody vegetation)

Figure 13: 1km resolution map of semi-natural vegetation abundance as an integration of semi-natural grasslands and woody vegetation maps. The classification was made by quantiles

The map shows an overview of the distribution of semi-natural vegetation in the EU, with a particular focus on agricultural areas. As expected, most of regions characterised by intensive agriculture score low in terms of semi-natural vegetation abundance. Nevertheless, results should be interpreted with care. For example, there are landscape types that inherently host a small percentage of semi-natural vegetation, such as rice fields in Northern Italy, or are highly appreciated as Val d'Orcia in Tuscany, which is also a World Heritage UNESCO site for the beauty of its (agricultural) landscape (Figure 14).

Figure 14: Rice fields in Piemonte (left), Val d'Orcia in Tuscany (right) - Italy

4. Integrated analysis of ecosystem services and the network of semi-natural vegetation

Target 2 of the EU Biodiversity Strategy to 2020 "focuses on maintaining and enhancing ecosystem services and restoring degraded ecosystems by incorporating green infrastructure in spatial planning". More precisely, by 2020 the Green Infrastructure must be established and at least 15% of degraded ecosystems must be restored.

In the frame of a EU-wide assessment of the Green Infrastructure, the role of agriculture is not fully disentangled. In the documents prepared by the Green Infrastructure Working Group at DG Environment, it is recommended that agricultural land is part of the Green Infrastructure, when managed multifuntionally so that provisioning of food and raw materials does not conflict with the provision of other ecosystem services. Besides this, other requirements of the Green Infrastructure are no net loss of biodiversity and that no negative environmental trade-offs can be accepted. The example of organic agriculture is mentioned, but it is likely that in the gradient from extensive to intensive agriculture a (fuzzy) boundary can be identified to better describe which type of agriculture should be part of Green Infrastructure. Also, in the Green Infrastructure documents mentioned above, a reference is made on the fact that "*Green Infrastructure exists in a range of states or conditions. Replacement of 'complex' Green Infrastructure with more 'simplified' Green Infrastructure represents a net reduction in infrastructure complexity and resilience, whereas if an area of 'very simple' Green Infrastructure is replaced by 'moderate' Green Infrastructure, this represents a net gain*".

This opens a number of issues on the relation between management intensity, the presence of elements of the Green Infrastructure and the different degrees to which farmed land can contribute to the establishment of the Green Infrastructure, especially in highly productive areas, and how the situation could be improved. This is in line with the discussions of the new CAP post-2013, which aims at improving the policy environmental performance also in terms of better provision of ecosystem services, in particular through the introduction of "greening measures": crop diversification, maintenance of permanent pastures and Ecological Focus Areas (EFAs). The latter foresee that farmers ensure that at least 7 % of their eligible hectares, excluding areas under permanent grassland, are ecological focus area such as land left fallow, terraces, landscape features, buffer strips and afforested areas. The role that EFAs can play in the establishment of the Green Infrastructure is therefore relevant.

In order to better understand how the elements listed above can contribute to achieving Target 2, an analysis is carried out of the results on energy return on investment and on yields in agriculture, coupled with the provision of other ecosystem services and the presence of the network of semi-natural areas.

4.1.1 Integrated analysis of ecosystem services

There are different ways to analyse ecosystem services, through PCA analysis to identify bundles of ecosystem services (Maes et al., 2011), the analysis of the total value of ecosystem services provision (TESV) and its links to biodiversity (Maes et al., 2012), various types of cluster analysis and even procrusters analysis (Dick et al, in prep.). In the identification of the Green Infrastructure the spatial distribution of values is key, so the TESV approach is adopted. The EROI index shows that the modification of the ecosystems due to agricultural practices and necessary to obtain agricultural production cannot be excluded from the analysis, and this leads to considerations on the trade-offs between production functions and so-called negative externalities which may cause a loss of regulating ecosystem services.

It is then interesting to separately address provisioning and “regulating and maintenance” ecosystem services. The reference is the MAES framework (CICES classification version 4 (2012)).

The ecosystem services analysed in this study are (see Annex I for short descriptions of each ecosystem service):

Regulating and maintenance:

- Deposition velocity
- Carbon storage
- Carbon sequestration
- Erosion control
- Pollination
- Organic matter in topsoil concentration
- Recreation Potential Index
- Total amount of nitrogen retained per km of stream
- Annual sub-surface water flow
- Coastal protection

Provisioning:

- Energy Return on Investment in agricultural production
- Grazing livestock density
- Timber growth
- Timber stock
- Annual water flow available from surface waters

Provisioning services include all material and biotic energetic outputs from ecosystems (typically food, feed, fibre, livestock, water, timber, renewable energy sources). Available layers (normalised) of ecosystem services belonging to this category are summed in order to provide $TESV_P$ representing the total value of provisioning services over Europe. The distribution of values, classified in quintiles, is reported in Figure 15.

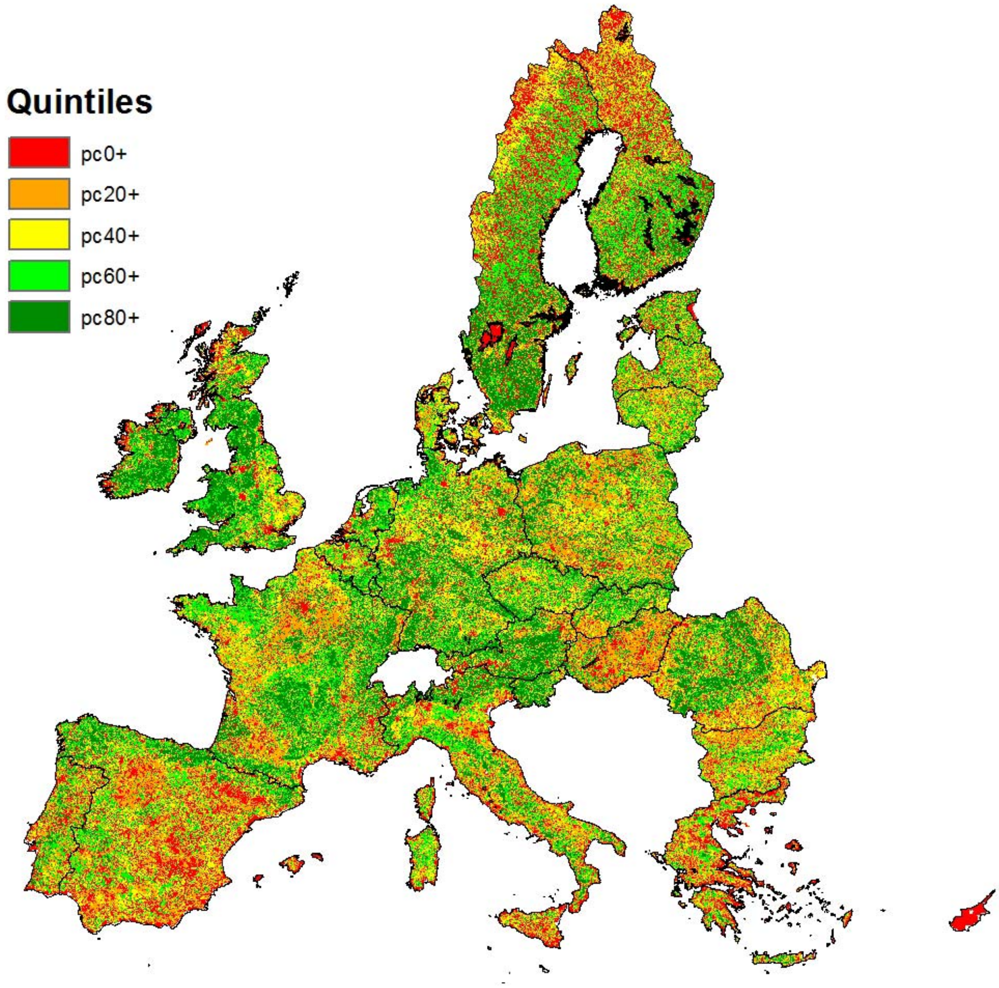


Figure 15: total value of provisioning services over Europe ($TESV_P$)

The map highlights primarily areas where there is a maximum level of provisioning services (whether crops, livestock, timber or water). In this map the areas that score a higher value are the forests, and for agriculture grazing areas where EROI values are high, compared to cropland. It is interesting to compare this map with the corresponding map including yields instead of EROI (Figure 16). The final picture is different in areas of intensive agriculture with high yields, which reach the fourth quintile if this second option is used.

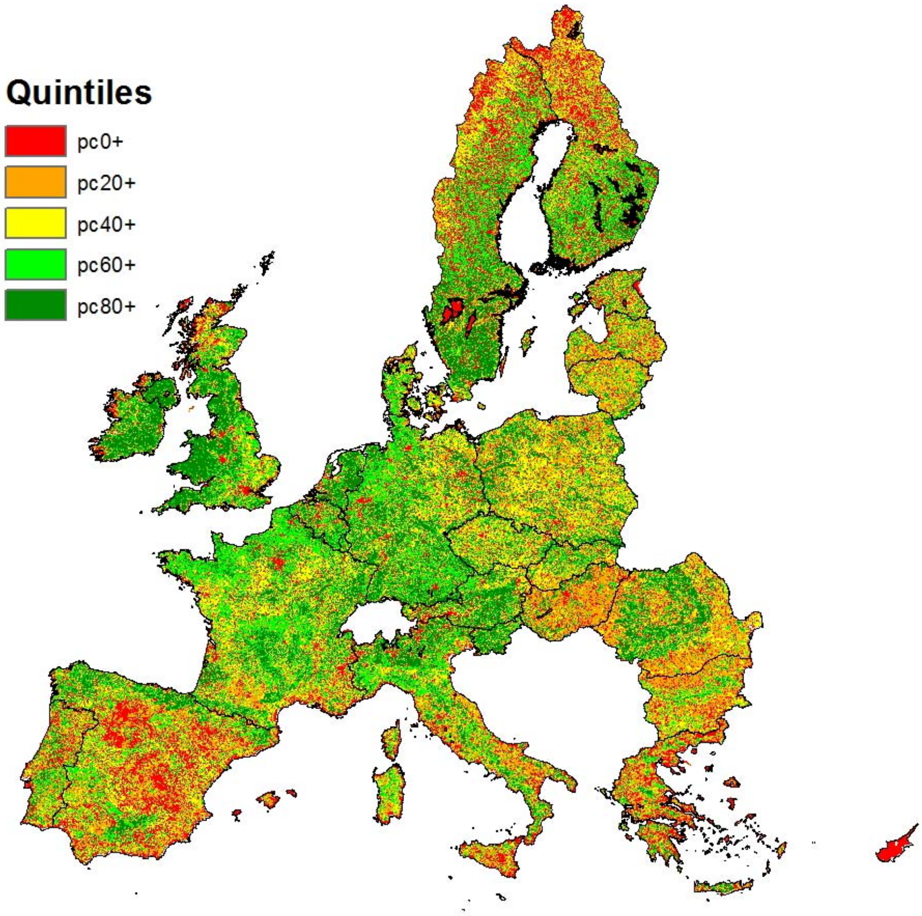


Figure 16: total value of provisioning services over Europe, including yields (MJ/ha) instead of EROI (MJ/MJ)

The same procedure can be applied to obtain the $TESV_R$ representing the total value of regulating and maintenance services over Europe. These include "*all the ways in which ecosystems control or modify biotic or abiotic parameters that define the environment of people, i.e. all aspects of the 'ambient' environment*" (CICES v 4) and include air, water and mass flow regulation (climate regulation, flood and coastal protection, erosion protection), water purification, pollination etc. The resulting map (Figure 17) shows that most of the addressed regulating services are provided by forests. Arable land scores very low, grassland areas and natural vegetation other than forest reach a medium value.

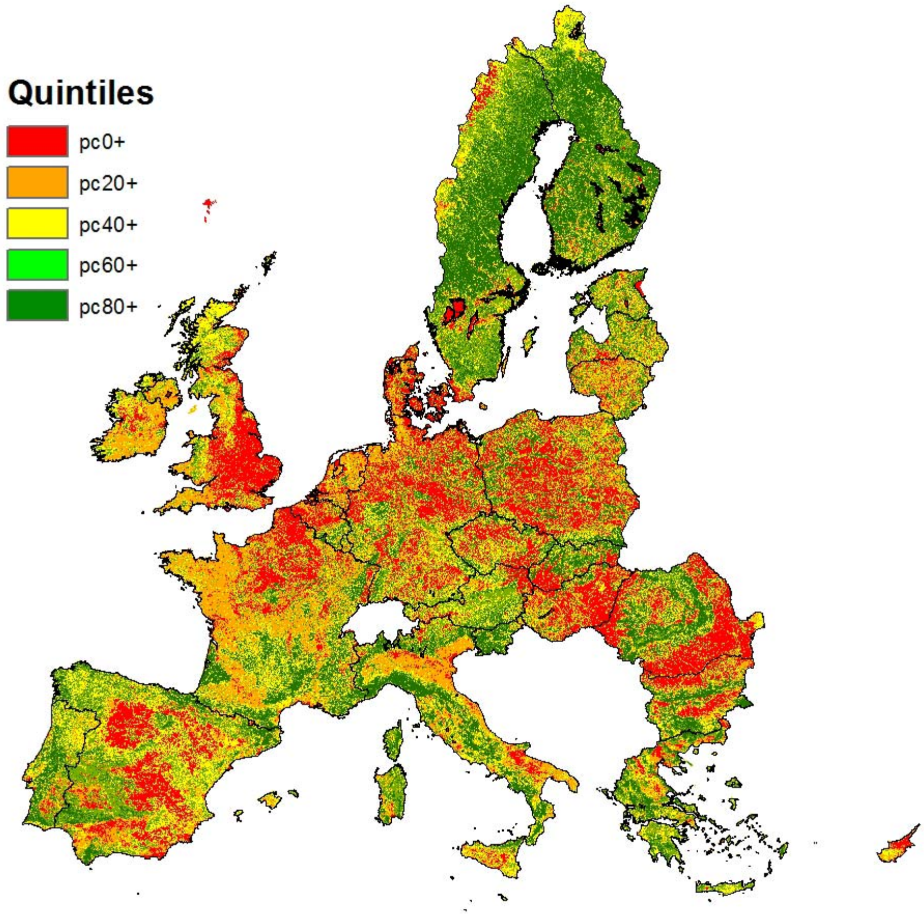


Figure 17: total value of regulating and maintenance services over Europe ($TESV_R$)

Cultural ecosystem services will be added to the modelling frame at a later stage.

It is difficult to set a threshold above which ecosystem services provision becomes relevant for the establishment of the Green Infrastructure, in order to identify a first draft as basis for discussion, the two maps of $TESV_P$ and $TESV_R$ are joined and respectively the two higher quintiles are highlighted (Figure 18). This map shows areas of multiple production of ecosystem services.

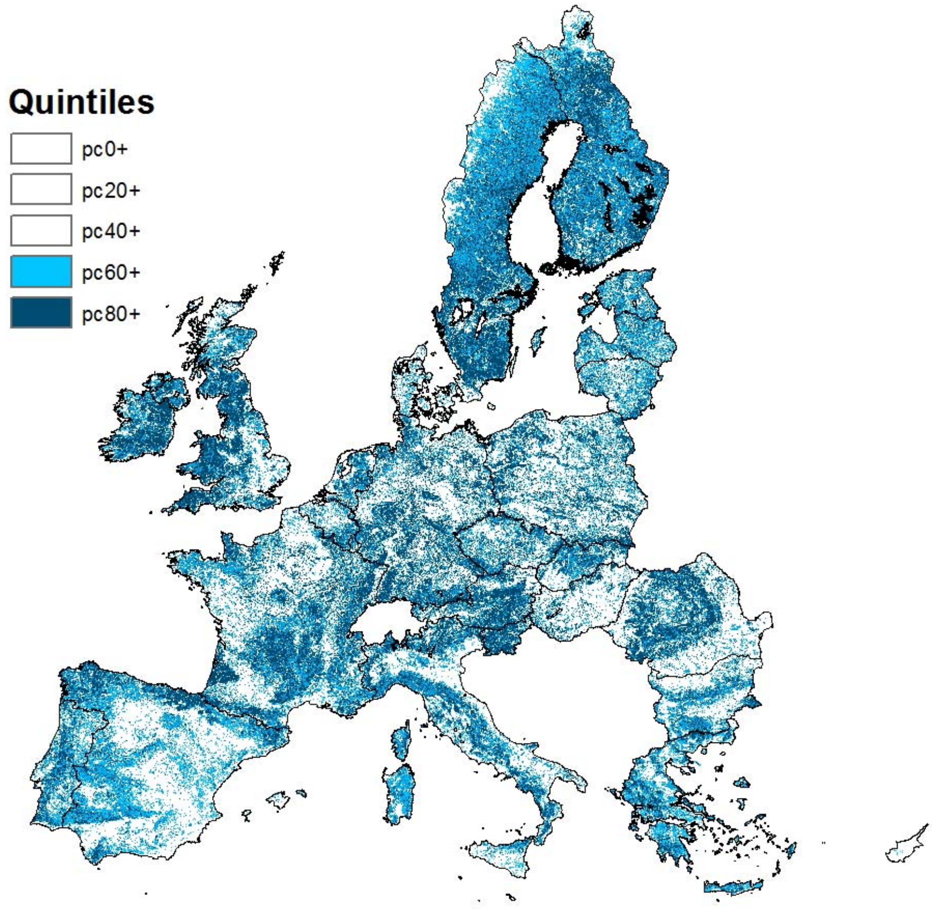


Figure 18: Fourth and fifth quintiles of $TESV_P$ and $TESV_R$

Other approaches can be selected to provide information that synthetises maximal provision by single ecosystem services, for example by ranking the quintiles in a 1-5 scale and summing the reclassified ecosystem service layers. Results for provisioning, and regulating and maintenance services are shown in Figure 19 and Figure 20. Also in this case, the higher the class the higher the provision of multiple services, but the range of values highlights areas that score high in one or just a few ecosystem services.

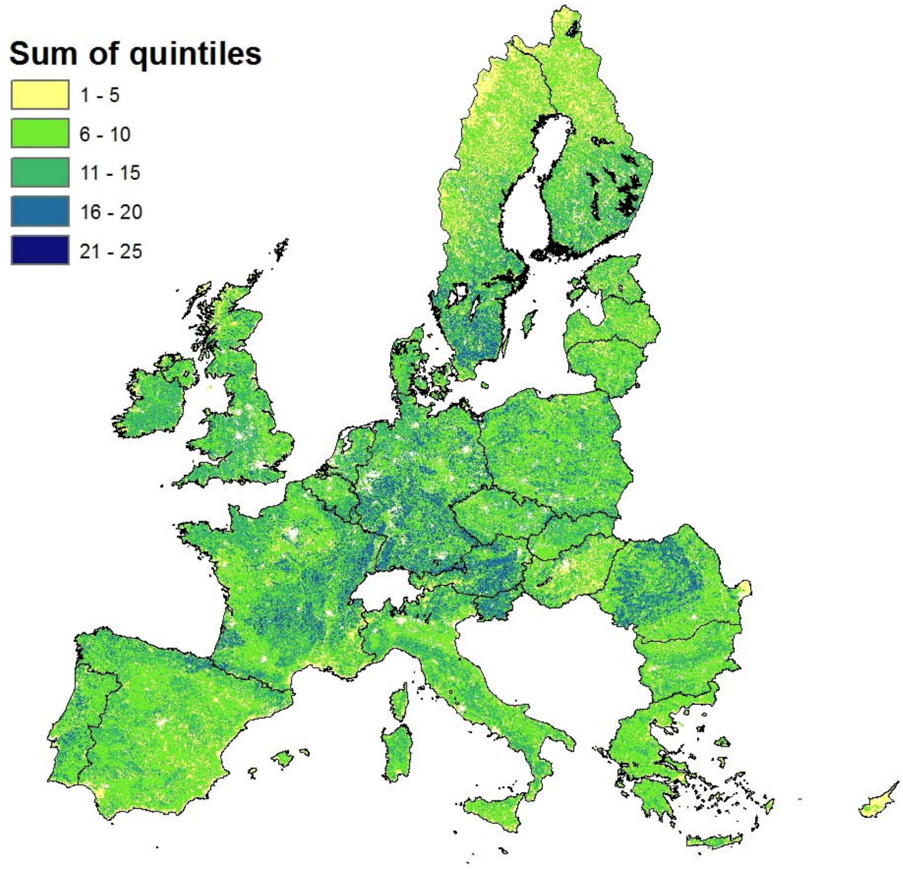


Figure 19: Sum of quintiles classified in a 1-5 range, for provisioning services

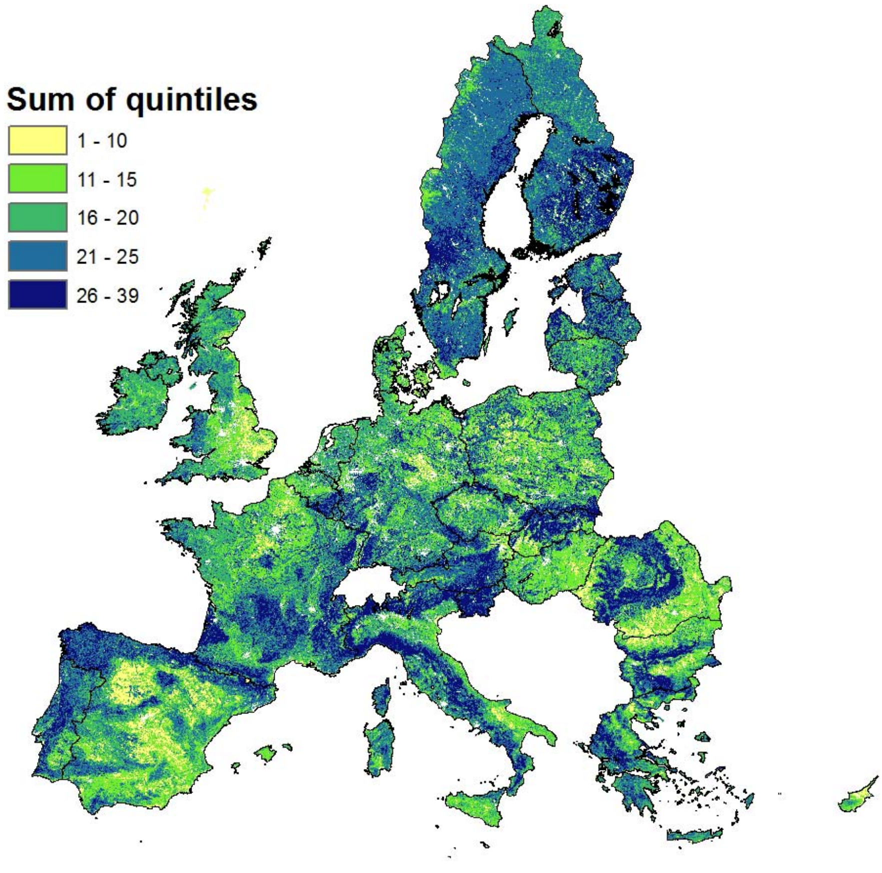


Figure 20: Sum of quintiles classified in a 1-5 range, for regulating services

Finally, Figure 21 provides a summary of areas belonging to the two upper quintiles in at least two ecosystem services (corresponding to the upper 40% of total provision, for provisioning and regulating services separately).

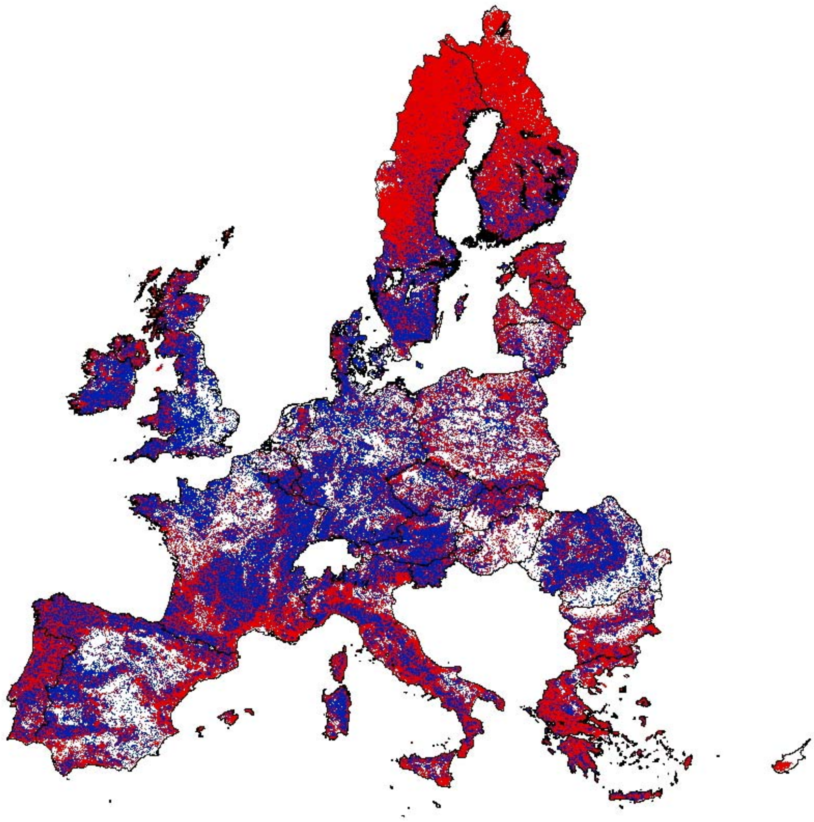


Figure 21: Areas belonging to the two upper quintiles in at least two ecosystem services (corresponding to the upper 40% of total provision, for provisioning services –blue- and regulating services –red- separately). Blue areas may overlap red areas.

4.1.2 The contribution of semi-natural vegetation in agricultural lands

The map in Figure 21 shows an optimistic estimate, if multiple provision of more than two services is taken into account, the mapped area decreases. As expected, the areas in white in the map are mostly agricultural lands, and the situation remains mostly unchanged if High Nature Value farmland is added to the picture.

Semi-natural vegetation as mapped following the procedure presented in Chapter 3 is not fully accounted for in the ecosystem services layers used so far in the analysis, except for pollination. Grassland is –to some extent- included, but the part concerning scrubland and woody vegetation is not entirely accounted for. It is therefore interesting to check what the correspondence is between i.e. the provision of regulating services, and the presence of semi-natural vegetation in agricultural lands: if the average of $TESVR_R$ is calculated per NUTS2 region over the agricultural land, and is compared to the abundance of semi-natural vegetation normalised over the agricultural surface, the trend shown in Figure 22 is obtained.

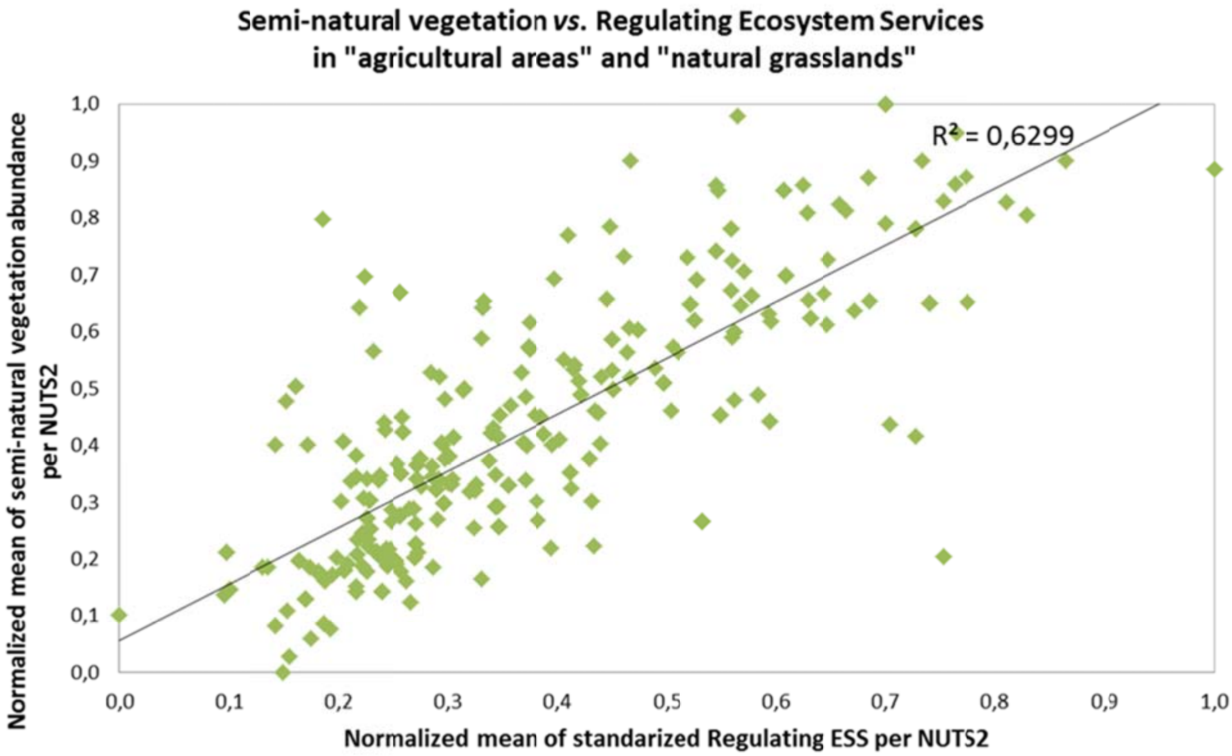


Figure 22: distribution of values between regulating ecosystem services and abundance of semi-natural vegetation at NUTS2 region

Outliers can be calculated and regions identified (Figure 23) where the presence of semi-natural vegetation is higher or lower than expected $TESVR_R$ (both layers are standardised).

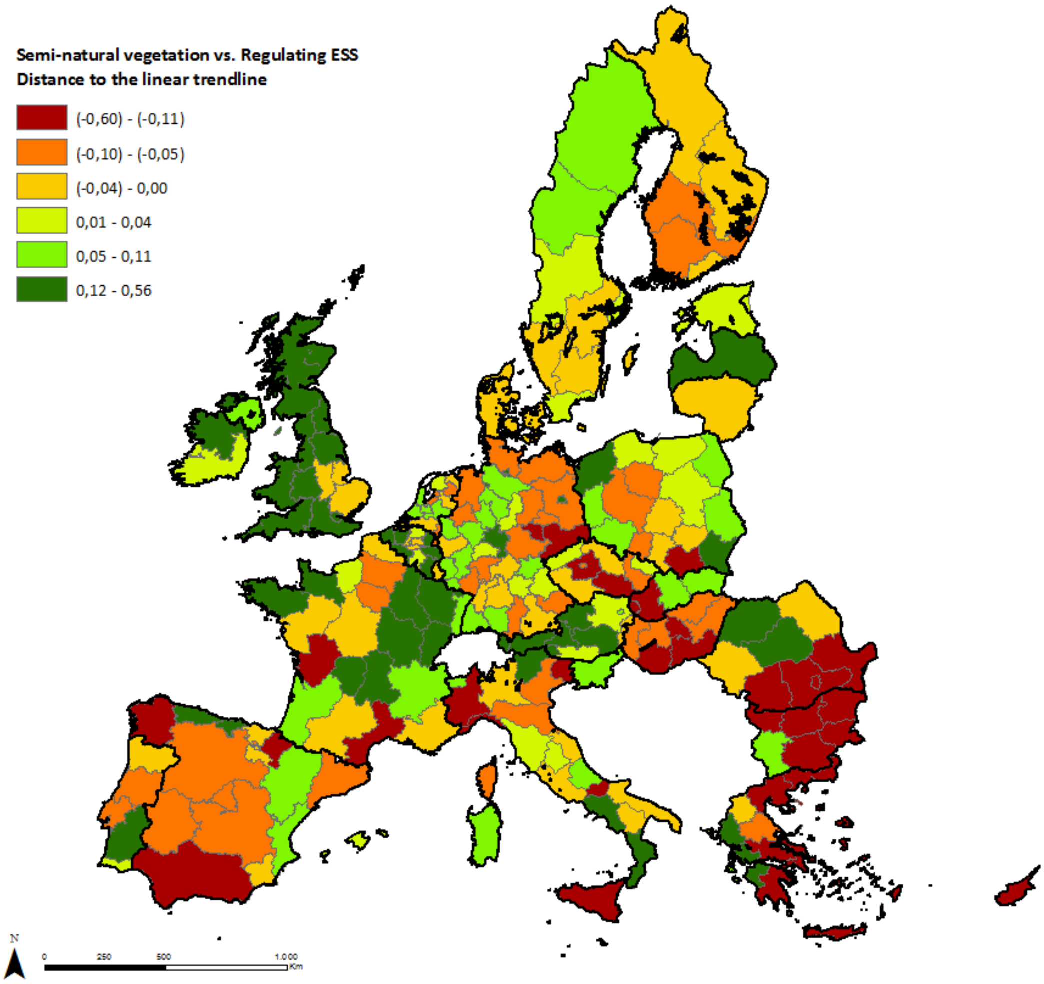


Figure 23: outlier regions in reference to the trend shown in Figure 22

It is interesting at this point to compare the yield with $TESVR_R$. Figure 24 shows the trend between these two variables and shows that there is a higher density of regions with high yields with a $TESVR_R$ value below the average. Figure 25 shows that in most cases such regions are the same identified in Figure 23, with some exceptions.

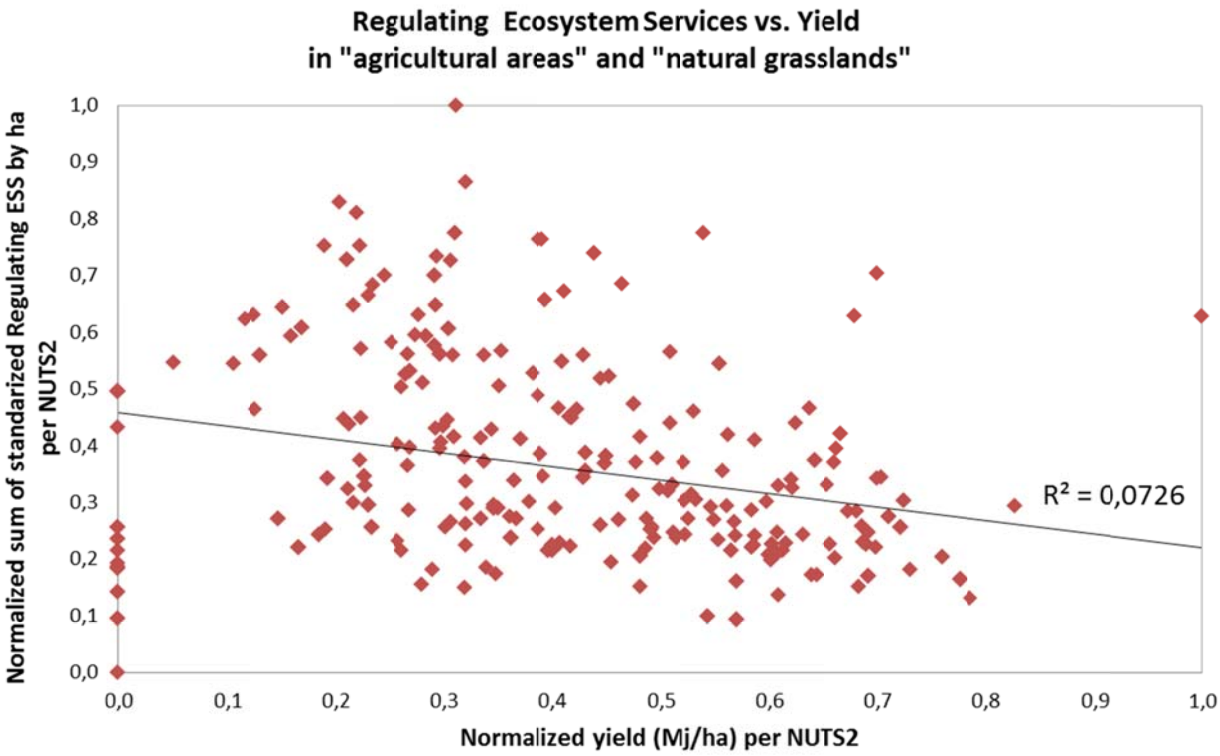


Figure 24: *distribution of values between regulating ecosystem services and yield at NUTS2 region*

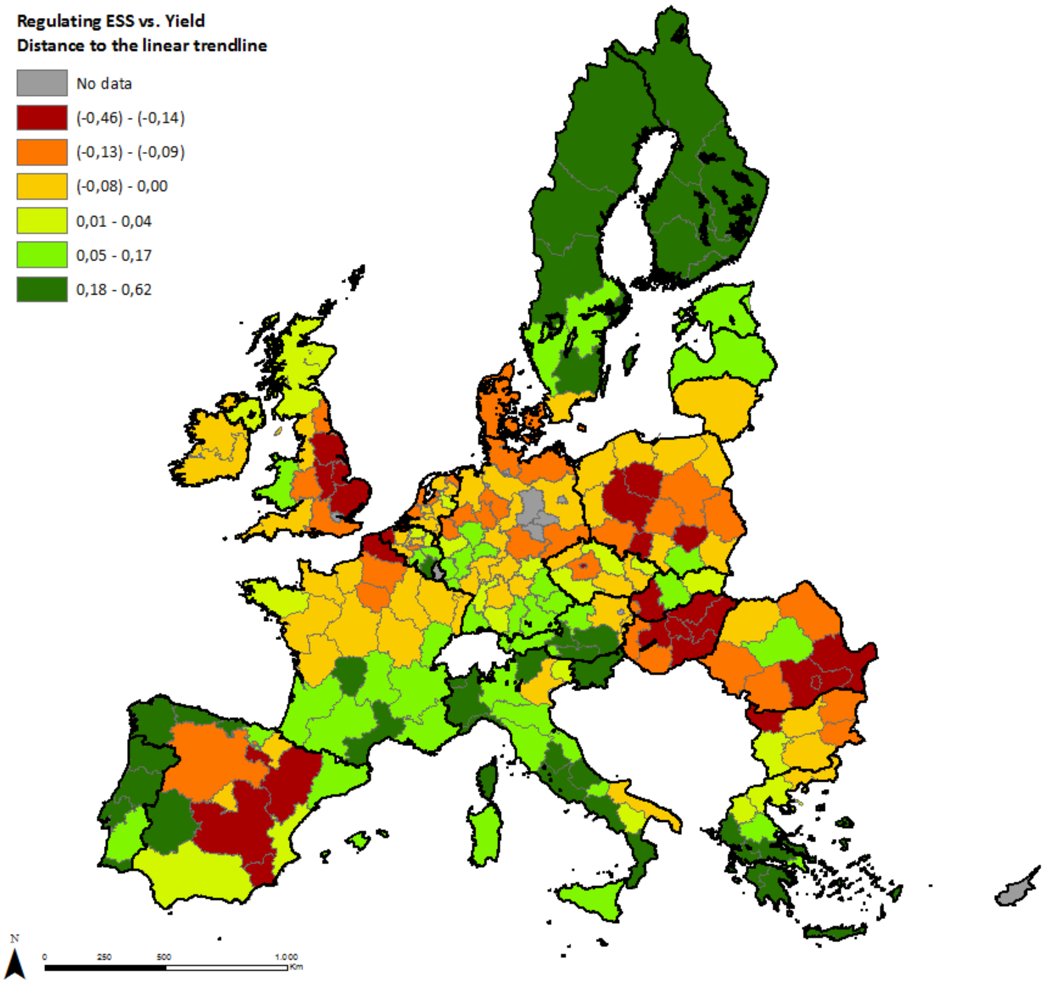


Figure 25: outlier regions in reference to the trend shown in Figure 24

For example the agricultural areas in South of Romania are outliers in both cases (Figure 26), while East of England (Figure 27) is an outlier in terms of the link yield- $TESVR_R$, but not in terms of the link provisioning ecosystem services-seminatural vegetation.

Figure 26: agricultural land in South of Romania

Figure 27: agricultural land in East of England

This is likely to be due to the different character of the two areas that despite being intensively used are hosting semi-natural vegetation to different degrees.

Similar examples can be found all over Europe, from which different conclusions can be drawn (i.e. the Spanish cereal steppe of Castilla y Leon lies also in the lower part of the two distributions, but there agriculture can be extensive and also part of Natura 2000 sites).

The former are examples of the type of analysis that can be carried out with the presented data and approaches. Further work is needed to fully understand how agricultural management and land use are linked to, are dependent from and are providing ecosystem services, possibilities are listed in the concluding section.

5. The way forward

This study presents options for integrating the contribution of agricultural lands in on-going discussions on the establishment of the Green Infrastructure, and for streamlining CAP greening efforts and the Biodiversity Strategy targets. This document is meant to provide a first draft for discussion. In particular points that should be addressed are:

- how "multiple provision" of ecosystem services should be intended;
- in-depth analysis of agricultural production (including the economic value) in relation to provision of ecosystem services ;
- trade-off analysis, including negative externalities from agriculture;
- how information on field size can be integrated in the analysis;
- how cultural ecosystem services (recreation) can be included in the analysis;
- highlight the role of extensive and high nature value farmland;
- what is the role of Natura 2000 sites and how the presented approach can be linked to restoration goals;
- last but not least, the role of biodiversity in this context.

6. Bibliography

Boyd, J., and S. Banzhaf (2007) What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63:616–626.

Baraldi, A., Puzzolo, V., Blonda, P., Bruzzone, L., Tarantino, C. (2006) Automatic spectral rule-based preliminary mapping of calibrated LandsatTM and ETM+ Images. IEEE Transactions on Geoscience and Remote Sensing 44(9): 2563–2586.

Britz, W. (2008) *Automated model linkages: the example of CAPRI.* Agrarwirtschaft, Jahrgang 57, Heft 8.

Clerici, N., Weissteiner, C., Paracchini, M.L., Boschetti, L., Baraldi, A., Strobl, P. (2013) Pan-European distribution modelling of stream riparian zones based on multi-source Earth Observation data. Ecological Indicators 24: 211-223. ISSN 1470-160X, 10.1016/j.ecolind.2012.06.002.

Costanza et al. (1997). The value of the world's ecosystem services and natural capital. Nature vol. 387.

Daily G.C. (1997) Nature's services: Societal dependence on natural ecosystems.Island Press. Washington D.C.

Dick J., Maes J., Smith R.I., Paracchini M.L., Zulian G. (2012) Comparison of ecosystem services identified by site managers and EU level mapping at 11 sites of the UK Environmental Change Network. Submitted to Ecological Indicators

EEA (2011). Common International Classification of Ecosystem Services (CICES): 2011 Update. Available at http://unstats.un.org/unsd/envaccounting/seeaLES/egm/Issue8a.pdf

Elbersen, B., Kempen, M., van Diepen, K., Andersen, E., Hazeu, G., Verhoog, D. (2006). Protocols for spatial allocation of farm types. SEAMLESS report no. 19, November 2006

Fisher, B., Kerry Turner, R., Morling, P. (2009) Defining and classifying ecosystem services for decision making. Ecological Economics. 68: 643-653.

Odum, H.T. 1984 Systems Ecology. Wiley, New York.

Kempen, M. & Kraenzlein, T. (2008), Energy Use in Agriculture: A Modeling Approach to Evaluate Energy Reduction Policies. Paper prepared for presentation at the 107th EAAE Seminar "Modelling of Agricultural and Rural Development Policies". Sevilla, Spain, January 29th -February 1st, 2008.

Kempen, M., Elbersen, B.S., Staritsky, I, Andersen, E. & Heckelei, T. (2011), Spatial allocation of farming systems and farming indicators in Europe Agriculture, Ecosystems & Environment, Volume 142, Issues 1-2, July 2011, Pages 51-62.

Kempeneers, P., Sedano, F., Seebach, L., Strobl, P., San-Miguel-Ayanz, J. (2011) Data Fusion of Different Spatial Resolution Remote Sensing Images Applied to Forest-Type Mapping. IEEE Transactions on Geoscience and Remote Sensing 49(12): 4977-4986.

Leip A., Marchi G., Koeble R., Kempen M., Britz W. and Li C. (2008). Linking an economic model for European agriculture with a mechanistic model to estimate nitrogen and carbon losses from arable soils in Europe. Biogeosciences 5 (1): 73-94. http://www.biogeosciences.net/5/73/2008/bg-5-73-2008.html.

Maes, J., Paracchini, M.L., Zulian, G. (2011) A European assessment of the provision of ecosystem services. Towards an atlas of ecosystem services. JRC 63505, EUR 24750 EN, ISBN 978-92-79-19663-8, ISSN 1018-5593, doi:10.2788/63557

J. Maes , M.L. Paracchini , G. Zulian , M.B. Dunbar , R. Alkemade (2012) Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. Biological Conservation 155: 1 - 12

Mapping and Assessment of Ecosystems and their Services. Discussion Paper – version 9.6. 13.11.2012

(MA) World Resources Insitute (2005). Millennium Ecosystem Assessment: Ecosystems and Human Well-being: Biodiveristy Synthesis.

Metzger, A., Bunce, B., Jongman, R.H.G., Mucher, C.A., Watkins, J.W. (2005) A climatic stratification of the environment of Europe. Global Ecology and Biogeography 14: 549-563.

Murdoch, W., Polasky, S., Wilson, K. A., Possingham, H. P., Kareiva, P. and Shaw, R. (2007) Maximizing return on investment in conservation. Biological conservation 139: 375-388

Paracchini, M.L., Petersen, J.-E., Hoogeveen, Y., Bamps, C., Burfield, I., van Swaay, C. (2008) High Nature Value Farmland in Europe - An estimate of the distribution patterns on the basis of land cover and biodiversity data. Report EUR 23480 EN. 87 pp.

Schramski JR, Rutz, Z, Gattie, DG, Li K. (2011) Trophically balanced sustainable agriculture. Ecological Economics 72: 88–96

TEEB (2010) Ecological and Economic Foundations. (Kumar ed.), Earthscan, London.

UK National Ecosystem Assessment (2011) The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge.

Wriedt G, Van Der Velde M, Aloe A and Bouraoui F. (2008) Water Requirements for Irrigation in the European Union. EUR 23453 EN. Luxembourg (Luxembourg)

Wriedt G, Van Der Velde M, Aloe A and Bouraoui F. (2009): A European Irrigation Map for Spatially Distributed Modelling. Agricultural Water Management 96 (5). p. 771-789.

Annex I Ecosystem Services used in the assessment

REGULATING AND MAINTENANCE ECOSYSTEM SERVICES:

REGULATION OF BIOPHYSICAL ENVIRONMENT

Ecosystems influence air quality by emitting chemicals to the atmosphere or by extracting chemicals from the atmosphere.

Deposition velocity

Spatial indicators for mapping air quality services at EU scale
For this assessment, we used the downward pollutant flux, or pollutant removal as basis for the spatial indicator. This quantity is calculated as the product of dry deposition velocity and pollutant concentration (Wesely and Hicks, 2000). Deposition velocity is the inverse sum of three resistances. The main ecosystem based parameters affecting deposition velocity are the height of the vegetation (related to the roughness length of the land) and the leaf area index. Both parameters are high for forests explaining their substantial contribution to the provision of clean air. The deposition flux has been used to estimate the contribution of ecosystems, in particular urban forests, to the reduction of air pollution both in biophysical quantities and as monetary values (Escobedo and Nowak, 2009; Karl et al., 2010; Nowak et al., 2006).
We used the deposition velocity as an indicator expressing the **capacity of vegetation to capture and remove air pollutants**. Subsequently, the associated service flow was calculating by multiplying modeled pollutant concentration for NO_2, SO_2 and NH_3 derived from the EMEP air quality model for the year 2000 with maps representing the dry deposition velocity of these compounds based on a parameterization as used in the MAPPE model (Pistocchi, 2008).
We only considered the contribution of ecosystems that are close to sources of pollution. Here, we buffered the CLC artificial areas with a 3 km buffer assuming that pollutants that are captured by vegetation inside this buffer are also emitted within this perimeter. This avoids tracing back the contribution of trees on air pollutant removal to the sources of emissions.

REGULATION OF PHYSICO-CHEMICAL ENVIRONMENT

Climate services are defined as the influence that ecosystems have on the global climate by emitting greenhouse gasses to the atmosphere or by extracting carbon from the atmosphere as well as the influence that ecosystems have on local and regional temperature, precipitation and other climatic factors. In this study, only the first aspect has been taken into consideration.

Two classically used indicators to approximate climate regulating services are presented in this study. Carbon storage was assumed as a proxy to estimate the capacity of ecosystems to contribute to climate change mitigation while the annually accumulated net ecosystem productivity was suggested as measure for the carbon service flow.

Carbon storage

Carbon storage data were derived by a re-classification system of landcover/landuse. This spatially-explicit global data set provides estimates and spatial distribution of the above- and below-ground carbon stored in living plant material, and provides an important input to climate, carbon cycle and conservation studies.

The data set was created by updating the classic study by Olson et al. (1983, 1985) with a contemporary map of global vegetation distribution (Global Land Cover database; GLC2000).
http://cdiac.ornl.gov/epubs/ndp/ndp017/ndp017b

Table 1: Values to estimate carbon storage based on landuse/landcover.

Class description	Class number	Revised Medium carbon Values [metric tons C / ha]	
		Boreal zone *)	Temperate zone
Tree Cover, broadleaved evergreen	1	nan	90
Tree Cover, broadleaved deciduous, closed	2	70	90
Tree Cover, broadleaved deciduous, open	3	70	90
Tree Cover, needle-leaved evergreen	4	70	130
Tree Cover, needle-leaved deciduous	5	70	130
Tree Cover, mixed leaf type	6	70	70
Tree Cover, regularly flooded, fresh and brackish water	7	70	90
Tree cover, regularly flooded, saline water	8	70	90
Mosaic: Tree cover / Other natural vegetation	9	30	30
Tree Cover, burnt	10	40	40
Shrub Cover, closed-open, evergreen	11	9	9
Shrub Cover, closed-open, deciduous	12	9	9
Herbaceous Cover, closed-open	13	9	9
Sparse Herbaceous or sparse Shrub cover	14	9	9
Regularly flooded Shrub and/or Herbaceous cover	15	9	9
Cultivated and managed areas	16	8	8
Mosaic: Cropland / Tree cover	17	40	40
Mosaic: Cropland / Shrub or Grass Cover	18	30	30
Bare, Water, Snow and Ice, Artifical Surfaces	19	0	0
	20	0	0
	21	0	0
	22	0	0
Irrigated Agriculture	23	45	45

***) Zoning occurred according the Biogeographical Zones delineated by Metzger et al. (2005)**

Carbon sequestration

Data on net ecosystem productivity are available in the Geosucces database, hosted by VITO (Belgium). The net ecosystem productivity (NEP) takes into account the soil respiratory flux originating from heterotrophic decomposition of soil organic matter. These carbon fluxes are quantified using the C-Fix model which is a remote sensed-based carbon balance product efficiency model wherein the evolution of the radiation absorption efficiency in the PAR (Photosynthetically Active Radiation) band (or fAPAR) of vegetation is directly inferred from space observations, SPOT-VEGETATION S10 (SPOT VGT S10) images, using the Normalized Difference Vegetation Index (NDVI) (Veroustraete et al., 2002). The data are available at:
http://geofront.vgt.vito.be/geosuccess/relay.do?dispatch=NEP_info
Data of NEP were accumulated for the year 2000 to result in the annual carbon fixation (gram C m-2 year-1).

Organic matter in topsoil concentration

Spatial indicators for mapping soil quality services at EU scale

The primary source for all European soil related data is the JRC's European soil data centre. Data on soil depth, moisture capacity and organic carbon content are available via the website (http://eusoils.jrc.ec.europa.eu/).

We used the organic matter in topsoil concentration [%], including data for Malta and Cyprus (Hiederer, 2012; Jones et al., 2005). The layer of organic matter concentrations in the topsoil was calculated from the map of topsoil organic carbon by applying a factor of 1.72. This factor assumes an average organic carbon content of organic matter of 58%. The composition of organic matter varies with respect to the organic carbon content and the map of topsoil organic carbon uses a maximum of 63%. For the organic matter layer any organic matter concentrations >100 were therefore set to 100%. The source data of the topsoil organic carbon map (European Soil Database Version 2.0) does not cover soil data for Malta and Cyprus. For these regions the data were taken from the Harmonized World Soil Database (Hiederer and Koechy, 2011).

Total amount of nitrogen retained per km of stream

This service relates to the role ecosystems play in the filtration and decomposition of organic wastes and pollutants in water; assimilation and detoxification of compounds through sediment, soil and subsoil processes.
In this assessment, we focused on the role of rivers and streams in removing nitrogen. The removal of other compounds via retention in other ecosystems will be the focus of subsequent work.

Data and indicators for mapping of nitrogen services at EU scale
We used the model GREEN (Geospatial Regression Equation for European Nutrient losses) to derive two indicators that describe the capacity and flow of nitrogen services in Europe. GREEN is a statistical model developed to estimate nitrogen and phosphorus fluxes to surface water in large river basins (Grizzetti et al., 2005). The model was developed and used in European basins with different climatic and nutrient pressure conditions (Grizzetti et al., 2005) and was successfully applied to the whole of Europe (Bouraoui et al., 2009; Grizzetti et al., 2008).
GREEN contains a spatial description of nutrient sources and physical characteristics influencing the nutrient retention. Europe is divided into a number of sub-catchments that are connected according to a river network structure. The sub-catchments constitute the spatial unit of analysis. In the application at the European scale, a catchment database covering all Europe was developed, based on the Arc Hydro model, with an average sub-catchment size of 180 km^2. (Bouraoui et al., 2009). For each sub-catchment, the model considers the input of diffuse and point nutrient sources and estimates the nutrient fraction retained during the transport from land to surface water (Basin Retention) and the nutrient fraction retained in the river segment (River Retention). In the case of nitrogen, diffuse sources include mineral fertilizers, manure applications, atmospheric deposition, crop fixation, and scattered dwellings, while point sources consist of industrial and waste water treatment discharges. In the model, the nitrogen retention is computed on an annual basis and includes both permanent and temporal removal. Diffuse sources are reduced by processes occurring on land (crop uptake, denitrification, and soil storage), and those occurring in the aquatic system (aquatic plant and microorganism uptake, sedimentation and denitrification), while point sources are assumed to directly enter surface waters and are, therefore, affected only by river retention. For each sub-catchment i the annual nitrogen load estimated at the sub-catchment outlet (Li, ton N/yr) is expressed as following:
$L_i = (1-RR_i) \times [(1-BR_i) \times DS_i+PS_i+U_i]$ Equation 1
where DS_i (ton N $year_{-1}$) is the sum of nitrogen diffuse sources, PS_i (ton N $year_{-1}$) is the sum of nitrogen point sources, U_i (ton N $year_{-1}$) is the nitrogen load received from upstream sub-catchments, and BR_i and RR_i (fraction, dimensionless) are the estimated nitrogen Basin Retention and River Retention, respectively. In the model, BR_i is estimated as a function of rainfall while RR_i depends on the river length and the size of lakes. For more details on model parameterisation and calibration see Grizzetti et al. (2008)and Bouraoui et al. (2009).

The capacity of freshwater ecosystems to remove nitrogen can be expressed using the in-stream retention efficiency (%), which explains what portion of the nitrogen entering rivers is retained. Fractional nutrient removal is determined by the strength of biological processes relative to hydrological conditions (residence time, discharge, width, volume). The product of the in-stream retention efficiency and the total nitrogen river loading yields the total amount of nitrogen that is retained per unit time. The latter indicator, normalized over the length in km was used as proxy for the nitrogen service flow.

FLOW REGULATION

Land use, relief, soil properties and climate (wind and precipitation) are the predominant variables determining the magnitude of erosion. Vegetation, in particular forests, help conserving soils and prevent the siltation of waterways and landslides.

Erosion control

Spatial indicators for mapping erosion control services at EU scale
The JRC's European Soil Data Centre (ESDAC) is the reference point for data provision of all soil related ecosystem services, including erosion control. The MESALES model uses data on land use, slope, soil properties and climate to predict the seasonal and annual averaged soil erosion (5 classes going from very low to very high). We intersected the map of the annual soil erosion risk with a map that retains the CLC classes with natural vegetation. The resulting map was used to spatially identify ecosystems that are situated in areas of different erosion risk giving more weight to ecosystems in areas with high erosion risk. This indicator is assumed to represent the **capacity of ecosystems to provide erosion control services**.
An indicator measuring the associated flow of this service needs to be developed yet.

Water storage capacity

Water regulation refers to the influence ecosystems have on the timing and magnitude of water runoff, flooding and aquifer recharge, particularly in terms of water storage potential of the ecosystem.
This service is closely related to water provision. For now, we made the distinction based on surface and subsurface water flows classifying ecosystems that capture the surface flow (rivers, lakes, wetlands) as providers of water and terrestrial systems that store or hold as regulators of water.

Data and indicators for mapping of water regulating services at EU scale
We used the annually aggregated soil infiltration (mm) as an indicator for the **capacity of terrestrial ecosystems to temporarily store surface water**. The data used are derived from the MAPPE model (Pistocchi, 2008; Pistocchi et al., 2010). MAPPE stands for Multimedia Assessment of Pollutant Pathways in the Environment of Europe and consists of models that simulate the pollutant pathways in air, soil sediments and surface and sea water at the European continental scale. Monthly infiltration of precipitated water in soils is calculated by distributing the net precipitation over run off and infiltration.
The service flow of water regulation by terrestrial ecosystems was approximated by using the annual sub surface water flow (mm or m3 year-1).

Coastal protection

Natural hazard protection refers to the capacity of ecosystems to reduce the damage caused by natural disasters. These include storms, floods, fires and landslides.

To avoid double counting, we refer to water quantity regulating services for the role of ecosystems to regulate water flows and to protect against floods. Similarly, protection against landslides may be covered by erosion control services.

Spatial indicators for mapping storm protection services at EU scale
As a first indicator for storm protection services, we mapped the area of coastal wetlands and dunes as a proxy for the capacity of ecosystems to protect against the consequences of sea-borne storms that hit the coast. The CLC2000 data served as source for this mapping. This work is in the process of publication. (Liquete et al., 2013)
An indicator assessing the associated service flow has still to be defined.

REGULATION OF BIOTIC ENVIRONMENT

Pollination

Pollination services refer to the role ecosystems play in transferring pollen between flower parts.

Spatial indicators for mapping pollination at EU scale
Klein et al. (2007) reviewed the importance of pollinators for world crops. They labeled 137 single crops and 115 commodity crops according to their dependence on pollination. For each crop, a dependency ratio was fixed. In addition, Gallai et al. (2009) presented an economic valuation of the vulnerability of world agriculture confronted with pollinator decline.
A second key publication (Ricketts et al., 2008) inferred relationships between distance to natural and semi-natural areas and pollinator richness, native visitation rate of crops and fruit/seed set.
A first mapping approach for an indicator which shows the capacity of natural ecosystems to provide pollination services has used these three key papers in order to map pollinator visitation rate as a function of distance to natural areas.
We used a European map of land use which includes the spatial distribution of crops, consistent with the official crops reported under the farm structure survey (Grizzetti et al., 2007). Next, crop dependency ratios (Gallai et al., 2009; Klein et al., 2007) indicating the dependency of crops on pollination (0-100%) were assigned to each crop.
For each crop land use pixel, the distance (m) to the nearest ecosystem was calculated using the CLC2000 map. The visitation probability (the probability that a crop gets visitated by a pollinator) was modeled using Ricketts et al. (2008) who presented a regression between distance and visitation rate based on a meta-analysis:
$P(\text{visitation}) = \exp(-0.53 \times \text{distance})$
where P stands for probability and distance is expressed in km. A maximum distance of 5 km is used as cutoff value.

For each crop land use pixel, the crop dependency and visitation probability were multiplied and this value was subsequently assigned to the nearest ecosystems which were assumed to sustain pollination. The sum of these contributions was finally considered as the pollination potential or the **capacity of natural ecosystem to provide pollination services**.

PROVISIONING ECOSYSTEM SERVICES

MATERIALS

Timber provision refers to the products made from trees harvested from natural forest ecosystems and plantations.

Timber stock

Coniferous and broadleaved growing stock as well as carbon stock of the above-ground biomass is mapped on a wall-to-wall basis with a spatial resolution of 500 m × 500 m per grid cell. An automatic up-scaling approach making use of satellite remote sensing data and field measurement data was applied for EU-wide mapping of growing stock and above-ground biomass in forests. The approach is based on sampling and allows the direct combination of data with different measurement units such as forest inventory plot data and satellite remote sensing data. For the classification, data from the Moderate Resolution Imaging Spectroradiometer (MODIS) were used. The classification results were evaluated by comparison with regional estimates derived independently from the classification from national forest inventories. The validation at the regional level shows a high correlation between the classification results and the field based estimates with correlation coefficient r = 0.96 for coniferous, r = 0.94 for broadleaved and r = 0.97 for total growing stock per hectare. The mean absolute error of the estimations is 25 m3/ha for coniferous, 20 m3/ha for broadleaved and 25 m3/ha for total growing stock per hectare. Biomass conversion and expansion factors were applied to convert the growing stock classification results to carbon stock in above-ground biomass (Gallaun et al., 2010)

Timber growth

Data for mapping timber services at EU scale
The **capacity of forests to produce timber** as well as the associated annual **timber increment** was approximated using two standing stock inventories. We firstly used the JRC forest inventory created by the AFOLU action to acquire regional statistics of the total area (ha), the standing stock volume (m_3 per statistical area per year) and the stock increment (m_3 ha_{-1} $year_{-1}$). Next, data for missing countries were gapfilled using the ESCIFEN database. These data were subsequently disaggregated to the $NUTS_X$ level using the CLC2000 data displaying the distribution of forests and agro-forestry areas as spatial surrogate.
The European Forest Institute (EFI) hosts the European Forest Information Scenario Database (EFISCEN) a forest inventory database of European countries, based on input from national inventory experts. The bases of the EFISCEN Inventory database are the individual national forest inventories of 32 European countries. For each forest type and age class, the forest area, the total and mean volume, the total annual increment and the current annual increment may be retrieved from the EFISCEN Inventory database. Such data are available for all countries which have an even-aged forest structure. Input data on area, growing stock volumes and increment are usually derived from national forest inventories. (http://www.efi.int/portal/virtual_library/databases/). Based on the EFISCEN inventory, the AFOLU action of the JRC produced provides aggregated statistics on the timber stock, expressed in ha and m3 and increment (m3 year-1). (http://fi.jrc.ec.europa.eu/Frameset.cfm).

WATER SUPPLY

Freshwater provision accounts for the availability of fresh water coming from inland bodies of surface waters for household, industrial and agricultural uses. In this assessment, we did not include groundwater resources.

Data and indicators for mapping freshwater provision at EU scale

Annual water flow

Wriedt and Bouraoui (2009) presented an assessment of water availability for Europe. This assessment presents a simplified methodology to break down the net precipitation water (or hydrological excess water) over surface and subsurface runoff. This analysis was done at the spatial resolution of sub catchments. A European catchment database HydroEurope was developed at IES-RWER Unit, providing catchment and river basin information complying with the ArcHydro database scheme. The database was developed to support water balance and nutrient transport modelling at European scale.
We used this information to assess the capacity and flow of freshwater ecosystems to contribute to the provision of fresh water. The **capacity of freshwater ecosystems to provide a reserve of freshwater** is approximated by the surface area of freshwater ecosystems. The **flow of freshwater provision** can be approximated by the annual water flow (mm or m^3 $year^{-1}$) that is available from surface waters.
As mentioned earlier, this assessment does not take into consideration the provision of subsurface fresh water reserves in aquifers and deep ground water.

The disaggregation of catchment data to 1 km grid sized data occurred via the Compound Topographic Index (CTI), and the SCS curve numbers for landuse (CLC). Both layer had equal importance. The Compound Topographic Index (CTI), which is calculated as Ln(As/tan(beta)), is representing a layer for the topographic influence of water accumulation in soil. The CTI is assumed to account not only for the topography (slope based) but indirectly also for soil conditions, since soil genesis is amongst other factors linked to geomorphological and topographic conditions. The SCS curve numbers, instead, express for a certain land use the water retention capacity. SCS curve number is a function of the soil's permeability, land use and antecendent soil water conditions. When attributing SCS curve numbers to landuse/landcover classes soils were assumed to exhibit moderate runoff potentials and 'fair' hydrologic conditions.

NUTRITION

Energy Return on Investment (EROI) in agricultural production

See Chapter 2. The index used in the analysis is the ratio Energy out / Energy in (MJ/MJ)

Grazing livestock density

Data and indicators for mapping of livestock services at EU scale
Naidoo et al. (2008) provide a methodology for global mapping of grassland production of livestock, from grazing on unimproved grasslands. To map livestock production on natural pastures, 3'-resolution global maps of livestock distributions were used and intersected with the spatial distribution of (unimproved) grasslands. Maps of gridded livestock data are produced by and are available at the FAO statistics database (FAO, 2007) http://www.fao.org/geonetwork (keyword gridded livestock).
We used the FAO maps of grazing livestock (the sum of goat and sheep densities) assuming that their total density reflects the capacity of grasslands (and other vegetation including agricultural areas) to provide livestock services. Urban areas were masked out. Cattle were not included due to risk of double-counting related to feed production already accounted for in the EROI.

CULTURAL ECOSYSTEM SERVICES

INTELLECTUAL AND EXPERIENTIAL

Recreation

Cultural ecosystem services are defined as the nonmaterial benefits obtained from ecosystems. Among these recreational pleasure that people derive from natural or managed ecosystems is defined as recreation service.

Data for mapping recreation services at EU scale

Due to data unavailability of EU27 harmonised data on accommodation facilities and tourist fluxes in non-urban areas at regional level, the exercise is carried out on recreational potential available to EU citizens.
The final results of the exercise is be a zonation of the EU into categories according to the Recreation Opportunity Spectrum (ROS) model (Joyce and Sutton, 2009), and an analysis of what is the provision of the ES recreation service to the average European citizen.
Recreation potential is mapped with the assumption that it is positively correlated to the degree of naturalness, to the presence of protected areas (following the assumption that they have been identified as holding a higher degree of naturalness, and as providers of recreation services and facilities), to the presence of coastlines (lakes and sea) and to the quality of bathing water. These variables are aggregated according to the methodology to build composite indicators. The final indicator provides information on the degree of potential recreation provision.

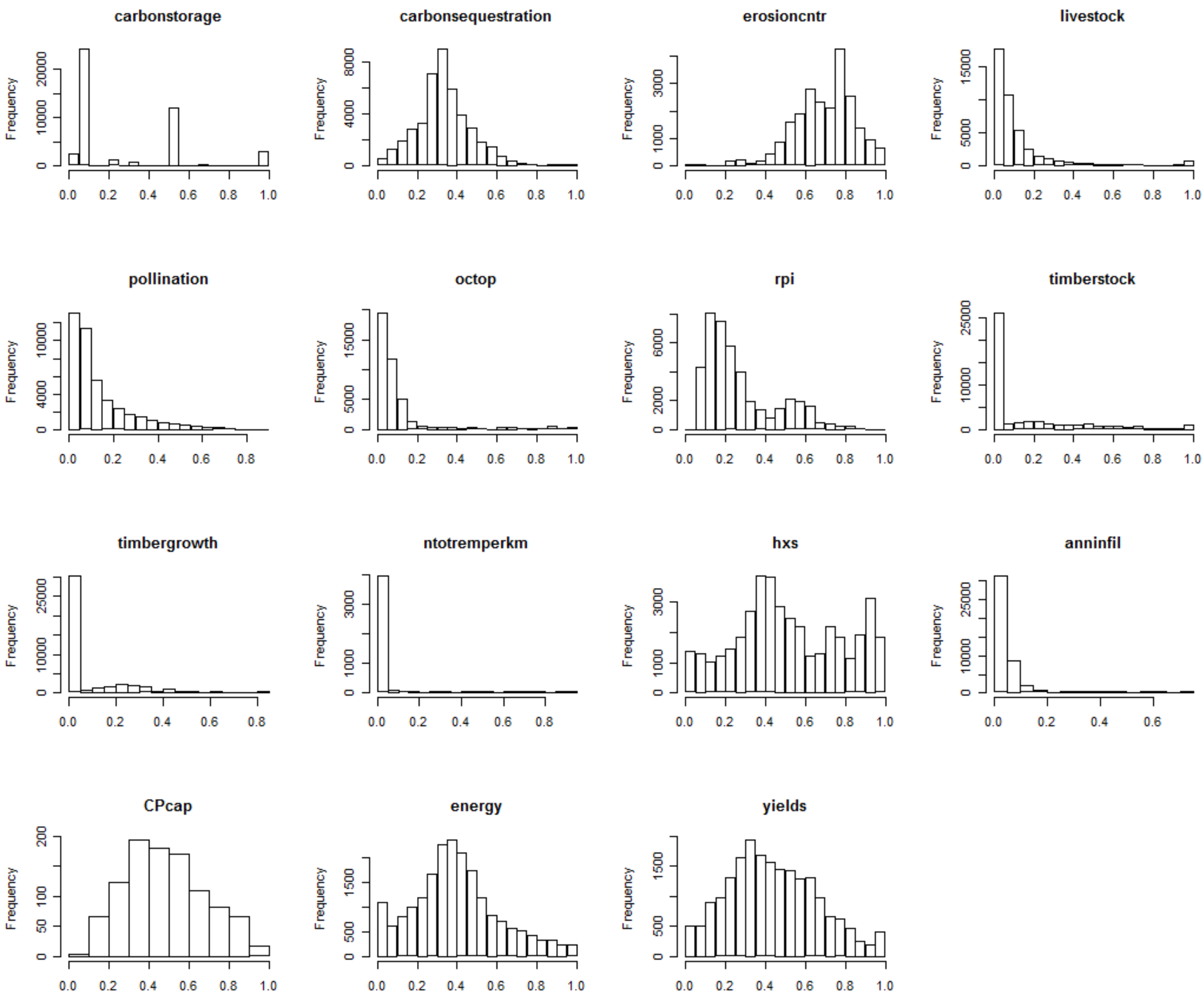


Figure 1: data distribution in normalized layers

General data processing:

Data used in this study is often being upsampled to from coarser scale to 1 km grid cells. If this was required for a continuous dataset, resampling occurred usually by a Bilinear resampling technique. All data layers were re-scaled to float values in the range [0,1], usually applying a min max normalization according to the scheme:

$$p_i' = \frac{p_i - p_{min}}{p_{max} - p_{min}}$$

Where p'i is the rescaled pixel value, pmin the global minimum and pmax the global maximum of the layer. In cases of effective or suspected outliers, re-scaling occurred between the percentile 1 and the percentile 99 instead of min and max. Then, values less then 0 or greater than 1 have been assigned values 0 and 1, respectively.

All data is held in the INSPIRE conform Lambert Azimuthal Equal Area projection, LAEA-ETRS 1989. The data extent is defined as the LAEA bounding coordinates: top, 6500000; left, 800000; right, 7500000; and bottom, 700000.