JRC TECHNICAL REPORTS

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2015

EUR 27538 EN

Joint Research Centre

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JRC97764

EUR 27538 EN

ISBN 978-92-79-52771-5 (PDF)

ISSN 1831-9424 (online)

doi:10.2788/679096 (online)



How to cite:
Pérez-Soba M., Elbersen B., Kempen M., Braat L., Staristky I., Wijngaart R. van der , Kaphengst T., Andersen E., Germer L., Smith L., Rega C., Paracchini M.L. (2015) Agricultural biomass as provisioning ecosystem service: quantification of energy flows ; EUR27538 EN; doi:10.2788/679096

# Table of contents

# Abstract

Agro-ecosystems supply provisioning, regulating and cultural services to human society. This study focuses on the agro-ecosystem provisioning services regarding the production of agricultural biomass. These services strongly respond to the socio-economic demands of human beings, and are characterised by an injection of energy in the ecosystems production cycle which is often exceeding the ecological capacity of the ecosystem, i.e. the overall ability of the ecosystem to produce goods and services linked to its bio-physical structure and processes that take place during the agricultural production. Agricultural production is identified as ecosystem service in widely recognised ecosystem service frameworks, but currently there is no clear agreement within the scientific and policy communities on how the ecological-socio-economic flow linked to this provisioning service should be assessed, beyond a mere accounting of yields. This study attempts to provide a new insight to this issue by proposing an approach based on the energy budget, which takes into consideration the energy needed by the ecosystem to supply the service. The approach is based on the concepts of Energy Return on Investment (EROI) and Net Energy Balance (NEB), and considers different bio-physical structures and processes of agro-ecosystems. The work is structured in three parts: the first aims at estimating inputs (machinery, seeds, fertilizers, irrigation, labour) in energy terms; the second at estimating biomass output in energy terms; the third to compare actual agricultural production with three reference scenarios encompassing a range of human input (no input – low input – high input scenarios). Results show that in general terms cereal and grassland systems have the largest energy gains (both in terms of EROI and NEB). Such systems are characterised by a lower economic value of their output compared to other producing systems such as fruits, which have lower energy gains but a higher embodied energy, which is recognized in the market as valuable. Comparison of actual production systems with the high input scenario confirms that current production in Europe is already highly intensive, and that increasing the energy input would not improve the efficiency of the conversion of such additional energy into biomass. Overall, the proposed approach seems a useful tool to identify which are the factors in the agricultural production process that could be modified to improve the energy efficiency in agricultural systems and the sustainability of their production. This study can be considered as a first step in the assessment of the total energy balance of the agro-ecosystem. In fact it deals with the quantification of energy regarding human inputs and the corresponding output and further analysis should address crucial issues such as the quality of the energy and the embodied energy in the plant production, which will help to better understand the complexity of the agro-ecosystems.

# 1. Introduction

In recent years, the scientific community has devoted relevant efforts in operationalizing the concept of ecosystem services. The links between biodiversity, ecosystems, the services ecosystems provide, and land management get more and more disentangled. Yet, there are still some areas in which efforts are needed at conceptual level, to better understand the role of ecosystems in supplying ecosystem services. One of these concerns agriculture.

Agricultural production is considered in ecosystem services frameworks (MA, 2005; TEEB, 2010a; Haines-Young and Potschin, 2013) a provisioning ecosystem service. In many studies it is assessed using as proxy agricultural production in terms of biomass or yields and eventually livestock (see e.g. Roces-Díaz et al, 2015; Williams and Hedlund, 2014). Such measurements, though, do not take into consideration the fact that agricultural output is not a mere product of the ecosystems, but a result of land management. In fact, agro-ecosystems would not exist without human intervention, and their soil biota, floristic and faunistic composition are deeply affected by agricultural practices.

When yields are used to calculate the supply of agricultural production as ecosystem service, the contribution of the ecosystem to such production is accounted for together with a number of other contributions coming from land management (fertilization, machinery, irrigation etc.).

In order to provide more insight in the composition of the energy balance in agricultural production , this report aims at quantifying, in terms of energy, human input in the agricultural process, and at mapping it at high resolution. To our knowledge this is the first attempt to provide such quantification at a continental scale.

The unit of measure used to perform the assessment is MJ/ha. All inputs and outputs of agricultural production are converted to this common unit of measurement, and budgets are calculated at the level of the soil surface per areal unit. Ultimately, the main reference for the energy budget is the ecosystem and calculations aim at understanding to what extent human interference through agricultural practices contributes to obtaining current agricultural production.

Having this information may not be sufficient to fully understand what level of intensity characterizes current agricultural systems. Hence a further effort is made, and energy budgets for scenarios of different agricultural intensity are calculated, from a minimum (agricultural areas all under extensive grazing) to a maximum (current farming systems make maximum use of fertilisers and water) intensity range.

## 2. Energy Return on Investment (EROI) and Net Energy Balance (NEB) as possible metrics to describe provisioning services delivered by agro-ecosystems

Ecosystem services can be conceptualised 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), in water streams, 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 biomass production process from agro-ecosystems are very complex as it is shown in Figure 1. The energy flows include:

1. Research & Development (R&D) energy: many, if not all, crops result from human intervention in genetic structure of crop and grass plant species, through either selection, crossbreeding or more recently gen-modification. In addition, a lot of energy is spent to define optimal growing conditions. The resulting seed quality (potential to produce desired type of biomass) can thus be expressed as ratio between energy content and energy invested per seed;
2. Before starting the agricultural process, seeds need to be delivered to place of application;
3. Farmers plant or sow the seeds by manual labour or aided by mechanical tools and (fossil) fuels;
4. Soils may be prepared for growing the crops by human and mechanical energy. Often highly concentrated chemical products are added (fertilizers, fungicides, nematocides), which again add energy input to the process;
5. Some crops require weeding and or aboveground pest control, again with manual, mechanical labour and energy intense chemical products;
6. Crops must be harvested (and transported, on their way to food processing, distribution and retail, which is not included in the present analysis). During harvest, desired biomass (usually the sugar and protein rich parts) are separated from the so called residual biomass (cellulose fibres, minerals), which can be used as source of fuel or fibre products, or fed back to the soil ecosystem, potentially saving on fertilizers;
7. Natural ecosystems have so far provided the genetic capital to produce biomass from plants in agricultural systems;
8. Sunlight, rain and wind are often grouped as abiotic natural capital, to distinguish them from the biotic natural capital involving the living organisms such as the plants and soil microorganisms as mycorrhiza, which supply essential nutrients to the root systems of the crops.

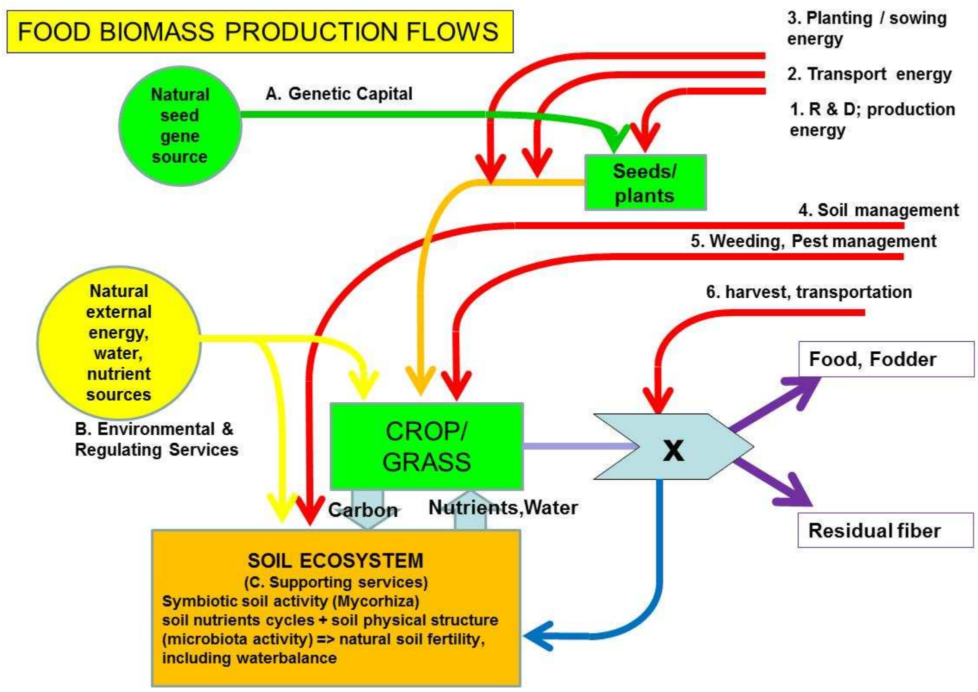


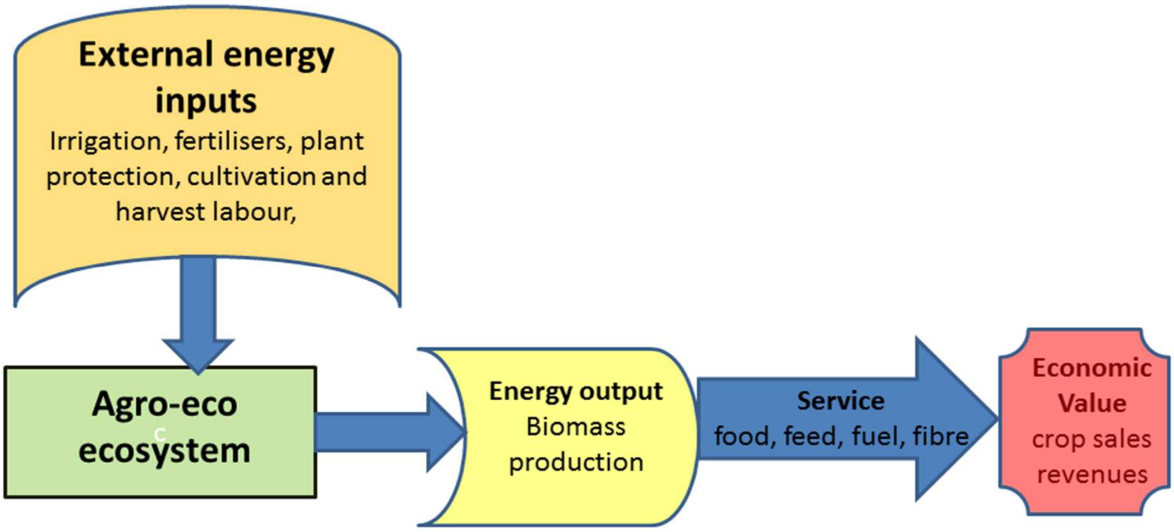

*Figure 1 The energy flows involved in food / feed biomass production. Solid lines indicate energy flows. Red lines = human activity; yellow lines = environmental / ecosystem processes; other colours: energy flows resulting from interaction of (natural) ecosystem & human flows.*

To date, there is no commonly agreed methodology to map and assess agricultural biomass production as ecosystem service. A commonly used indicator is yield expressed in different units of measure (ton/ha; MJ/ha; DM/ha) (Egoh et al., 2012). Such indicator, though, does not take into consideration the fact that agricultural biomass production would not be supplied by ecosystems without substantial human intervention which greatly relies on fossil fuel energy. The aim of this report is therefore to provide one step further in analysing the provision of biomass by agro-ecosystems by making more explicit the energy resource efficiency involved in the production process. To reach such target, this study explores the possibility to use two energy-based metrics: **Energy Return on Investment** (EROI) and **Net Energy Balance (NEB)**. EROI is defined as the energy gained from an energy-obtaining effort divided by the energy used to get that energy (Hall, 2011). Similarly, NEB is the energy gained minus the energy used. The EROI concept was originally developed in the field of ecology, the first studies dating back to 1970s, but since then it has been mostly applied in energy-related researches. EROI analysis gained momentum particularly in the last 10 years, linked to the debate on the peak oil and alternative energy supplies (see e.g. Hall *et al.*, 2014, Raugei *et al.*, 2012, Murphy *et al.*, 2011). In parallel, the EROI methodology is being increasingly used in food and agricultural research as a key indicator of the sustainability of agricultural production systems (Schramski *et al*., 2013; Markussen and Østergård, 2013, Martinez-Alier, 2011, Moore, 2010). To date, however, such studies range from farm to national scale; to the best of the authors' knowledge, the present is the first attempt of an EROI-based study in the agricultural domain at a continental (European) scale.

This study focuses on the direct use of the soil as natural resource for plant production, therefore direct inputs and outputs in and from the soil are considered. Such a perspective excludes all the indirect inputs (seed production) and output processes (e.g. animal production). Consequently, not all the energy flows shown in Figure 1 are considered. The energy inputs (the denominator in the EROI formula) included are labour, machinery, fertilizers and irrigation. Economic values, which are inherent to the valuation of the benefits provided by agricultural production to human well-being are briefly addressed in the study.

Figure 2 shows the major energy flows from agro-ecosystems to society, which are the objective of this study.

*Figure 2 Energy flows as addressed in the present study*




Moreover, the EROI approach can be considered as a building block of a conceptual model to assess provisioning ecosystem services in a broad sense, as biomass produced for energy consumption is based on biological processes (photosynthesis and other) and is directly captured by humans. 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 these activities can be expressed in energy units as well as the output gained in biomass. Another advantage of using an energy metric is that it enables a quantified assessment of many different human-influenced and natural ecosystems that are all characterised by flows of energy.

This study 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). This should be kept in mind when comparing the results of the present study with figures obtained by other studies applying EROI analysis to agricultural systems (e.g. Schramski *et al*., 2013)

In addition to the desired types of biomass (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.

Lastly, it should also be noted that the caloric (Joule or kcal) 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.

# 3. Analytical framework for the quantitative assessment of EROI and NEB

## 3.1 Introduction

In the present study, the choice has been made to address EROI and NEB at soil level. This because the study aims at supporting research on ecosystem services and from this perspective other approaches such as Life Cycle Analysis and agricultural modelling in the wider sense include processes that are not pertinent to the ecosystems in the strict sense. This implies that energy input and output included in the balance have to be directly linked to crops and to the land management activities directed at producing the crop, to management during cultivation (e.g. weeding, spreading plant protection products and fertilizers and irrigating) and to harvesting. The processing of the harvest in further end-products for human consumption is excluded.

The same applies to the production of meat or milk, which is excluded from the balance or at least stops after the cutting of grass, even though this grass may in fact be fed to animals to produce the milk and meat. The latter however need further inputs not linked directly to the soil (e.g. external feed, labour, machinery). The abiotic or environmental input such as solar energy, water and nutrients from the soil are not included in this study, which focuses solely, for the input part, on the energy flow deriving from human activities. This procedure also applies to the reference layers against which EROI and NEB of the actual agricultural systems are compared (see section 4.4).

An energy-based approach has many advantages as it enables to:

- express in a comparable way the size of the outputs even though these have a very different nature (e.g. wheat, grass, wood, corn);
- assess the net energy production by plants, comparing the energy input in the soil with the energy output in the yields;
- estimate the efficiency of the production systems which may range strongly within and between regions depending on management;
- express the production function of agricultural ecosystems in a range of indicators (see Table 1), which can be used further to develop a statistically robust analysis of the level of provisioning services delivered by agricultural ecosystems in the whole EU;
- analyse the provisioning service of agricultural ecosystems at different levels of human interference ranging from no interference, low interference to very high interference.

The study is articulated in three main steps: the first aims at estimating inputs (machinery, seeds, fertilizers, irrigation, labour) in energy terms (sections 3.2-3.3, detailed information in Annexes 2-3); the second at estimating biomass output in energy terms; (sections 3.3, detailed information in Annex 4); the third to compare actual agricultural production with three reference scenarios encompassing a range of human interference (described in section 3.3.2 and Annex 6, results in section 4.4). All calculations are made on a 1 km * 1 km grid, data are compliant to INSPIRE standards.

## 3.2 The CAPRI energy balance model

CAPRI (Common Agricultural Policy Regionalised Impact) is an EU-wide quantitative agricultural sector model aimed at assessing the effects of the Common Agricultural Policy (CAP). It features a global, spatial multi-commodity market module and a pan-European supply module based on non-liner programming models. Building on a large amount on statistical data from different sources (FAO, EUROSTAT, OECD), it allows to simulate agricultural production levels in Europe in different policy scenarios providing as well a wide set of related economic, environmental and landscape indicators (Britz and Witzke, 2013). Results generated at the regional (NUTS2) level can be downscaled to a finer spatial resolution of 1km cells (see Box 1).

Within CAPRI, a sub-module was developed that enables to calculate various indicators in relation to energy (Kempen and Kranzlein, 2008). It was designed for evaluating energy use and energy reduction policies in EU agriculture and it provides several energy indicators which incorporate the energy requirements for the input quantities of mineral fertilizer, direct energy sources, machinery, buildings, plant protection, seeds, production support systems (such as irrigation) and others. An overview of the type of indicators and units provided by the CAPRI energy module is given in Table 1.

*Table 1 Overview of parameters produced in the CAPRI energy module and the related units. Source: CAPRI modelling system*

| Parameter | Parameter Unit | Description |
|---|---|---|
| Energy per CAPRI activity unit | MJ/ha<br>MJ/head | Covers all energy requirements necessary for one CAPRI activity unit per year |
| Energy per CAPRI output unit | MJ/kg | All energy requirements for one CAPRI activity unit are divided by the output level; allocation between main product and by-products is carried out for a number of activities |
| Energy efficiency<br>Type “energy” | MJ/MJ | The output level of CAPRI activity is assessed by its energy content, whereas allocation between main product and side products is done for some activities. The results is divided by all energy requirements of the CAPRI activity unit. In short: Energy output (per kg) divided by energy input (per kg) |
| Energy balance | MJ | The output level of all CAPRI activities of a region are assessed by its energy contents, whereas allocation between main products and side products is done for some activities and then sum up over the region. The input energy requirements for all CAPRI activities are multiplied with the relevant activity levels and then sum up over the region. The results show energy requirements (INPUT) and energy output (OUTPUT). Imports and exports of energy can be shown separately |

| | | |
|---|---|---|
| Energy requirements-overview | MJ/ha<br>MJ/head | On an activity-based, regional level, the composition of total energy requirements can be shown on an aggregated level. |
| Energy requirements-detail | MJ/ha<br>MJ/head | On an activity-based, regional level, the composition of total energy requirements can be shown in detail. |
| Energy input units | Input unit/ha<br>Input unit/head | On an activity-based, regional level, the composition of input units driving he energy needs can be shown in detail |
| Energy content products | MJ/kg product | On an activity-based level, the energy contents for products can be shown; energy assessment of input is based on his parameter; energy content is assumed being equal throughout all NUTS II regions |

CAPRI models agricultural activities at farm level, therefore, for the assessment of the energy flows in this study, it was first necessary to convert the calculation approaches in the CAPRI module that were applicable to the farm level to the soil level. This means that among the available energy indicators at farm level, only those that affect the energy balance at soil level were selected.

As said in Chapter 2, two main indicators are used to quantify the energy balance of agro-ecosystems:

1) Energy Return on Investment (EROI) = MJout/MJin per ha.

2) Net Energy Balance (NEB) = MJout-MJin per ha

The two indicators are calculated per crop type and per crop group type. The calculations are done at regional level (CAPRI regions) and, to take account of the diversity in agro-environmental diversity, also at the level of Homogenous Spatial Mapping Units (HSMUs) as will be further explained in Section 3.3.1

In detail, the following factors are considered in energy flow calculation:

- On the input side, energy flows in relation to machinery, seeds, fertilizers (including nitrogen from manure), irrigation and labour are included.
- On the output side, biomass production and related energy output is taken into account in produced food, feed and other biomass potentially used for fibre, fuel and other products. To determine the total biomass output, the starting point is the biomass that can be removed sustainably which includes biomass already harvested in some measure as part of regular crop management activities such as straw baling and pruning and cutting in permanent crops. In the interpretation of the results as categorized according to crop type and grouped crop types, account needs to be taken of the composition of the crop activities on the final results.

## 3.3 Approach to calculate a soil energy balance

The first step is to convert the farm energy balance to a soil energy balance. In order to do this, all cropping activities in a region are considered, and for these activities energy input and output factors are linked as far as they are directly linked to the soil on which these crops are cultivated. The crops included in the assessment are listed in Table 2. EROI and NEB are calculated per crop, but then aggregated to different clusters of crops to produce the final results of the analysis. The grouping of the crops is described in Annex 1.

*Table 2 Overview of crops included in CAPRI*

| Crop acronyms | Crops | In/excluded |
|---|---|---|
| SWHE | soft wheat | in |
| DWHE | durum wheat | in |
| RYEM | rye | in |
| BARL | barley | in |
| OATS | oats | in |
| MAIZ | sugar maize | in |
| OCER | other cereals | in |
| RAPE | oil seed rape | in |
| SUNF | sunflower | in |
| SOYA | soya | in |
| OOIL | other oil crops | in |
| OIND | other industrial crops | ex |
| NURS | nursery crops | ex |
| FLOW | flowers | ex |
| OCRO | Other crops | ex |
| MAIF | fodder maize | in |
| ROOF | fodder root crops | in |
| OFAR | fodder other on arable land | in |
| GRAE | extensive grassland | in |
| GRAI | intensive grassland | in |
| PARI | paddy rice | in |
| OLIV | olives | in |
| PULS | pulses | in |
| POTA | potatoes | in |
| SUGB | sugar beet | in |
| TEXT | flax and hemp | in |
| TOBA | tobacco | in |
| TOMA | tomatoes | in |
| OVEG | other vegetables | in |
| APPL | apples | in |
| OFRU | other fruits | in |
| CITR | citrus | in |
| TAGR | table grapes | in |
| TABO | table olives | in |
| TWIN | wine | in |
| FALL | fallow | in |
| ISET | Set aside obligatory - idling | in |

| | | |
|---|---|---|
| GSET | Set aside obligatory used as grass land | in |
| TSET | Set aside obligatory - fast growing trees | in |
| VSET | Set aside voluntary | in |

On the input side, there are two dimensions of energy inputs:
1) Input per resource (e.g. fertilizer, machinery, fuel)
2) Input per activity/process (e.g. cultivation, irrigation)

The difference between these dimensions can be illustrated with the following example. Ploughing a field requires 4000 MJ for fuel and 3000 MJ for energy used to produce the machinery (tractor and trailed machinery). The latter is allocated to the crop according to the hours of machinery used in cultivating and harvesting that crop and its depreciation. Irrigating the plot requires 2000MJ for fuel and 1000 MJ for energy used to produce the pump in the factory, which is again allocated to the crop according to the hours of irrigation and the depreciation of the pump. In total, the energy input is 10000 MJ, which can be allocated to the crop and aggregated in two ways:

1) 6000 MJ fuel and 4000 MJ machinery (resource dimension), or
2) 7000MJ for cultivation and 3000 MJ for irrigation (activity dimension).

An overview of all energy input indicators per crop per resource and per activity is given in Table 3. The energy input per resource refers to all the energy that is used to produce the resource that is further used in the establishment, cultivation and harvesting of a crop.

*Table 3 Input indicators included in the soil energy balance*

| **Indicator** | **Unit** | **Description** |
|---|---|---|
| Plant protection products | MJ/ha | Energy that is needed to produce the plant protection products that are needed per hectare per crop |
| Electricity | MJ/ha | Energy input as electricity |
| Diesel | MJ/ha | Energy input as diesel fuel (energy content of diesel + energy used in processing) |
| Other fuels | MJ/ha | Energy input as other fuel (energy content + energy used in processing) |
| Machinery | MJ/ha | Share of the energy needed to produce the machinery used for planting, cultivation and harvesting, allocated proportionally to the hours of use over the total expected life of the machine |
| Seed | MJ/ha | Energy used during production of the seed |
| Mineral fertilizer (Nitrogen, Phosphates and potassium) | MJ/ha | Energy used during production of the mineral fertilizer |
| Seeding/planting | MJ/ha | Energy used for planting/seeding the crop. |
| Cultivation management | MJ/ha | Energy used in mechanisation (tractor use) and fuel for managing the crop once established (e.g. weeding) |
| Application of fertilizer | MJ/ha | Energy used for applying the fertilizers |
| Application of manure | MJ/ha | Energy used for applying manure |
| Application of plant protection products | MJ/ha | Energy for plant protection products |
| Application/pumping of irrigation water | MJ/ha | Energy used in mechanisation (e.g. pump) and fuel for applying irrigation water |

| | | |
|---|---|---|
| Processing harvested goods | MJ/ha | Energy used to conserve harvested good, mainly drying of cereals |
| Labour | MJ/ha | Energy needed by humans to perform all the crop production related activities |

Plant protection products, seeds and mineral fertilizers all require energy when produced. The input of this energy can directly be linked to the crop, as how much of these inputs are used per crop is a known variable. Therefore, these can also be easily linked to the land on which these crops are grown and thus expressed in input per hectare (e.g. MJ/ha). Assessing the energy input used in the production of machinery is more complex, as the machinery is not used only for a single crop; furthermore, some crops need more machinery input than others. At this regard, the CAPRI model considers the (average) operation time of machinery per crop as a distribution factor based on data derived from national machinery inventories. In case of data gaps, values of countries are used which have most similar farming characteristics.
To calculate the energy contents of fertilizers, both artificial and manure fertilizers need to be included and allocated to a crop. The incorporation of manure required additional processing as in the CAPRI farm energy balance calculation, all manure fertilizer was (indirectly) allocated to animal production, while for the soil energy balance this needs to be allocated to the cropping activities (including grasslands).
Since CAPRI calculates input of nitrogen (N), phosphate (P) and potassium (K) in kg per crop, the energy input used for spreading the manure also needs to be allocated to N, P. K contents of manure. How this is calculated is explained in Annex 2. The reason why the energy input only includes the fuel consumption of the tractor and other machinery used, and not the energy used in the production of the machinery, is that according to the logic of the CAPRI energy model this part of the energy input is completely allocated to the 'cultivation' part of the cropping activities.
For irrigation, figures from different sources were used to get the most up-to-date and spatially detailed overview of irrigation share per crop and total irrigation water consumption per crop. Several of these sources were already included in the CAPRI model. These are based on various national sources providing information on irrigated crop area and/or water use combined with crop specific expert information. However, as part of this project, these CAPRI irrigation data were further up-dated with more spatially detailed irrigation data based on Wriedt et al. (2009) in which irrigation shares per crop area and total irrigation water consumption are provided at 10*10 km grid. Further details are provided in Annex 5.
Labour was not initially included in the CAPRI energy balance module. Within the scope of this project, a first simple estimate was made of the energy contents of one hour of labour input It was assumed that, on average, a farmer needs a basic intakes of 2900 Kcal/day plus additional 1200 kcal to do heavy physical work, giving a total caloric need of 4100 kcal/day, equivalent to approximately 500 kcal (2092MJ) per working hour, considering 8 working hours a day. Further details are provided in Annex 3.
On the output side, a distinction was made between:

- output of harvested products used for food and feed;
- output of biomass that can be used for production of non-food products including bioenergy.

The latter category includes all biomass that can be harvested sustainably and which is already harvested in some measure as part of regular crop management activities such as pruning and cutting.
The CAPRI model calculates crop yield in kg fresh weight. The CAPRI energy module was fed with data on energy content of the output products (food, feed and other biomass) that were collected from literature. In Annex 4 an overview of the energy content of all output included in the assessment is given. As a starting point, coefficients are estimated

from the energy of forage (as defined in animal science literature) and heating value of biomass. As values are typically given per kg dry matter, all the coefficients had to be converted to fresh weight.

### 3.3.1 Calculation of EROI and NEB at regional and HSMU level

The calculation of EROI and NEB are made at the scale of regions (CAPRI regions) and at a more detailed scale of Homogenous Spatial Mapping Units (HSMU) (see Box 1).

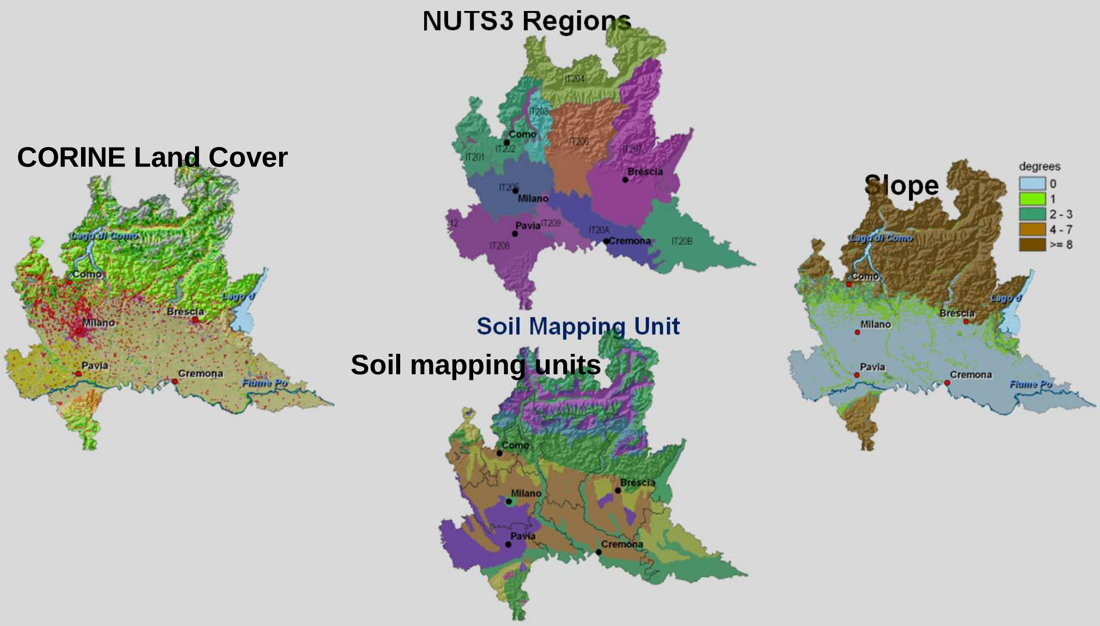
The approach used to convert all the input and output factors to this detailed spatial level is illustrated in Annex 5 and can be synthetized as follows: since most administrative regions (e.g. NUTS regions) are very diverse from an agro-physical perspective, there is a need to split these regions into smaller entities to take better account of the diversity of farming conditions and farm management practices. These conditions and practices are very influential in the energy input and output relations of cropping activities. It therefore makes sense to establish a soil-level energy balance at the level of HSMUs, enabling a better approach to keep diversity within regions into consideration. In order to do this, HSMU-specific energy input and output factors need to be available. Some of these factors (yield, manure and mineral fertilizers) are already available within CAPRI at the HSMU level. As regards energy inputs of irrigation, seed, plant protection, harvest and labour, disaggregation at HSMU level starting from data at NUTS2 level was implemented as part of this project. Further details on the approach used for this exercise are provided in Annex 5. In Chapter 4, results are presented both at regional and HSMU level.

## *Box 1: Homogeneous Spatial Mapping Units (HSMUs)*

Within the Dynaspat project (Kempen et al., 2007; Leip et al. 2008), the Homogeneous Spatial Mapping Units (HSMUs) have been created and land use information has been assigned to these units in a statistical allocation procedure. In the SEAMLESS project, the allocation of Farm Accountancy Data Network (FADN) farms to HSMU then followed a similar statistical and econometric procedure as the land use allocation and the results were then aggregated into dimensions of a farm typology.

HSMUs are an intersection of land cover (Corine LC 2000), relief (slope in five classes), Soil Mapping Units (so-called soil landscapes from the European soil map) and the NUTS 2/3 boundaries (depending on the size of the NUTS regions) (see the image below in this box). Each HSMU has identical values for land cover class, slope class and Soil SET. Other parameters (such as annual rainfall) may differ inside the HSMU. These HSMUs can be multiple polygons (open) which implies that one HSMU can be spread over different locations within a NUTS area. Attributes belonging to every HSMU are calculated (characteristics in terms of soil, climate, land cover, yielding capacity). These attributes were used to allocate the land uses to the HSMUs, but also the farms. Further details on the allocation of land uses and farm types can be derived from Kempen et al. (2011) and Elbersen et al. (2006 and 2010).

***An HSMU is an intersection of land cover, slope, soil mapping units and NUTS boundaries***




In order to calculate the soil-level energy balance at the HSMU level it was necessary to first allocate all energy input and output factors to the HSMU level. In the CAPRI-Dynaspat module, all crop areas are already distributed over HSMUs. The same applies to some input and output factors which have already been allocated in a statistical allocation procedure to the crops per HSMU (see Table 1 in Annex 5 for an overview) or will still be allocated to HSMU within the scope of this project. The allocation already done took yield level as the distribution factor (so everything is proportional to yield). The yield was derived from the MARS-CGMS1, a crop growth model providing yield predictions for all major crops in the EU taking account of detailed soil and meteorological data integrated with statistical yield information. Details on the spatial allocation procedure of already allocated farm management factors can be derived from Leip et al. (2008).

### 3.3.2 Calculation of the reference scenarios

In order to compare the different levels of land use intensity of agricultural ecosystems in terms of energy, different reference situations reflecting various human interference into the provisioning function of natural systems have been envisaged.

Given data availability and the logic discussed in Chapter 2, the following reference situations are considered:

- the EU is completely covered by natural grassland (all present agricultural land use per region/HSMU is covered by natural grassland, extensively grazed by wild animals);
- agriculture is entirely under low-input farming practices;
- agriculture is entirely under high input farming practices (intensive crop production)

The natural grassland layer assumes a situation in which the present agricultural land area of the EU is covered by grassland that is maintained by the grazing of wild animals. No external inputs are assumed. The climate and soil conditions determine the biomass yield in combination with the extensive grazing of wild animals. The yield is both water limited and nutrient limited. The nitrogen availability in natural grasslands is restricted to the nitrogen base supply per soil type which is maintained by the nitrogen fixation of the vegetation. This fixation is very low as under purely natural circumstances there is practically no nitrogen deposition resulting from intensive livestock systems and other sources. The base nitrogen supply can therefore be purely based on the natural nitrogen availability of every soil texture class and is estimated per STU (soil typological Unit) based on its texture class (see Annex 6).

The low input layer assumes a similar land use pattern as the actual one, but at a 50% lower input level for nitrogen and no irrigation.

The high input layer assumes a similar land use pattern as the actual one but at maximum yield. This implies that crop growth is simulated assuming no water, nor nitrogen limitation.

All the three scenarios were built using the The Crop Growth Monitoring System (CGMS) of the European Commission Joint Research Centre, a comprehensive system used to monitor and forecast the growth of crop biomass based on daily acquisition of meteorological data, remote sensing and crop-growth simulation models. The latter take into account weather conditions, soil characteristics and management practice to simulate the evolution of crop biomass over time. More details on CGMS and the preparation of these three reference layers are given in Annex 6.

For each reference layer the, EROI and NEB have been calculated. The results are compared against EROI and NEB of the actual farming situation to understand the relative performance of actual farming.

### 3.3.3 Calculation of the economic value

The economic value per crop and per hectare is defined as the product of yield and national market prices (yield*market price). For non-marketable feed, a shadow value is estimated based on marketable commodities. For example, the value of roughage is determined by taking the value of the replacement, e.g. the value of oil cake and cereals to be bought to replace the roughage in terms of crude protein and energy. The amount of replacement and the related price determines the shadow value of the roughage.

For the calculation of the output values, the subsidies paid under Pillar 1 and 2 of the Common Agricultural Policy of the EU are excluded, but the market price may be affected by market intervention policies (e.g. export subsidies, interventions).

# 4. Results

EROI and NEB calculations are presented in this chapter for the actual situation, i.e. the one calculated with the detailed statistically-based farm information for the years 2003-2005 contained in the COCO (Complete and Consistent) and CAPREG (CAPRI Regionalised) databases embedded in the CAPRI system.

For the presentation of the results, different crop groups have been defined (see Annex 1). A further analysis of which groups of crops are most suitable for the presentation of the final results is provided in Annex 7. From this analysis, it becomes clear that the best coverage of HSMUs is reached by including the category "CropsAll" and "ArablePermGrassFallow". In Annex 1 an overview is given of the different land use categories included in these 2 aggregated classes. From that overview it becomes clear that these 2 aggregated classes cover practically all crops and grassland area. The reason for working with different land use aggregations is that there are agricultural crop activities which produce relatively small amounts of energy, e.g. vineyards, olives and fallow and will therefore generally show a negative energy balance result. In the interpretation of the results as categorized according to grouped crop types account needs to be taken of the composition of the crop activities on the final results.

In the following section, an overview is first given of the specific input and output levels per crop group. This provides an understanding of the differences in crop types in input and output mixes and also of how these differ among EU regions, environmental zones and within regions. This is then followed by a presentation of the final EROI and NEB results and how they relate to the economic value. The latter represents a proxy of the willingness to pay for the energy output of agriculture. Finally, EROI and NEB of the actual farming situation is compared with the three reference layers previously described (high input, low input and all natural grassland).

## 4.1 EROI and NEB – Actual farming system

The EROI and NEB calculations were made per crop and were then aggregated to total area averages and crop group averages to make them comparable and to analyse the overall patterns and trends and incorporation of different types of land uses (see Annex 1). After all some crops produce only very small amounts of feed output leading to a negative energy balance (e.g. vineyards, citrus, olives and fallow).

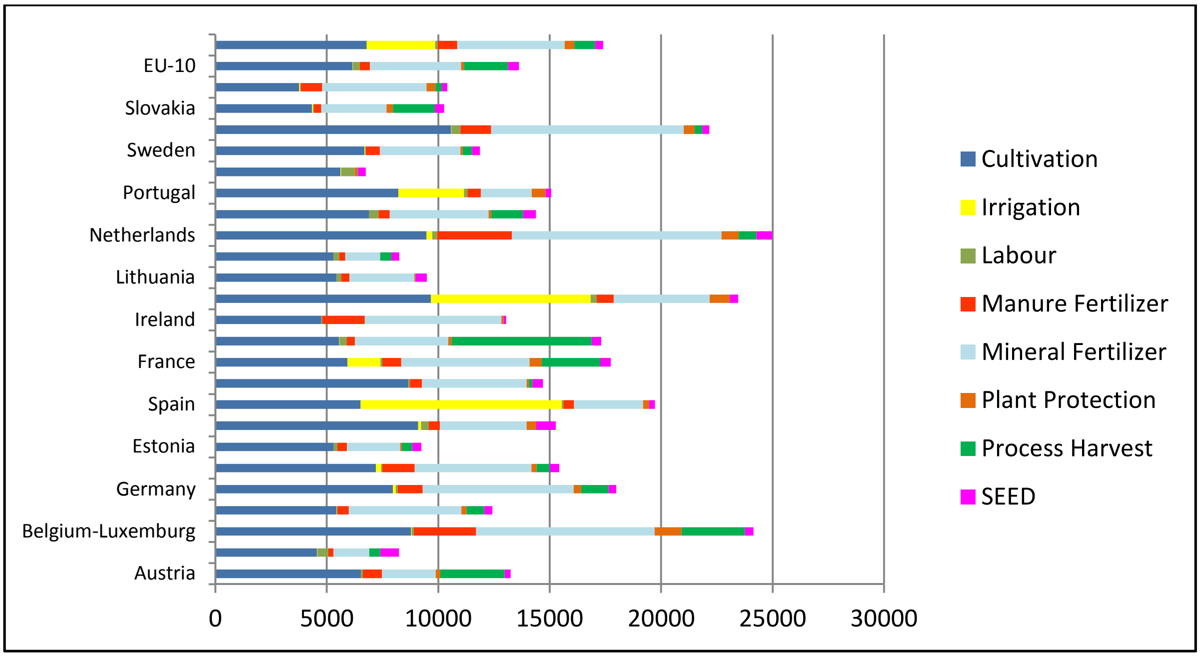
Overall, results indicate that there are very large differences in input and output levels between crops, but also within crop groups among EU regions.

In Figure 3, an overview is given of the average input per hectare per category. Overall, it emerges 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 stands out as a Country with a relatively low input level per hectare.

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

The categories taking the largest part of the input are mostly energy for cultivation and fertilizers. In some Mediterranean Countries (Italy and Spain), irrigation also adds significantly to the input side.

*Figure 3: Composition of input (MJ/ha) for all crops in EU countries*




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 in the current farming system). The results in Figure 4 show that highest output levels in food are found in Denmark, Poland, Finland, Germany, Czech Republic and Belgium. EU-10 Countries, generally presenting lower input level, have a higher output level than the EU-15, at least as far as the food output is concerned. The comparison of the input and the output already shows that high input levels are often associated to high output levels and vice versa. This is especially true in relation to total biomass output, but not necessarily in relation to food output. This is also confirmed by the NEB figures, shown in Figure 5.

*Figure 4 Average output (MJ/ha) for all crops in terms of food, feed and other biomass*

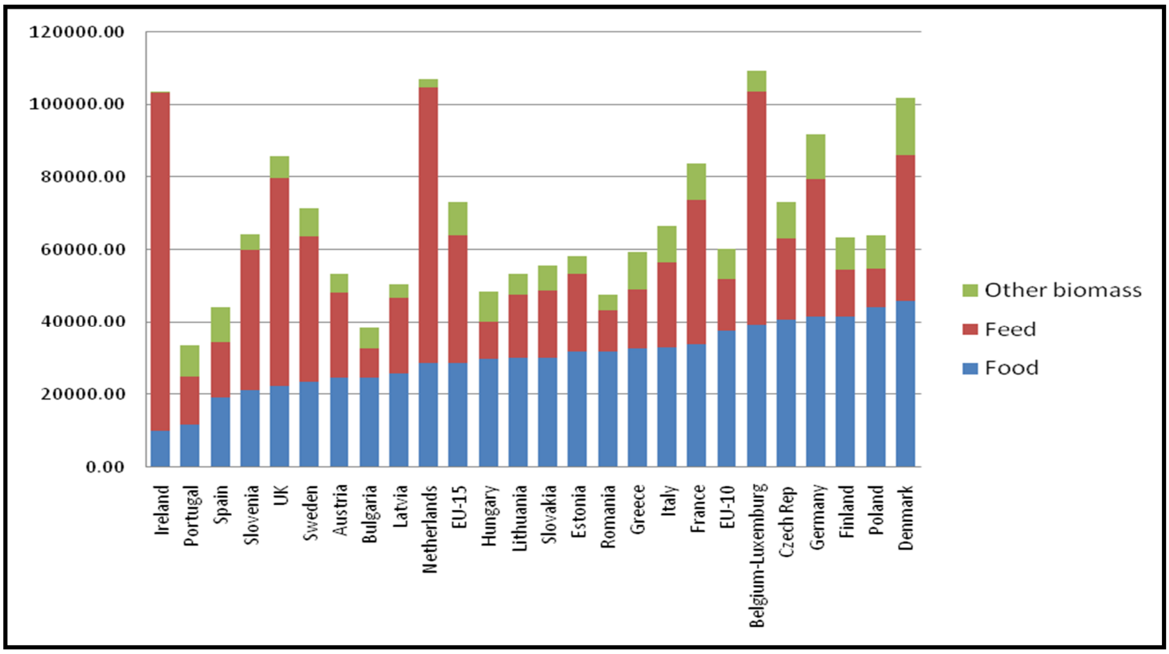
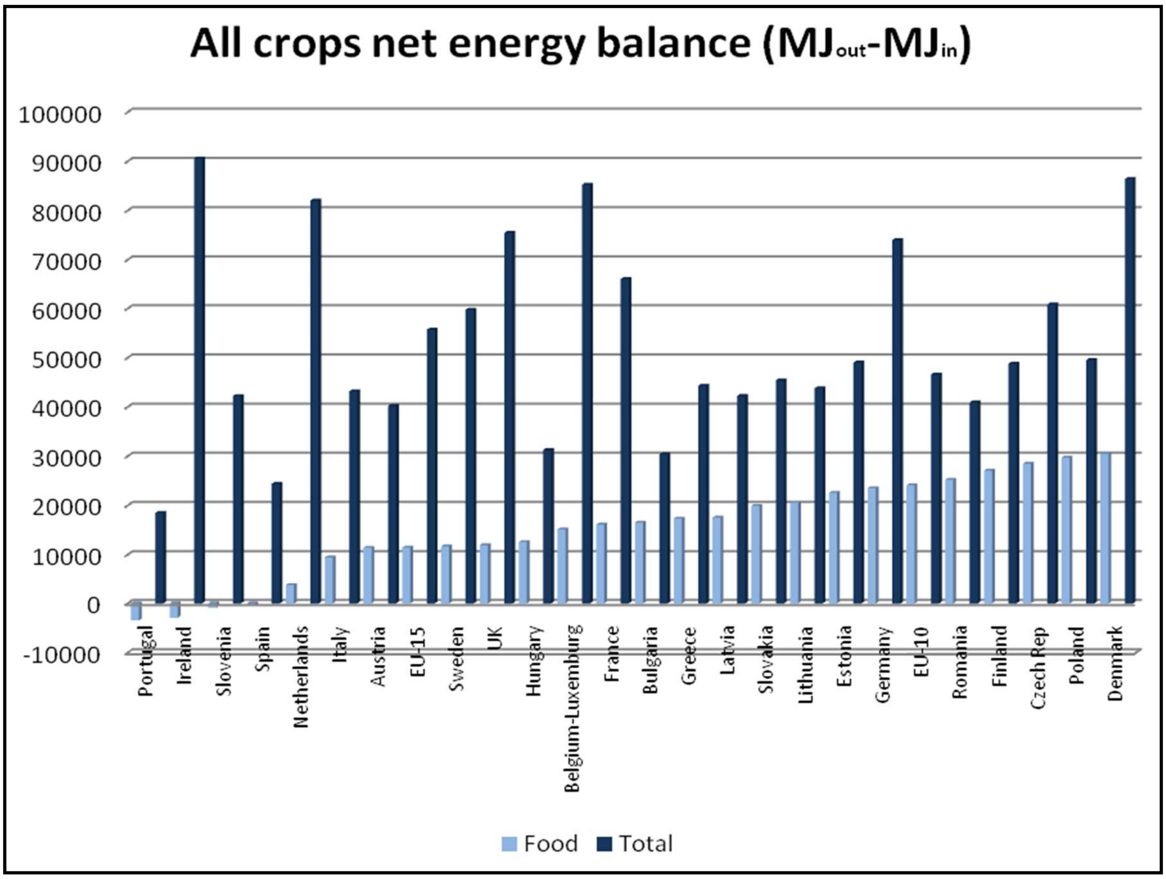


*Figure 5 Average Net Energy Balance per hectare (MJ/ha) for all crops*




The highest net output in terms of total biomass is reached in Ireland, Belgium, Denmark, Netherlands, UK and Germany, all showing both relatively high and low input levels. Explanatory factors for such a distribution should clearly be sought in a combination of elements, but location in the Atlantic zone with a temperate climate is likely to 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 (see Table 4 and Annex 8, Tables 1 and 2). Countries with a very high share of arable land on the total of the agricultural area are Denmark, Finland, Hungary, Czech Republic and Sweden. These high arable land shares are often associated to high or 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 ones with the higher output levels, particularly in total biomass. Countries with a more mixed land use pattern, as most southern EU Countries, generally show a lower output level, particularly in areas hosting a high proportion of fallow land, as is the case for Portugal, Spain and Bulgaria.

*Table 4 Relative area shares per crop (%/total Utilised Agricultural Area)*

| Country | total | Fallow | Vegetable | Gras | Fruit | Olives | Vineyard |
|---|---|---|---|---|---|---|---|
| **Austria** | 39% | 5% | 0% | 54% | 0% | 0% | 1% |
| **Bulgaria** | 51% | 10% | 1% | 34% | 1% | 0% | 3% |
| **Belgium-Luxemburg** | 55% | 2% | 3% | 38% | 1% | 0% | 0% |
| **Czech Rep** | 72% | 2% | 1% | 24% | 1% | 0% | 0% |
| **Germany** | 63% | 7% | 1% | 28% | 0% | 0% | 1% |
| **Denmark** | 84% | 8% | 0% | 7% | 0% | 0% | 0% |
| **Estonia** | 66% | 4% | 0% | 30% | 0% | 0% | 0% |
| **Greece** | 37% | 9% | 3% | 29% | 4% | 16% | 2% |
| **Spain** | 35% | 16% | 1% | 31% | 4% | 9% | 4% |
| **Finland** | 81% | 15% | 0% | 3% | 0% | 0% | 0% |
| **France** | 58% | 6% | 1% | 32% | 1% | 0% | 3% |
| **Hungary** | 74% | 4% | 2% | 17% | 2% | 0% | 2% |
| **Ireland** | 27% | 1% | 0% | 72% | 0% | 0% | 0% |
| **Italy** | 50% | 4% | 3% | 26% | 4% | 7% | 5% |
| **Lithuania** | 58% | 7% | 1% | 32% | 1% | 0% | 0% |
| **Latvia** | 56% | 6% | 1% | 36% | 1% | 0% | 0% |
| **Netherland** | 50% | 2% | 4% | 43% | 1% | 0% | 0% |
| **Poland** | 67% | 9% | 1% | 21% | 2% | 0% | 0% |
| **Portugal** | 36% | 10% | 1% | 32% | 4% | 10% | 6% |
| **Romania** | 60% | 3% | 2% | 33% | 2% | 0% | 2% |
| **Sweden** | 71% | 15% | 0% | 14% | 0% | 0% | 0% |
| **Slovenia** | 35% | 0% | 1% | 59% | 1% | 0% | 4% |
| **Slovakia** | 65% | 0% | 1% | 33% | 0% | 0% | 1% |
| **UK** | 35% | 3% | 1% | 61% | 0% | 0% | 0% |

Although part of the energy ratios per Country can be explained by the composition of the agricultural land use, diversity in management of the crops is also an important factor for regional differences, which also become clear when comparing input and output levels per Country and environmental zone per crop (see Annex 9).

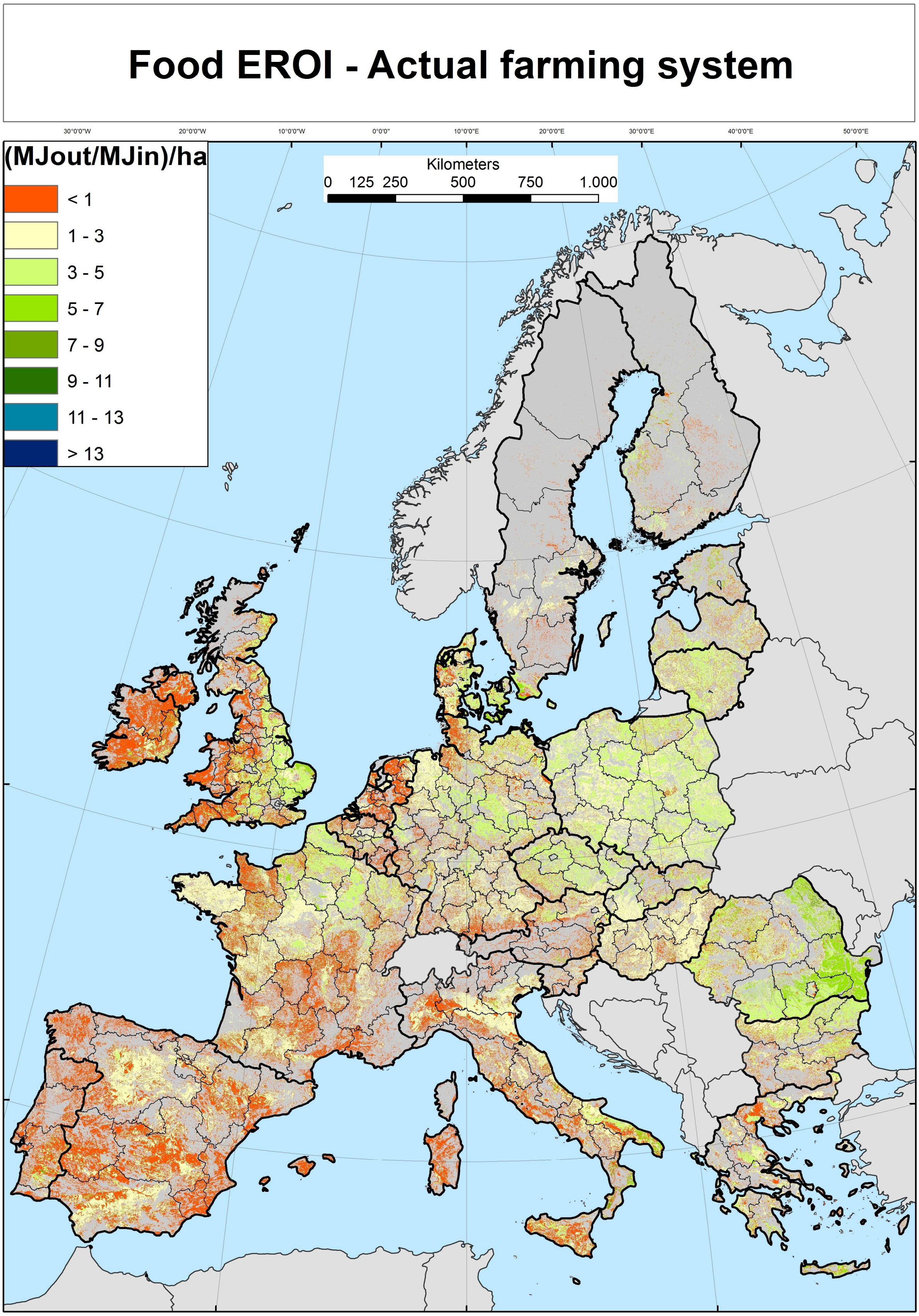
For all crops, the energy for fertilizers and cultivation on average accounts for the largest share of the input, but the largest variation in input levels per region is found for irrigation, as shown in Annex 9. Clearly, average input levels are lower in the Alpine, Boreal-Nemoral and Continental-Pannonian zones. In the Atlantic-Lusitanian zone and the Mediterranean, 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 extreme values are more distant 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 determined by high level of energy input in cultivation and by mineral fertilizer application.

For cereals, the largest share of the input is generally represented by mineral application, followed by energy input for harvesting, but the largest regional variation is found in the irrigation level and in harvesting. Permanent crops show by far the highest average inputs and the largest regional variation in input levels. This diversification is caused by large variations in both cultivation and irrigation inputs. For grassland, the variation is also enormous, with irrigation and fertilizer inputs being highly diversified between regions.

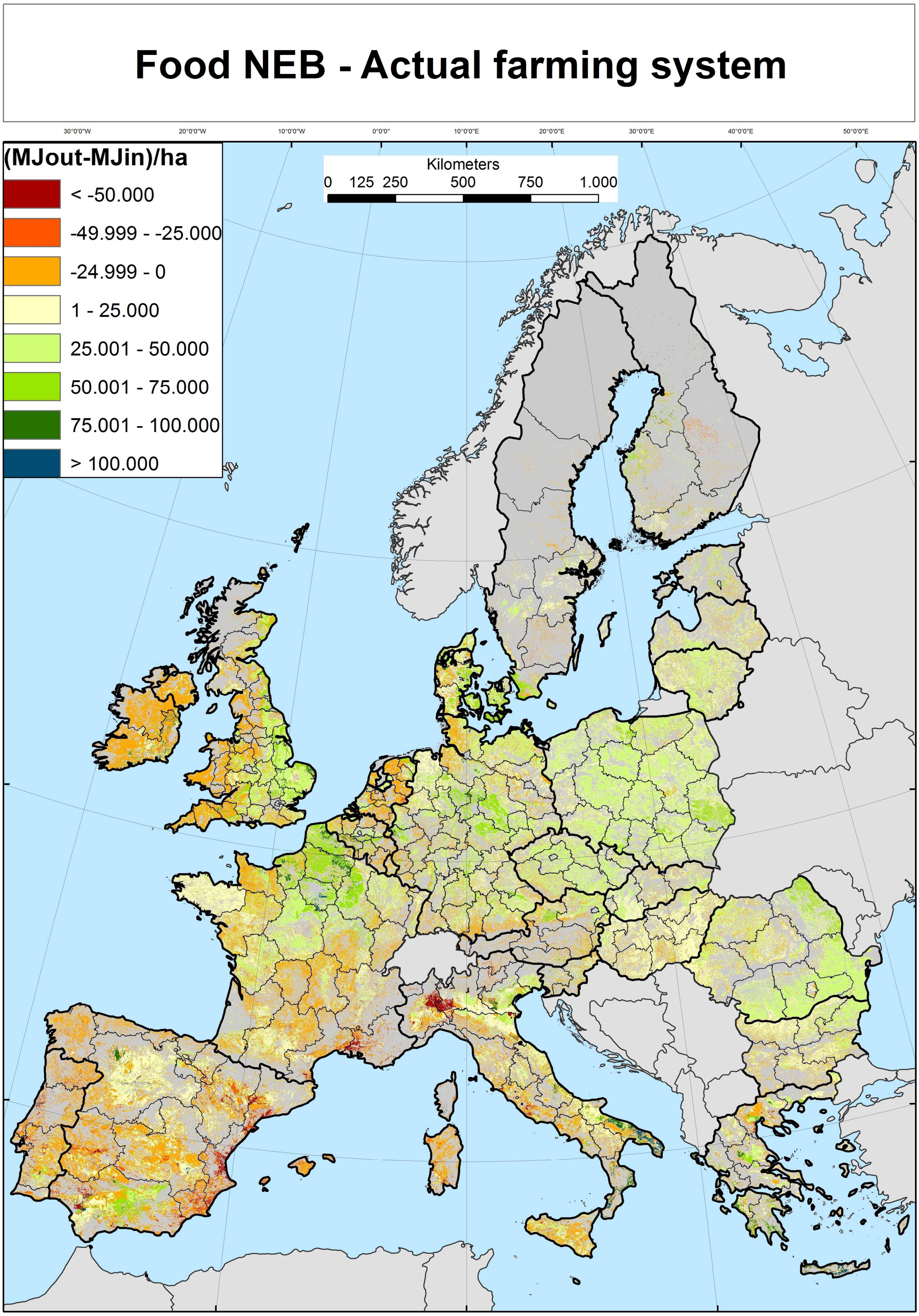
Overall, it can be concluded that variations in input levels are very wide within crops, both for the whole EU and within environmental zones, particularly in relation to irrigation, process harvesting and mineral fertilizer applications.

Maps 1 and 2 below show EROI and NEB levels for food output under the actual farming system for the whole of the EU. Maps 3 and 4 show EROI and NEB levels for total biomass.

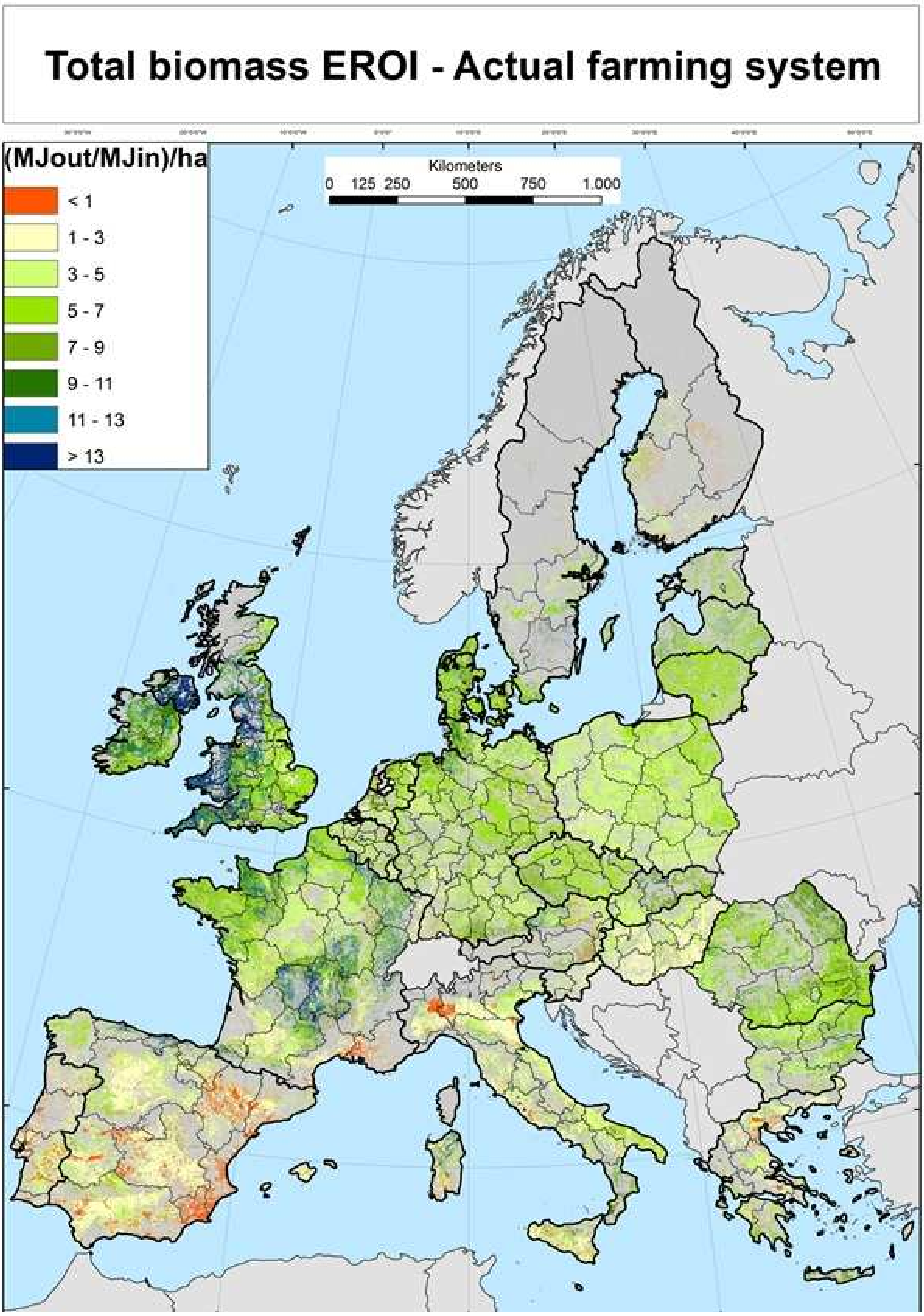
*Map 1- EROI per hectare calculated for food at HSMU level - actual farming system*



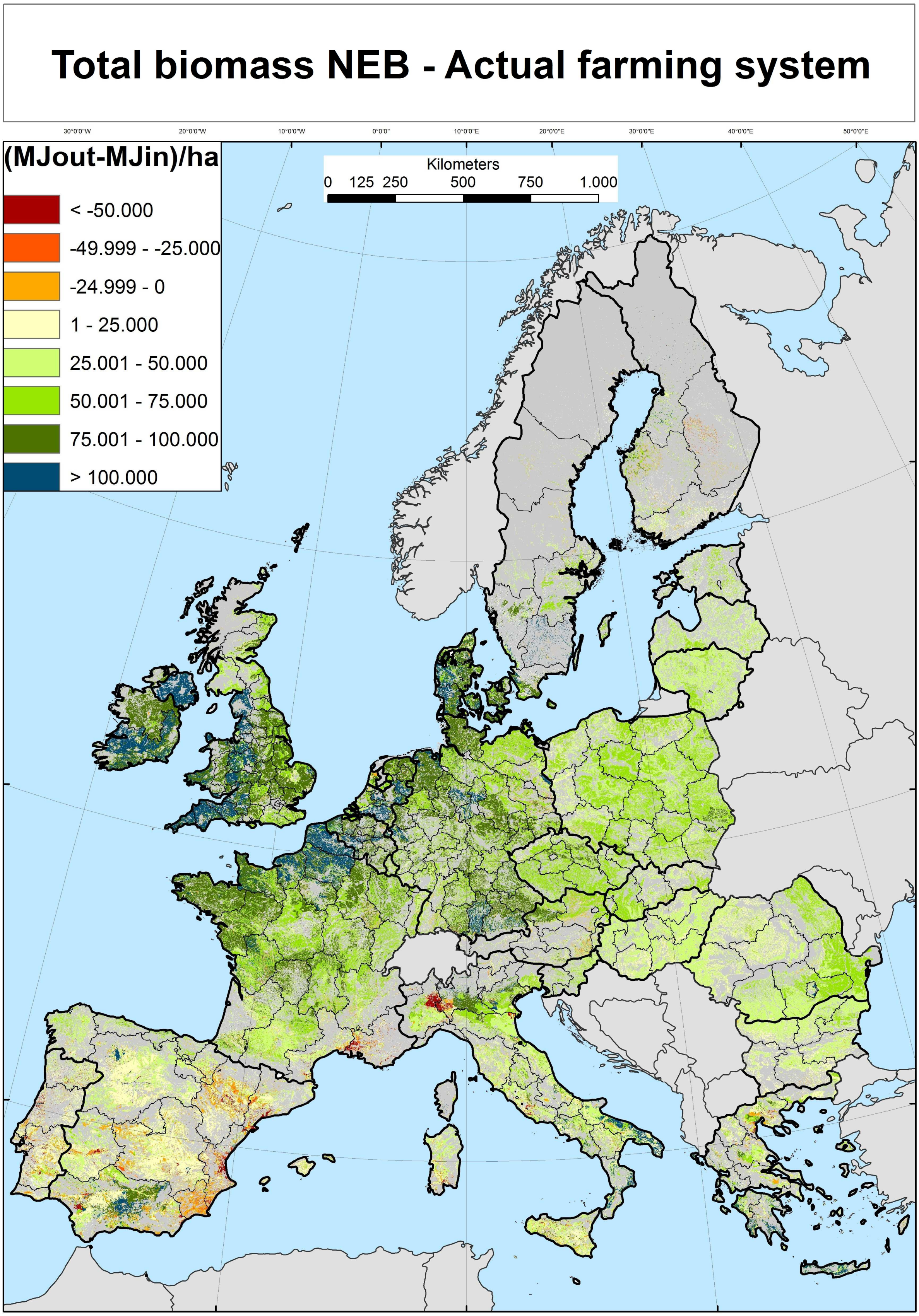
Map 2 NEB per hectare calculated for food at HSMU level–actual farming system



*Map 3 : EROI per hectare calculated for total biomass at HSMU level – actual farming system*



*Map 4: NEB per hectare calculated for total biomass at HSMU level–actual situation*



As it might be expected, the maps show a highly diversified situation across Europe, reflecting the intrinsic differences in agricultural areas, climatic conditions, farming intensity and mechanization of farming practice.

Some general trends can be highlighted: overall, EROI and NEB show a positive correlation, meaning that generally highest net energy gains are associated to high efficiency (in energy terms) of production systems. This however is just a general trend and several exceptions emerge from the maps, for instance in Atlantic arable land of Belgium and the Netherlands, and North-West France where NEB values are very high but EROI is medium.

A geographic trend also emerges, with Atlantic Regions having generally higher NEB and EROI compared to Mediterranean ones and Eastern Europe laying in between, although exceptions can be found also in this case (e.g.: Apulia region in Italy and several areas in Andalusia where olives is the main crops, showing high NEB).

When only the food output is considered, negative NEB and EROI values <1 are found either in regions dominated by pastures (e.g, Ireland, Northern and Central France, The Netherlands) or in the Mediterranean zones, where irrigation accounts for a significant part of energy input. Conversely, the highest EROI and NEB values are found mostly in arable–dominated areas such as eastern England, Northern France, Poland, Rumania, central Germany and in some spots in Andalusia (Southern Spain) and Apulia (South-East Italy) dominated by olive groves

When total biomass output is taken into account (Maps 3-4), only few spots show negative NEB (EROI<1), located in Mediterranean areas of Southern France Spain Greece and Italy and mainly corresponding to rice fields and permanently irrigated areas. In all cases, this is probably due to high energy input due to irrigation. The highest NEB values are located mostly in grassland areas in the Atlantic UK, Ireland, North and Western France, Denmark, Germany and central Po Valley. Again, NEB and EROI follow similar patterns, although some differences can be spotted, e.g. in Picardy - Nord-Pas de Calais (Northern France) or the Central Po valley, where very high net energy gain are associated to medium/low EROI values.

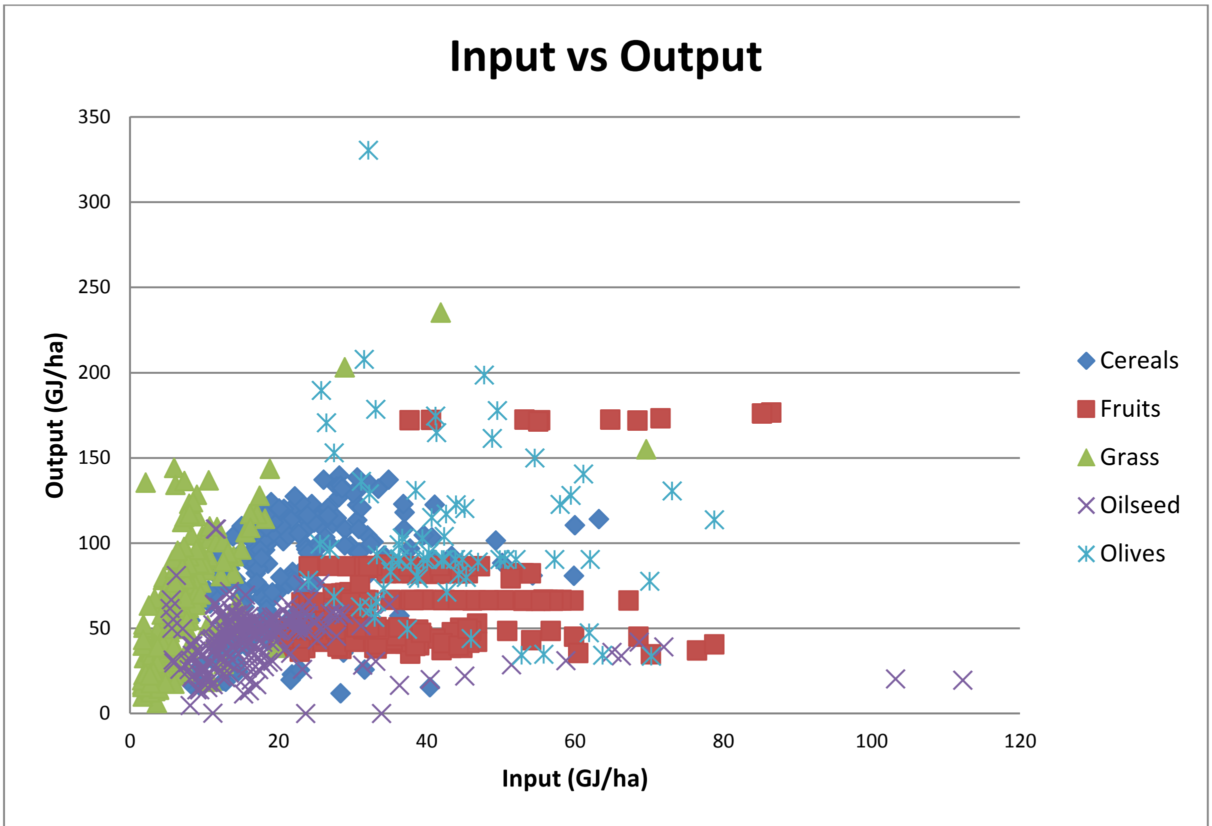
## 4.2 Relation between input and output

The spatial distribution of EROI and NEB values shows 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 largest energy gains are in arable and grassland systems in which, generally, high outputs are reached with lower input levels. This is confirmed in Figure 6, showing how grasslands have low input levels while their output levels vary from very low to very high. Arable crops, like cereals and oilseeds, 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 shows a large diversity. Overall, input levels are clearly higher than in grassland and arable, 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 being almost zero. Cereals, oilseeds and fruits are aggregates of various crops. Therefore, a low correlation can partly be explained by changing crop shares within these aggregates. Only grassland, which is a pure class, shows a medium, positive correlation between input and output.

In fruits and olives, overall input levels are clearly higher than in grassland and arable, while the output levels are generally 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 6: Input and output relation*




Overall, it can be concluded that no specific trends can be identified in the general relation between inputs and outputs, but some patterns can be distinguished within crops.

## 4.3 Relation between NEB and economic value

As part of provisioning ecosystem services, agricultural biomass provides benefits to humans that can be measured in economic terms. The economic value of the agricultural biomass is defined as product of yield and national market prices (yield*market price). For non-marketable feed (e.g. grass) a shadow value is estimated based on marketable commodities (see Section 3.3.3 for further explanation).

Results are presented in Figure 7, which shows that the relation between both indicators is very weak, but positive. Hence, there is some indication that if NEB is high there is also a higher economic valuation. However, when this relation is examined within crop groups the relational patterns are less distinct than when total input and output are compared. Nevertheless, some clusters can be distinguished (see Figure 7 and Table 5).

*Figure 7: Relation between Net Energy Balance and economic value*

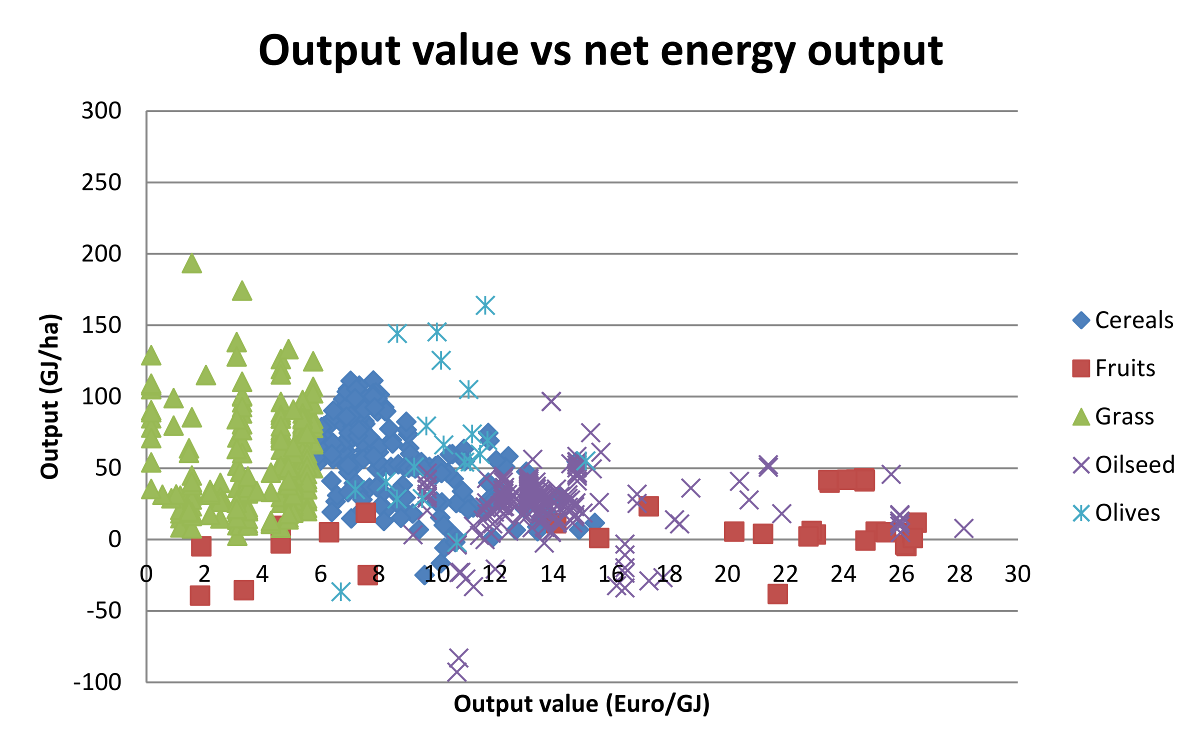



*Table 5 Characteristics of crop groups at EU-27 level*

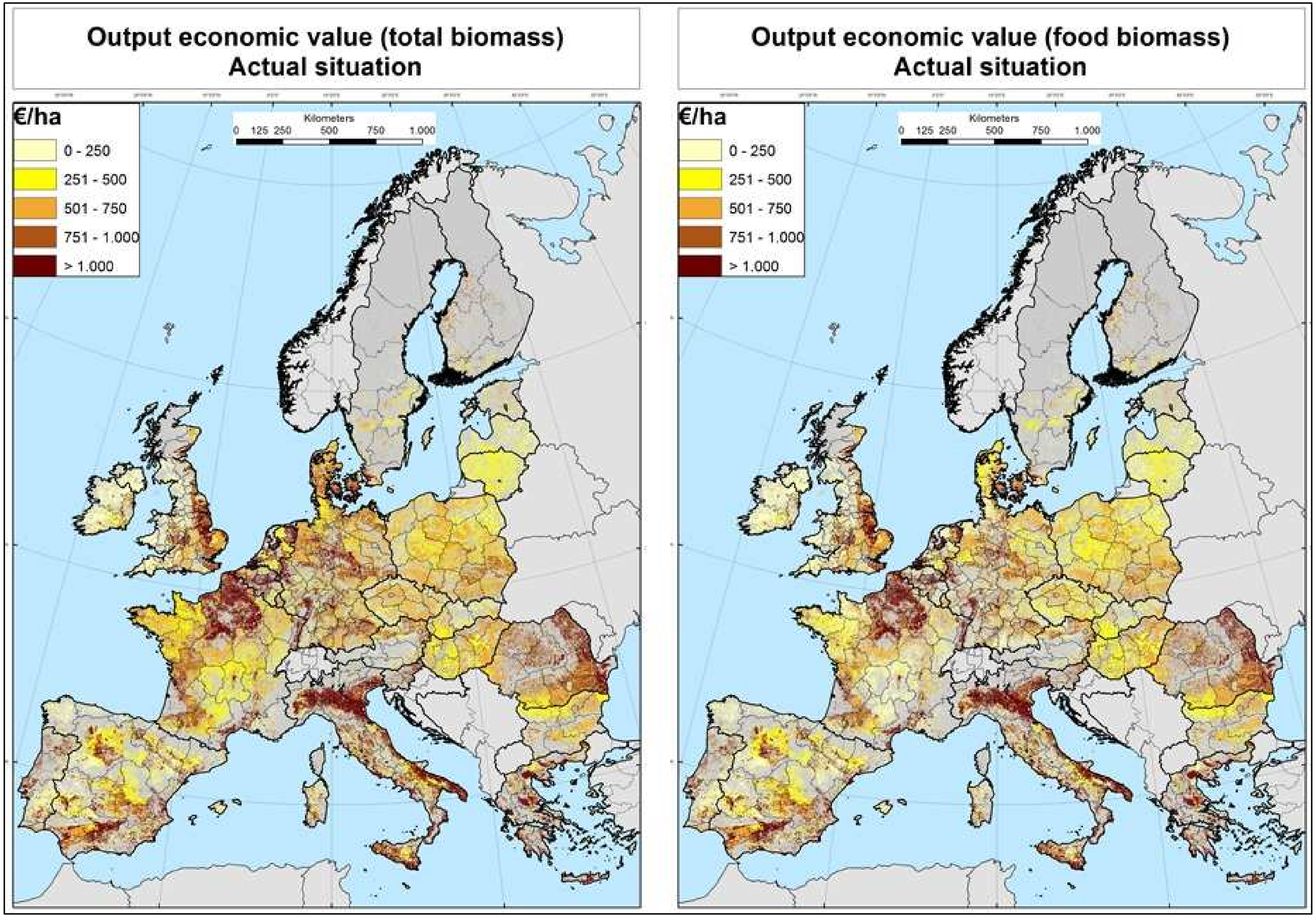
| | **Input (GJ/ha)** | **Output (GJ/ha)** | **Net Energy balance (GJ/ha)** | **Output Value (Euro/ha)** | **EUR/GJ** |
|---|---|---|---|---|---|
| Cereals | 20 | 84.0 | 63.9 | 642 | 7,8 |
| Oilseed | 15.7 | 44.7 | 29.0 | 618 | 13,7 |
| Grass | 6.5 | 57.9 | 51.5 | 164 | 2,9 |
| Fruits | 40.3 | 52.4 | 12.1 | 4465 | 62,1 |
| Olives | 41.8 | 133.5 | 91.7 | 1420 | 10,3 |

The diagrams and the table show that the prices of agricultural products are not strongly correlated with their NEB, nor with the relative energy content of the output (GJ/ha). For instance, cereals have only a slightly higher NEB per hectare than grass, but the economic value of their output is four times greater.

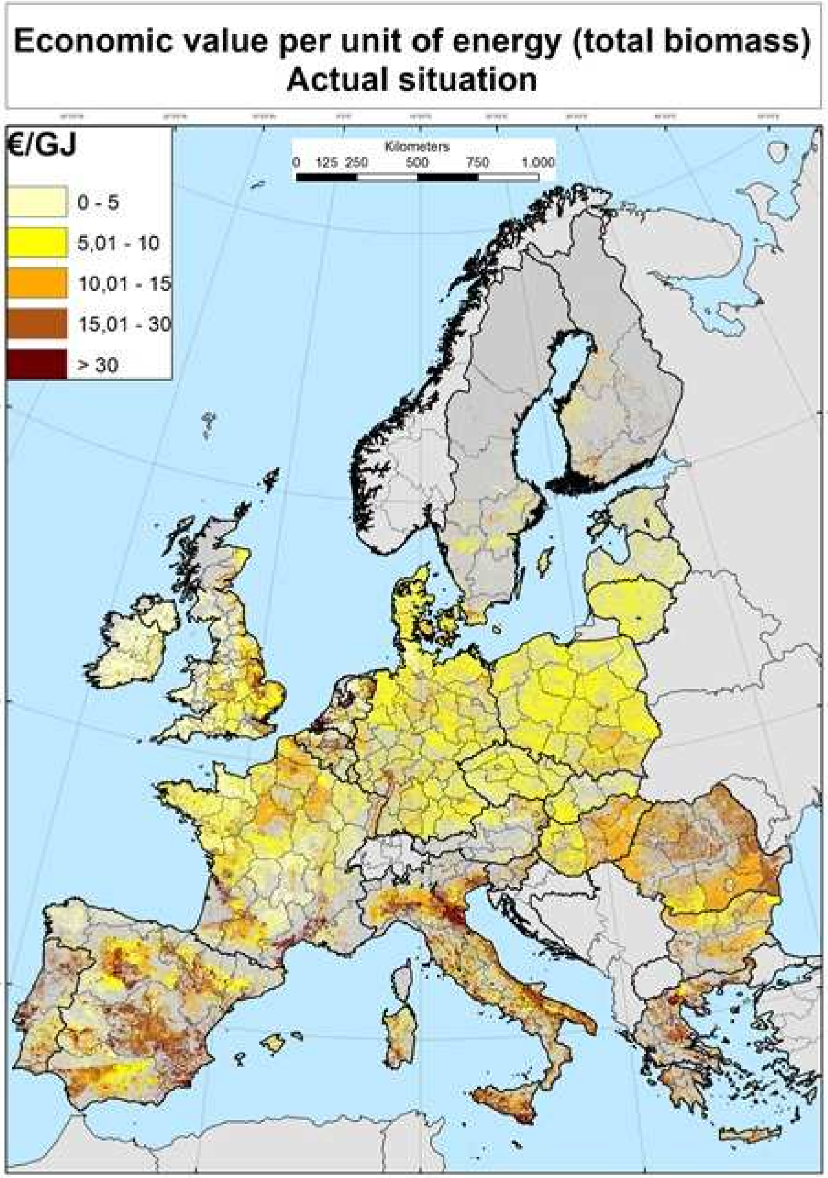
This is reflected by the crops economic value per unit of energy, reported in the last column of Table 5, which ranges from 2.9 €/GJ for grass to more than 60 €/GJ for fruits. This great variability indicates that it is not just the caloric content of food that determines its economic value, but other factors shall be considered, as the total energy embedded in the production process, the degree of concentration of the caloric energy in agricultural outputs and their overall nutritional value (see also section 5 for further considerations).

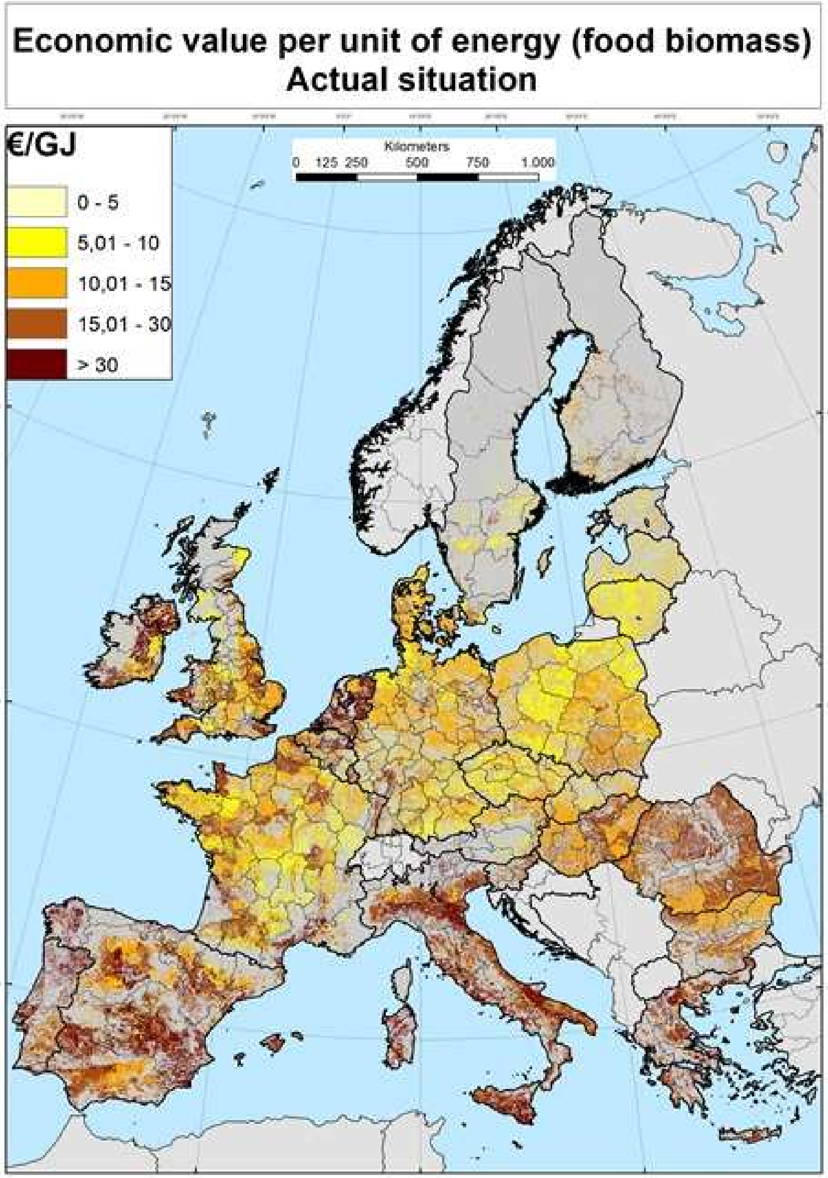
Maps 5 and 6 below show respectively the economic value of total and food output (€/ha) and the economic value per unit of produced energy (€/GJ - total biomass and food biomass) in the current farming system.

*Map 5 Economic value of total biomass output (left) and food output (right). Actual situation*



*Map 6 Economic value per unit of output energy; left: total biomass; right: food biomass. Actual situation*



## 4.4 Comparing EROI and NEB of actual farming situation against varying levels of human interference in ecosystems

Three different reference situations (reflecting various human interference into the provisioning function of natural systems) were calculated to compare the different levels of land use intensity of agricultural ecosystems in terms of EROI and NEB:

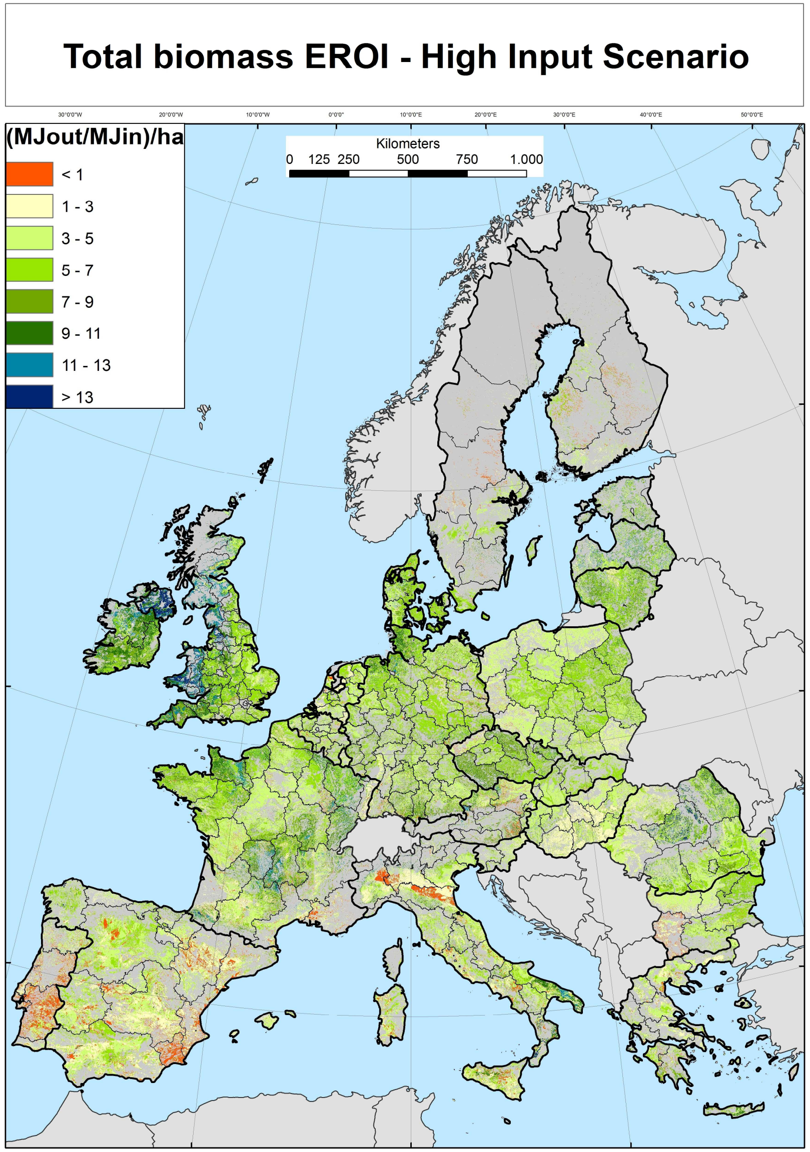
- Grassland scenario: all agricultural land in Europe is maintained as permanent natural grassland with minimum intensity grazing.
- Low-input farming: no irrigation is assumed, and input level of nitrogen are decreased by 50% compared to actual ones.
- High-input farming (intensive crop production): no water nor nitrogen limitation are assumed, so the yields are the maximum achievable at each location.

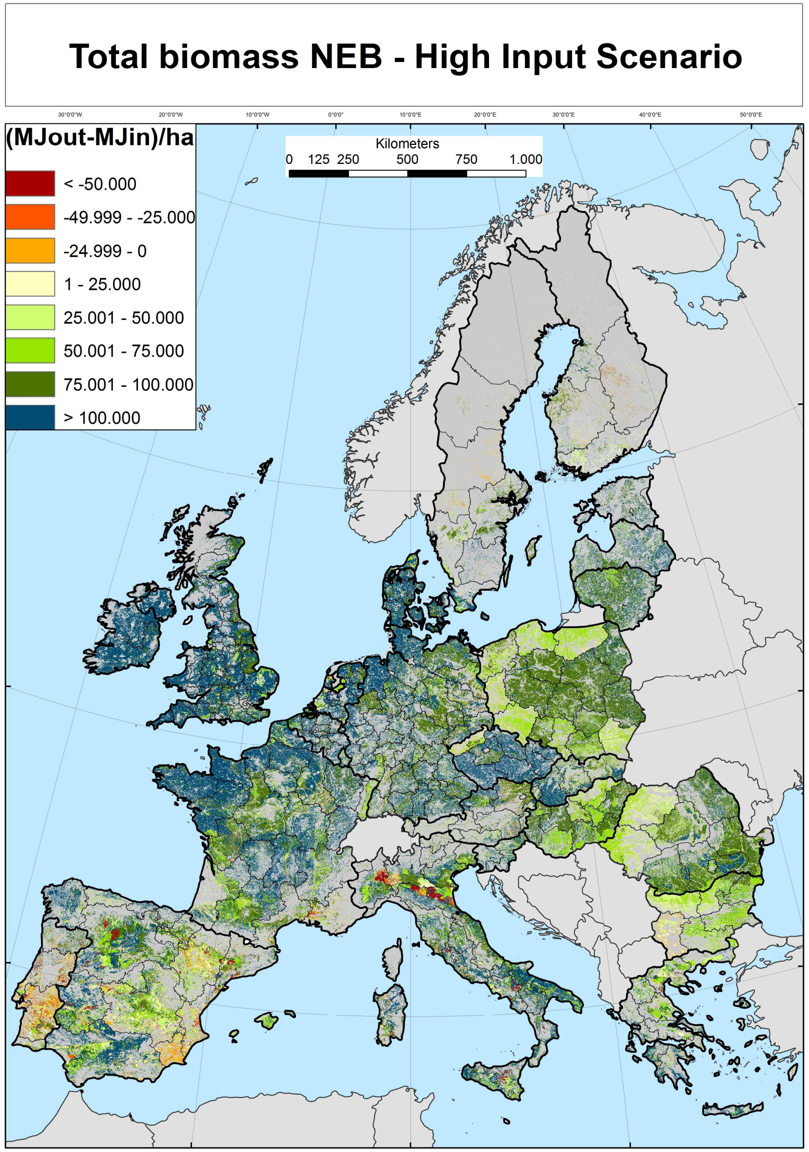
More details on the preparation of these layers are given in Annex 6.

### *4.4.1 Comparison of EROI and NEB for actual farming situation and reference scenarios (total biomass)*

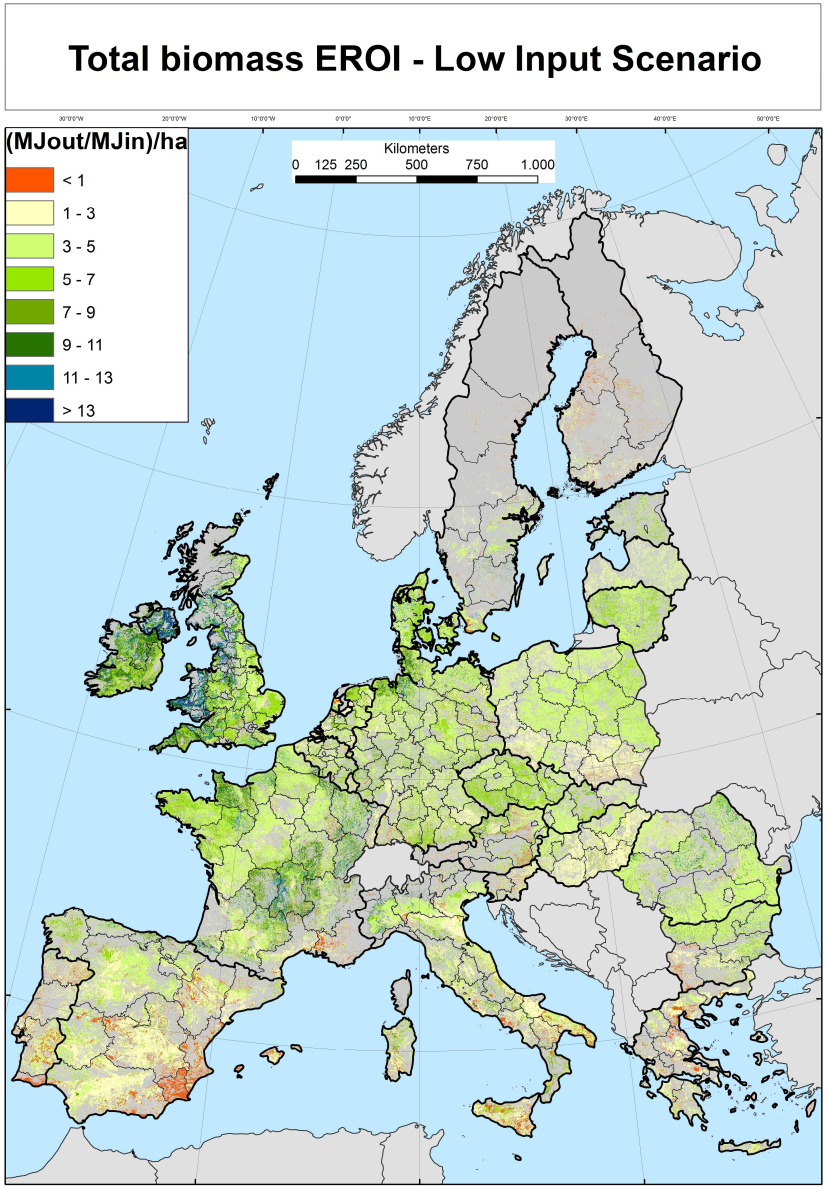
Maps 7-9 below show the NEB and EROI calculations per HSMU in the three reference scenarios.

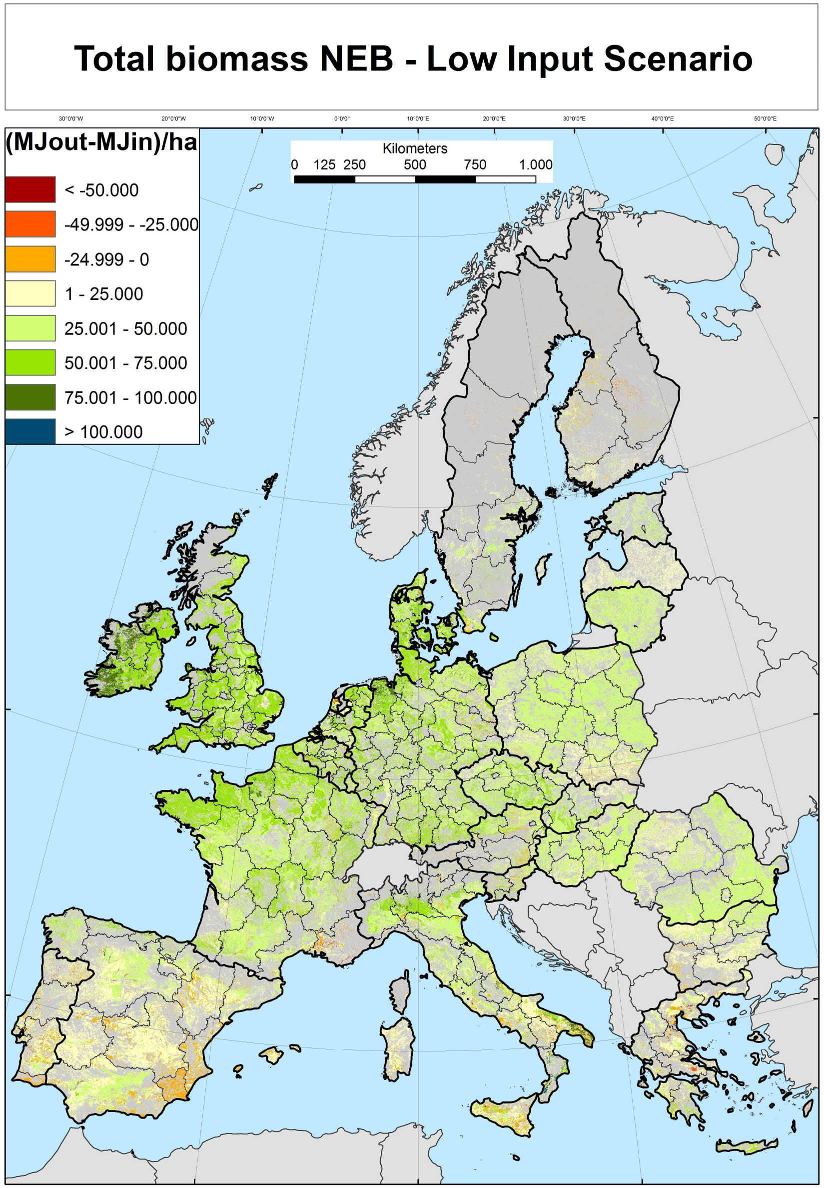
*Map 7: EROI (left) and NEB (right) for total biomass at HSMU level in the High-Input scenario*



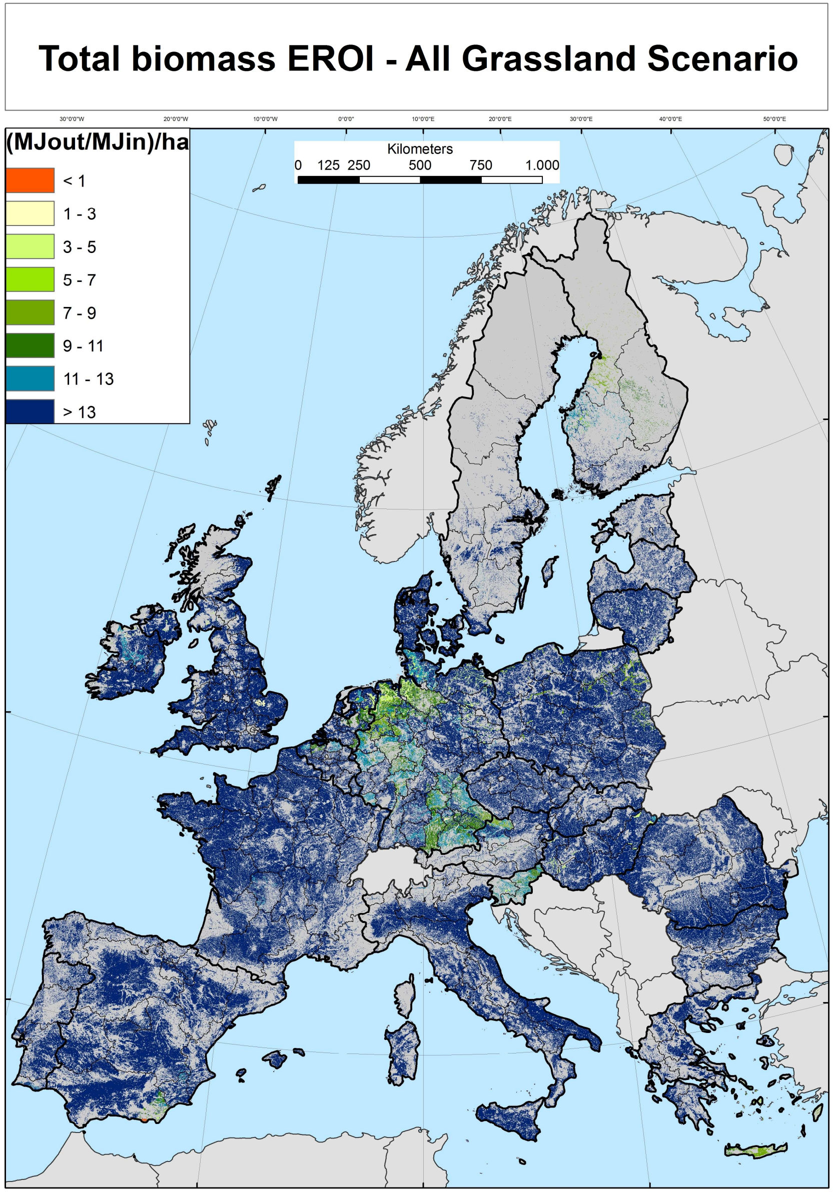



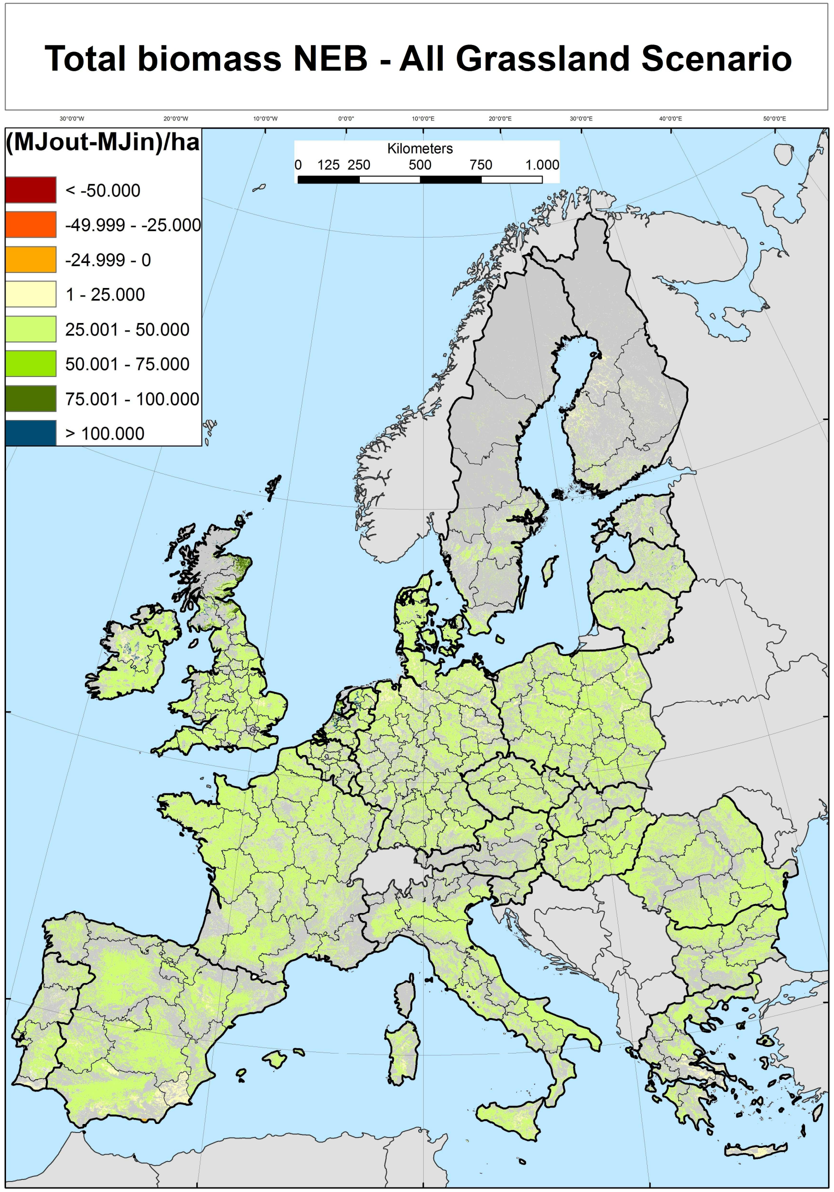
*Map 8 EROI (left) and NEB (right) for total biomass at HSMU level in the Low-Input scenario*



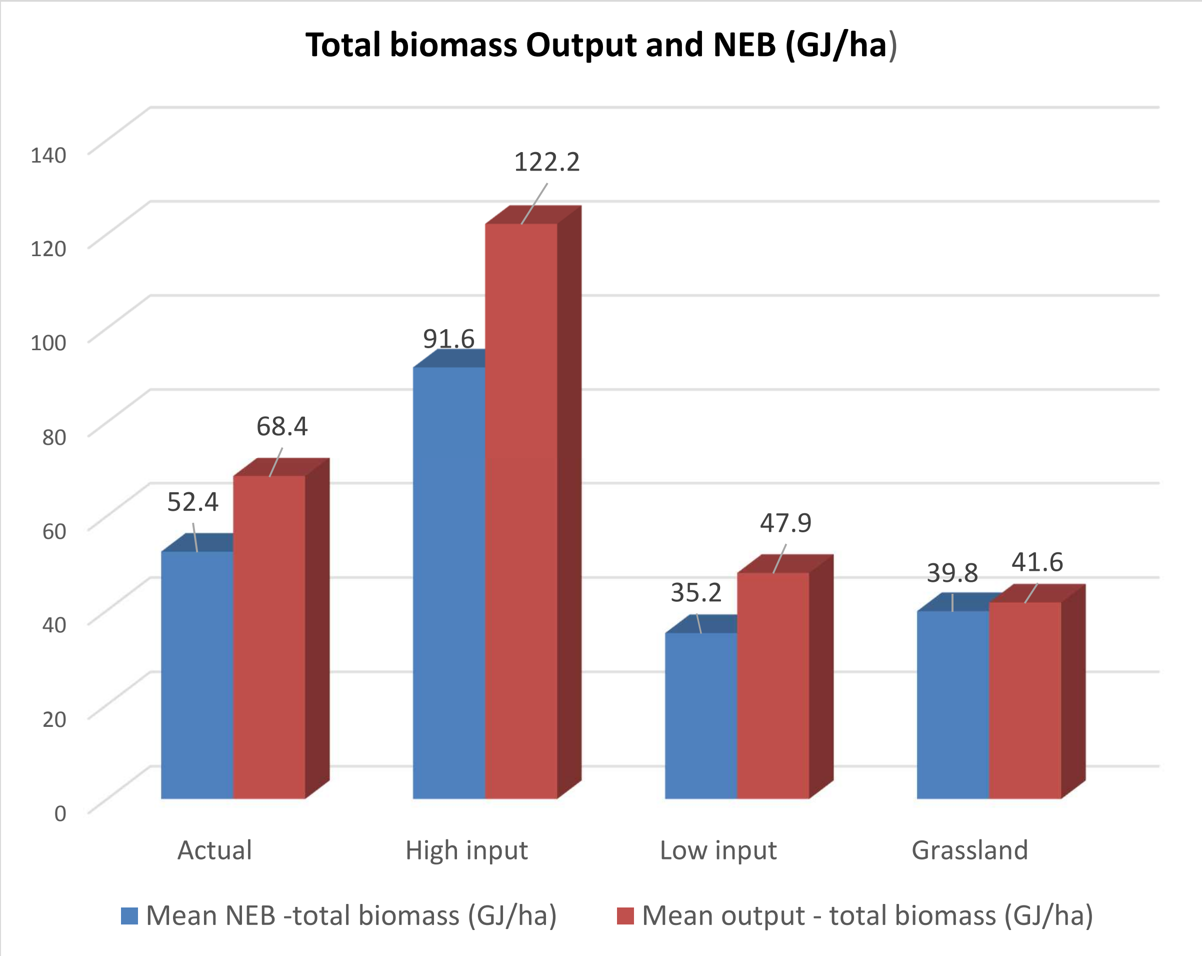
*Map 9 EROI (left) and NEB (right) for total biomass at HSMU level in the "All Natural Grassland" scenario*

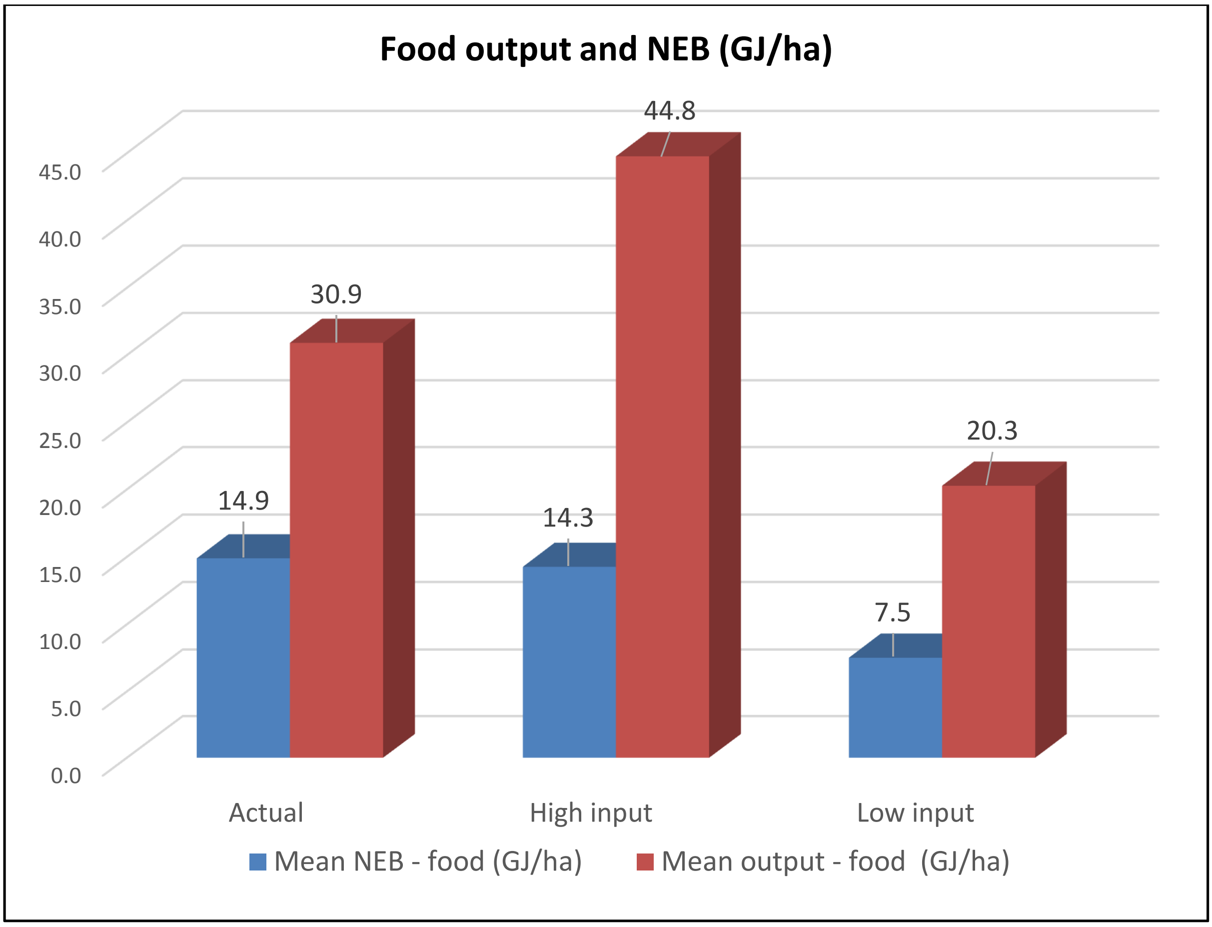


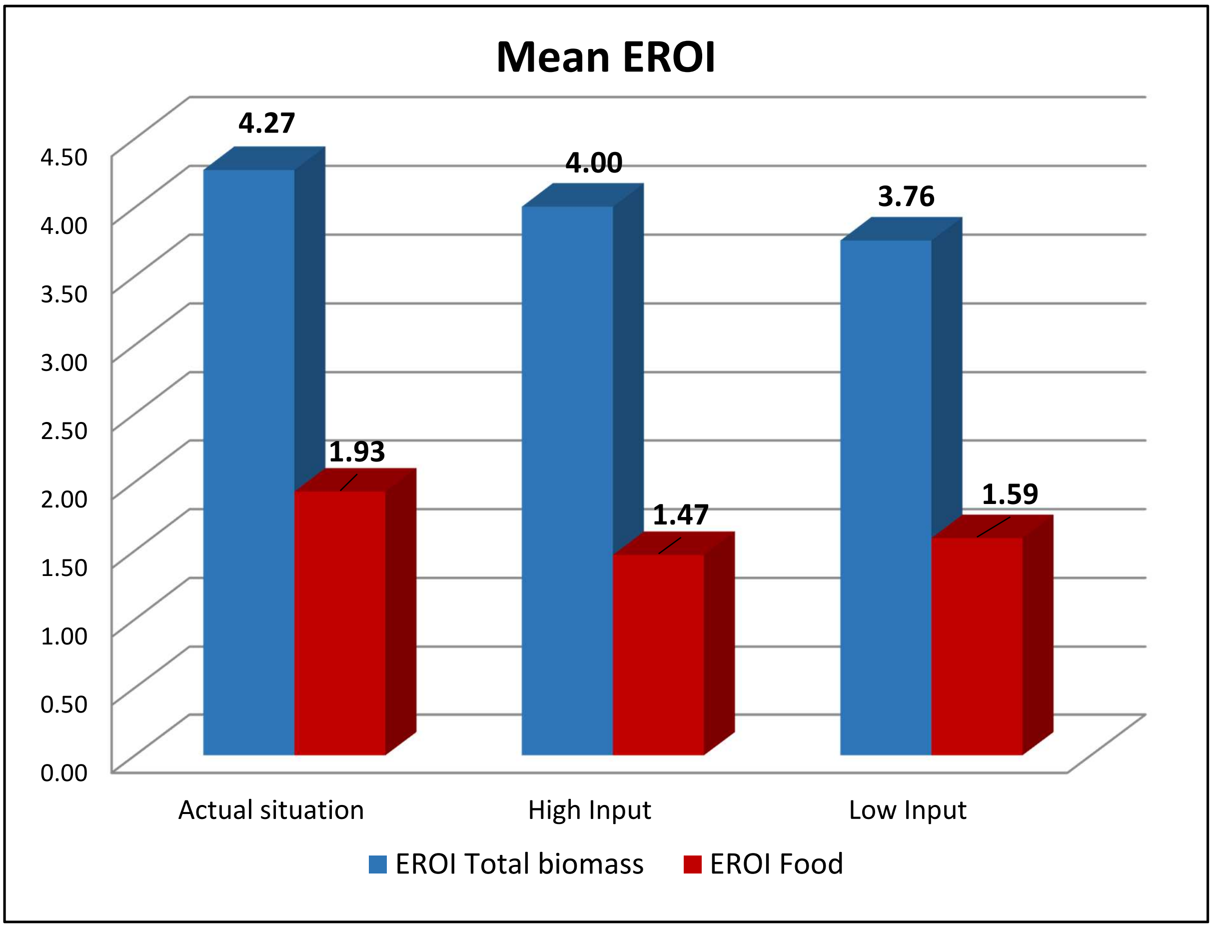
The diagrams below synthesize the main differences between the actual farming system and the three scenarios. The first diagram shows the average per hectare total output and NEB for all biomass in the actual situation and the three scenarios; the second shows the average per hectare total output and NEB for the food component in the Actual situation, High Input and Low Input scenarios. The third one presents EROI mean value for total biomass and food in the Actual, High-input and Low-input scenarios.

*Figure 8: Mean values of per hectare NEB and EROI in the different scenarios*





Food output and NEB (GJ/ha)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
14.9
30.9
14.3
44.8
7.5
20.3
Actual
High input
Low input
Mean NEB - food (GJ/ha)
Mean output - food (GJ/ha)

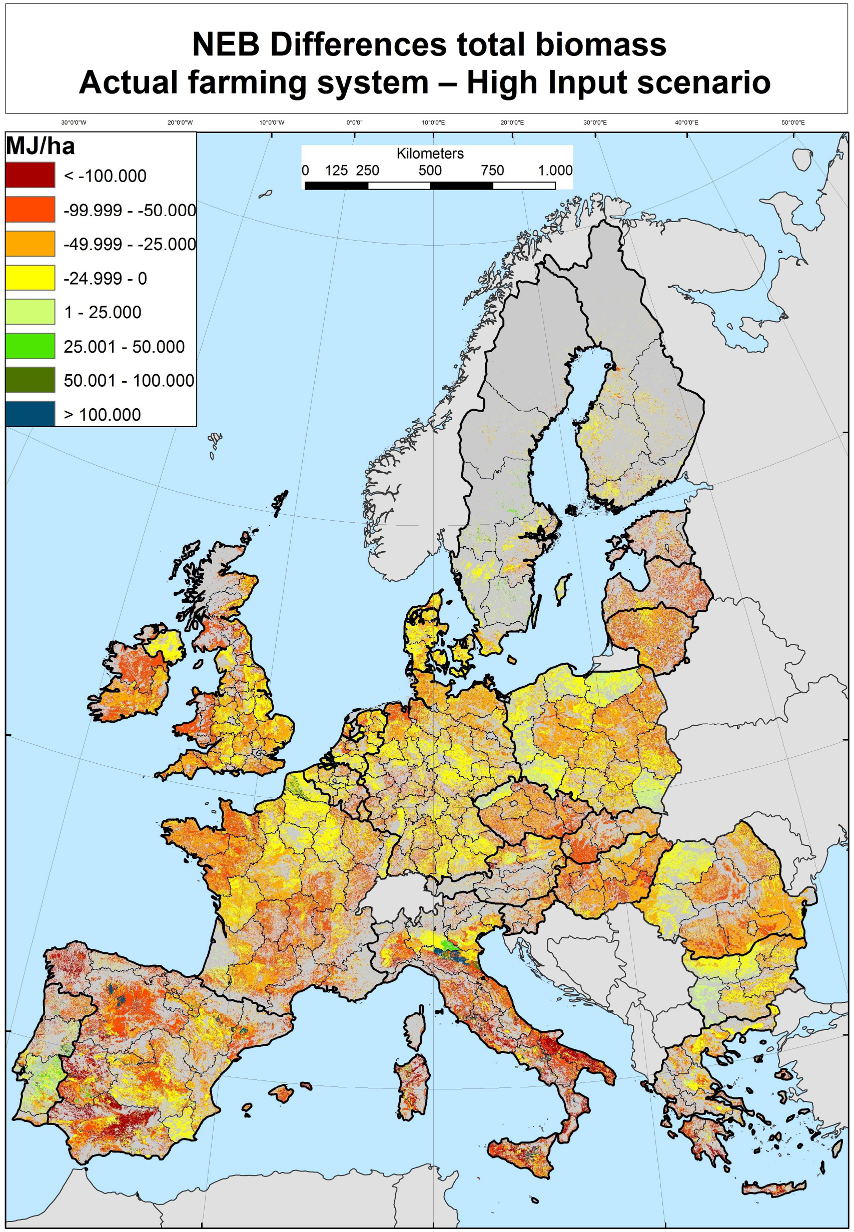
Mean EROI
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
4.27
1.93
4.00
1.47
3.76
1.59
Actual situation
High Input
Low Input
EROI Total biomass
EROI Food

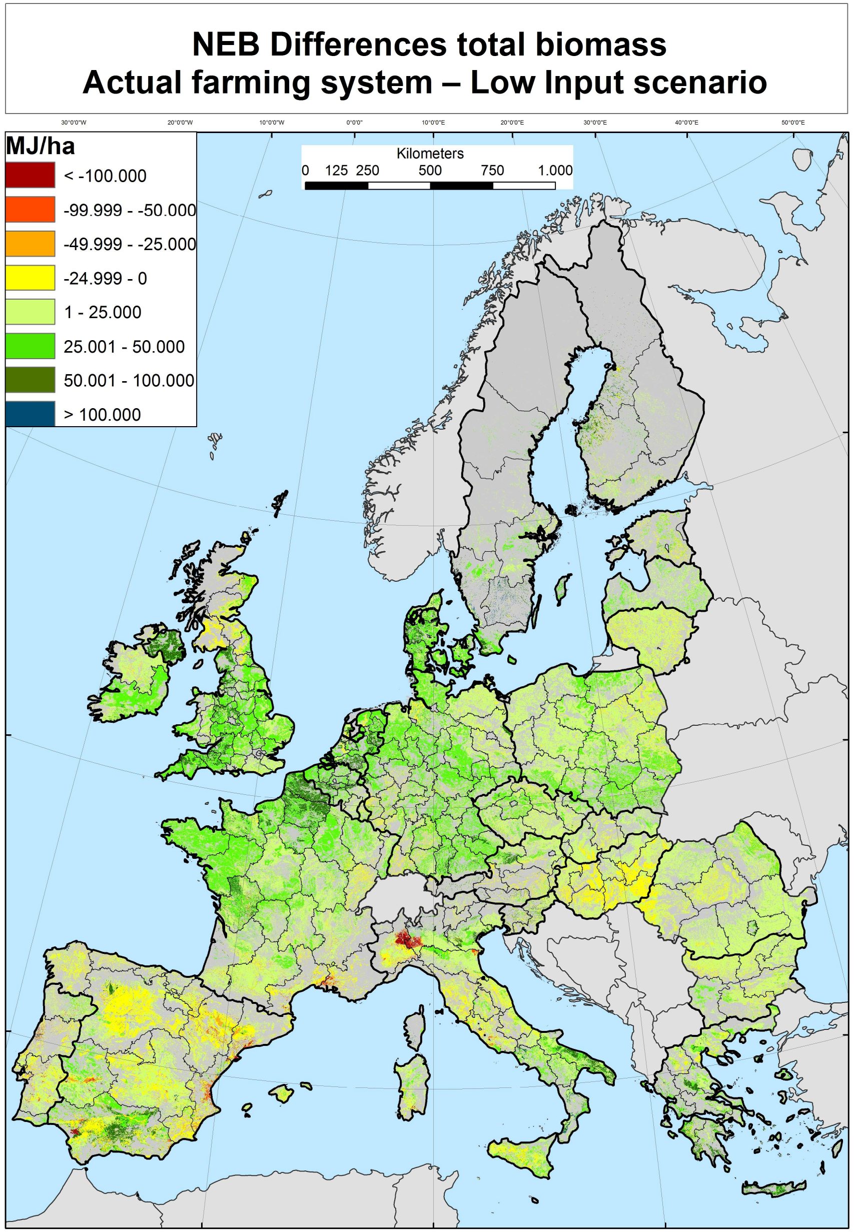
NEB increases only for total biomass whilst it remains virtually unchanged for the food component. This means that higher yields do not correspond to increased efficiency in the conversion of human input into food biomass, which is also showed by the diagram reporting average EROI values. Conversely, the low input scenario features lower average NEB in both components (total biomass and food). The highest average EROI is reached in the actual situation, both as regards to total biomass and food. This means that the current European farming system has already reached a high level of efficiency and that increasing input would of course increase absolute outputs but the marginal increase in the efficiency of this conversion would be slightly negative. The EROI of total biomass in the Low Input scenario is the lowest, but if only the food component is examined, the High Input scenarios has slight lower efficiency that the Low Input ones

The Grassland scenario has the lowest average output, but its NEB is higher than the lower input scenario. It has also by far the highest EROI (not reported in the diagram) with an average value of 24.6, due to the very low energy input needed.

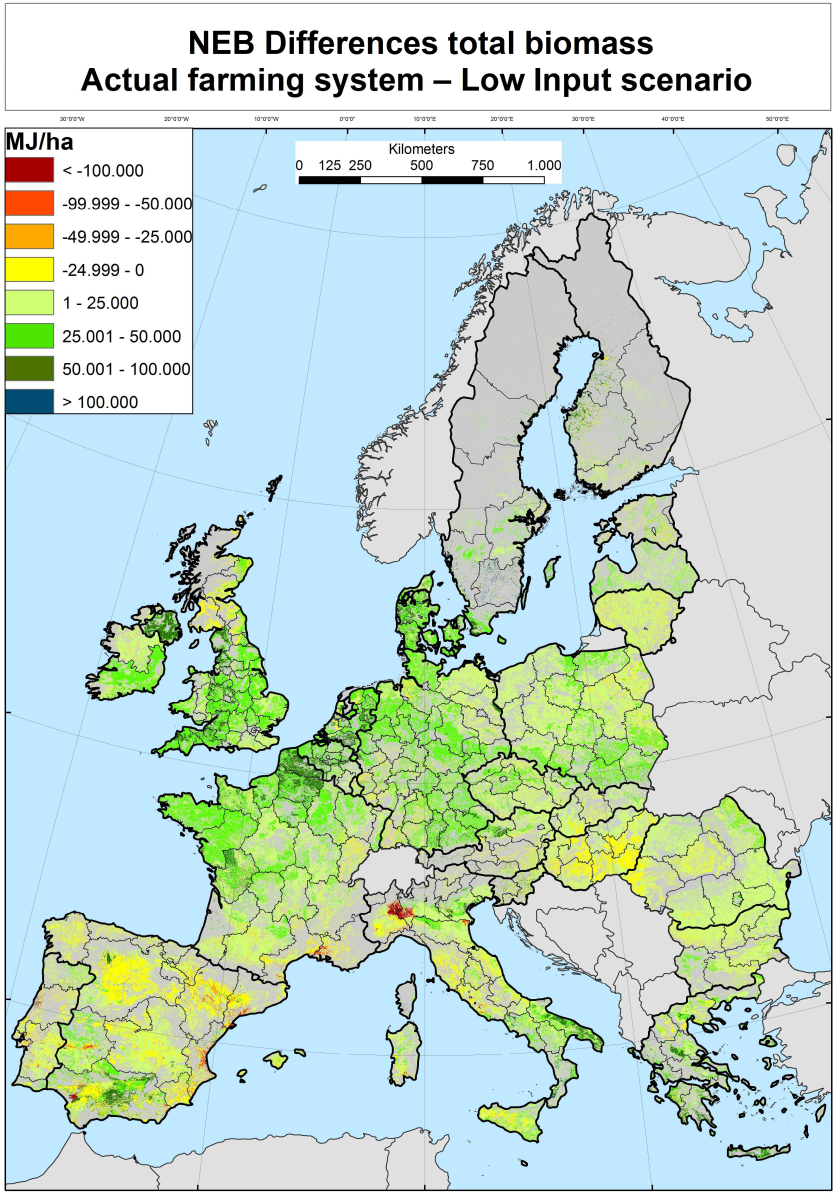
The variation between the scenarios is illustrated in a spatially explicit way in the following Maps, showing the differences in the NEB for total biomass (Maps 10-12) and for the food component (Maps 13-15).

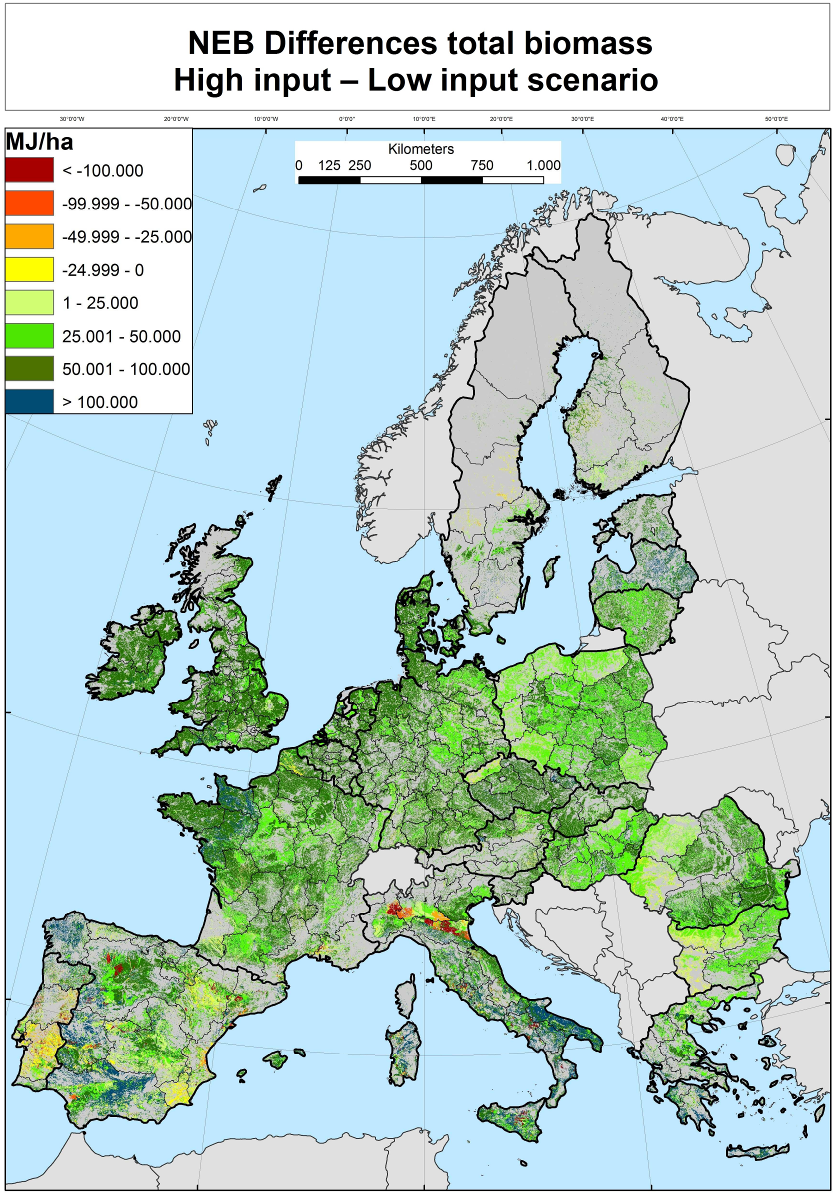
*Map 10: difference in total biomass NEB between actual system and High Input scenario (left) and Low Input scenario (right)*



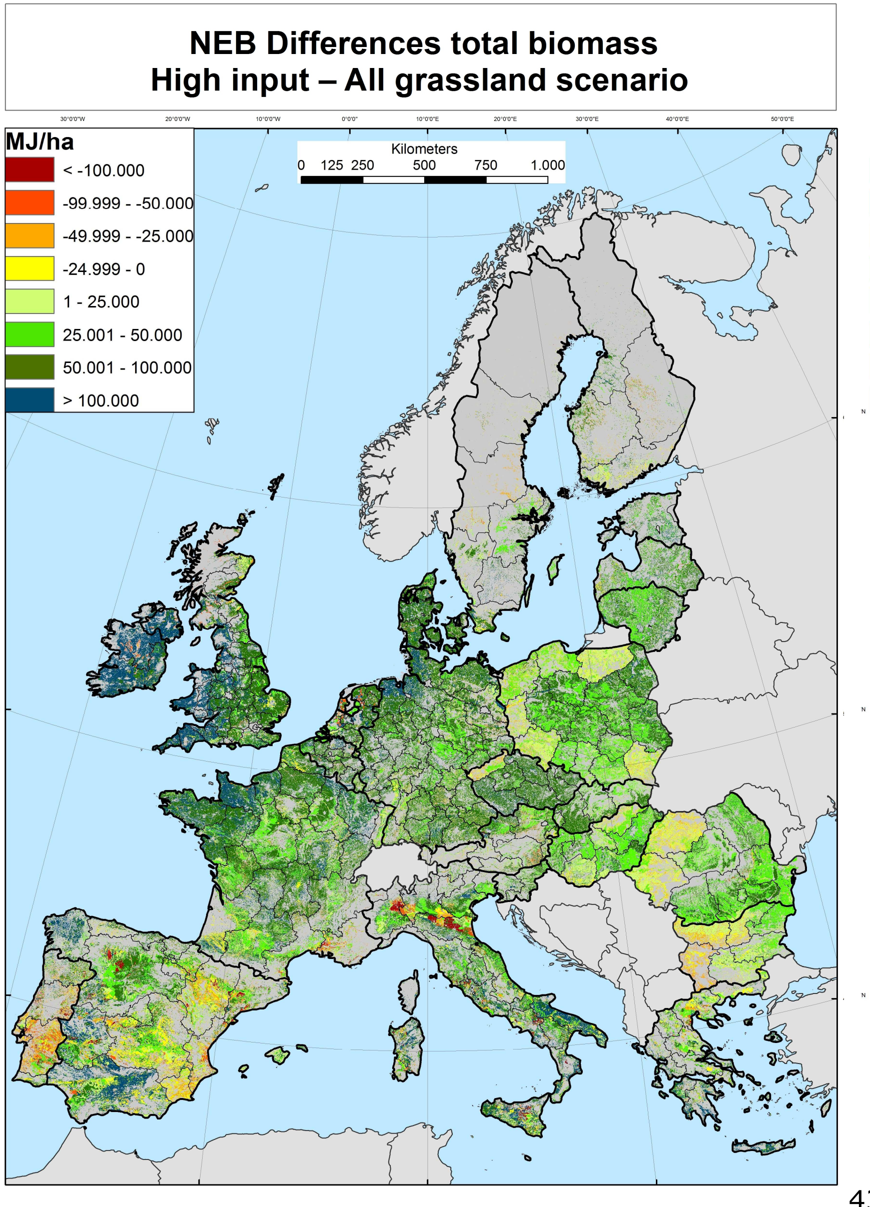



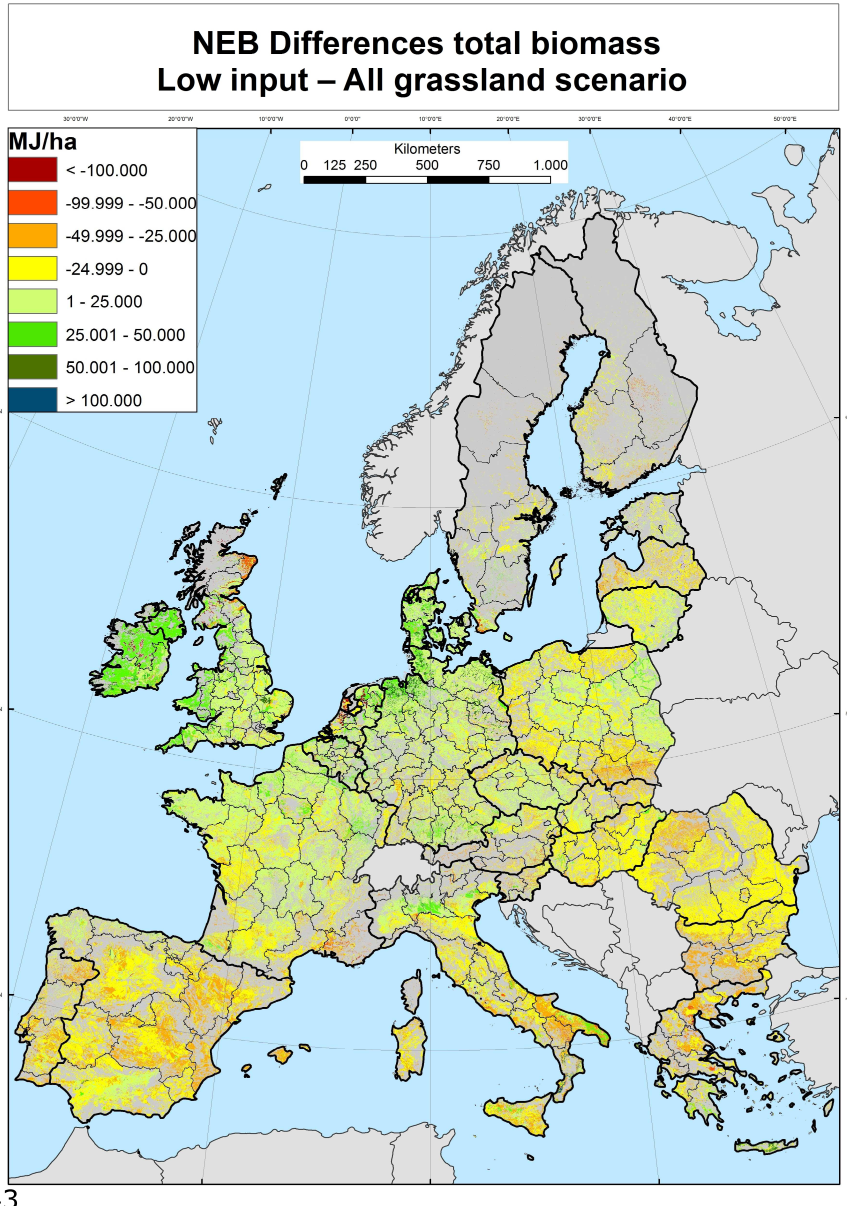
*Map 11: difference in total biomass NEB between Actual and Low Input scenarios (left) and between High and Low Input scenarios (right)*



*Map 12: difference in total biomass NEB between High Input and Grasslands scenarios (left) and between Low Input and Grassland (right)*



Map 10 (left) shows that in almost all EU Regions the High Input scenario has higher NEB than the current farming system, although some spots where the opposite occurs can be found e.g. in the Po Plain in Italy, Portugal and Bulgaria. With higher inputs, large gains in NEB would be reached in particular in Spain and Central-southern Italy, probably due to the elimination of water limitation hypothesized in this scenario.

Whilst overall the current situation performs better in NEB terms than the Low input scenario, it can be seen (Map 10 right) that this pattern is more pronounced in Atlantic regions and Central Europe, whilst several areas in the Mediterranean zone (Spain, Central Italy) show a slight decrease of NEB. This also applies to large parts of the arable production areas in Hungary.

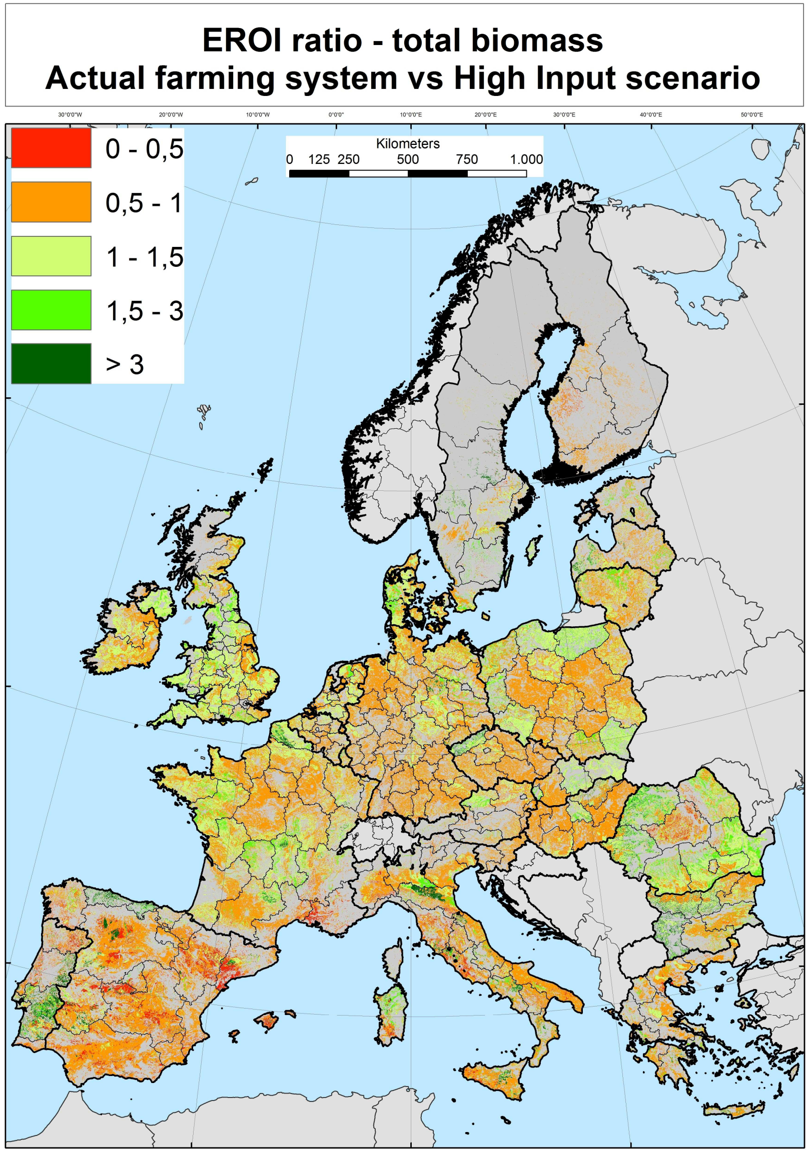
A similar but more pronounced pattern is observable when comparing the Actual situation and the Grassland scenario (Maps 11 left): natural grassland would yield higher NEB in many areas of the Mediterranean region and South-Eastern Europe, whilst the current systems perform better in central Europe and Atlantic regions. Whilst the High input scenario has higher NEB than the Low input in virtually all of Europe (Map 11 right) except for some regions in Italy and Spain, this is not the case in the grassland scenario (Map 12 left). In the latter case in fact the High input underperforms also in several areas in South-eastern Europe (Romania and Bulgaria).

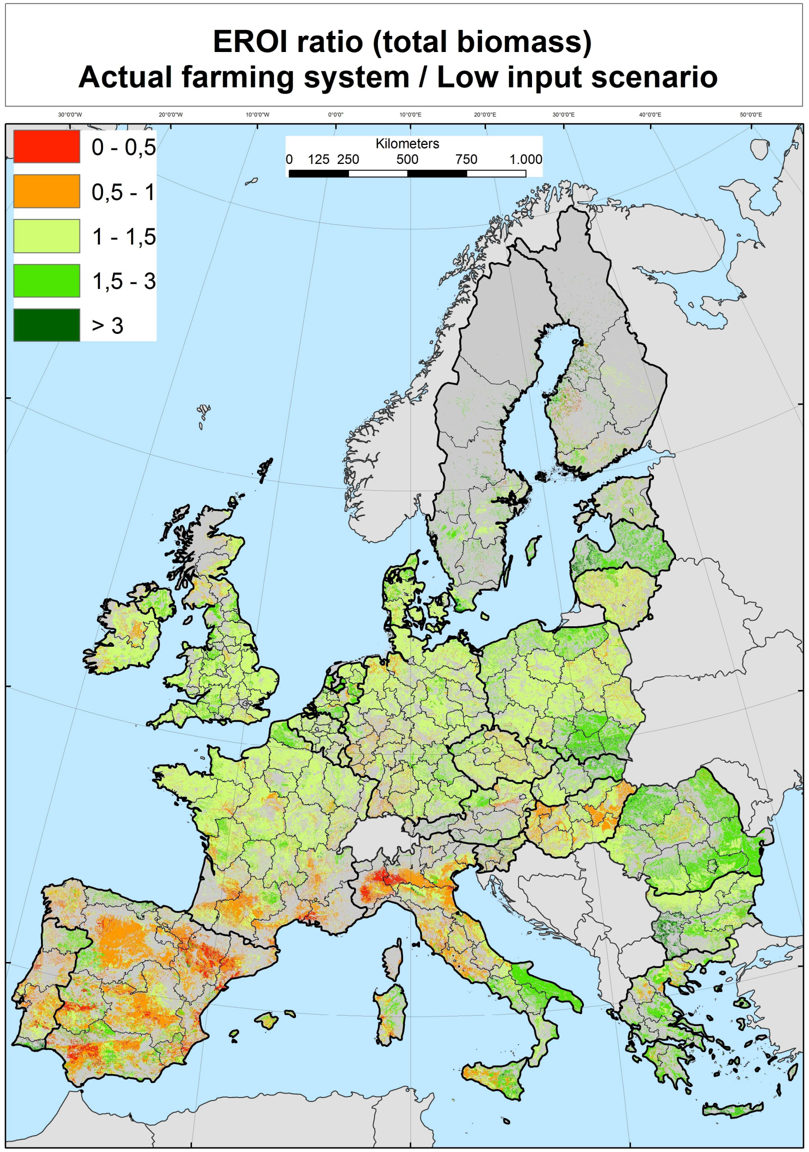
Low input and Grassland scenarios are the closest in terms of NEB (for total biomass), and differences in their NEB values are less pronounced (Map 12 right). Again, in general, the Low input scenarios perform better in the Atlantic region and worse in the Mediterranean, but the pattern is mixed.

Some spots stand out consistently in almost all scenarios showing trends that are at odds with the general patterns: these mainly coincide with rice cultivated areas in North-West Italy, Extremadura, Andalusia (Guadalquivir Delta) and Catalonia (Ebro Delta). These regions always show negative NEB.. This is also the case for the permanently irrigated crops in Castilla y León (North West Spain). In all cases, energy consumption related to irrigation probably determines negative NEB and low EROI values. Olive groves have very high average NEB values, and are amongst the few crops in the Mediterranean zone that in the Actual situation perform better than in the Grassland scenario, this being particularly visible in Apulia Region (South East Italy) and Andalusia (Spain).

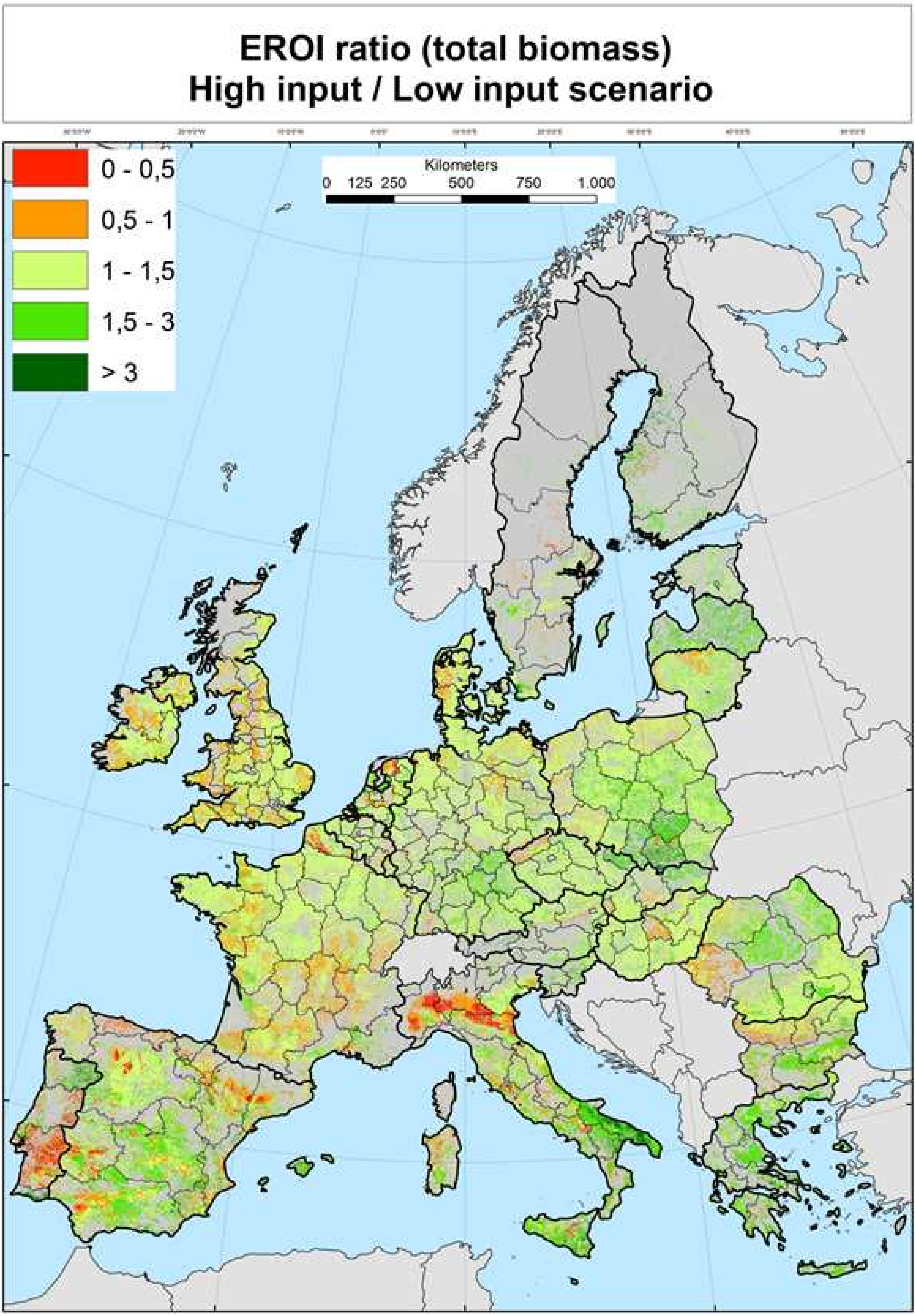
Maps 13-14 below show the results of the comparison between EROI values in different scenarios. They thus reflect the relative efficiency of agricultural systems in the different scenarios in converting (human) input energy in caloric energy. As synthesized by Figure 8, the mean EROI value for total biomass in the High input scenario is close to that of the actual farming system. The spatial pattern appears mixed, with no emerging geographical trend. Conversely, when comparing EROI of the Actual system and Low input scenario, it emerges that the former has a higher efficiency in central Europe and in the Atlantic Region, whilst the lower input would improve the EROI mainly in Mediterranean Regions (Spain, Southern France and Italy). The comparison between the High and Low input scenarios (Map 13) shows again a rather mixed pattern, with EROI ration <1 scattered all over Europe. Overall, these results indicate that for several regions in Europe the current situation already represents a relative maximum in EROI, which would decrease in case of an increase in intensity of farming but also in case of a decline in input level.

*Map 13 Ratio o of per hectare EROI: Actual system vs High Input (left) and Actual vs Low  Input scenario (right)*



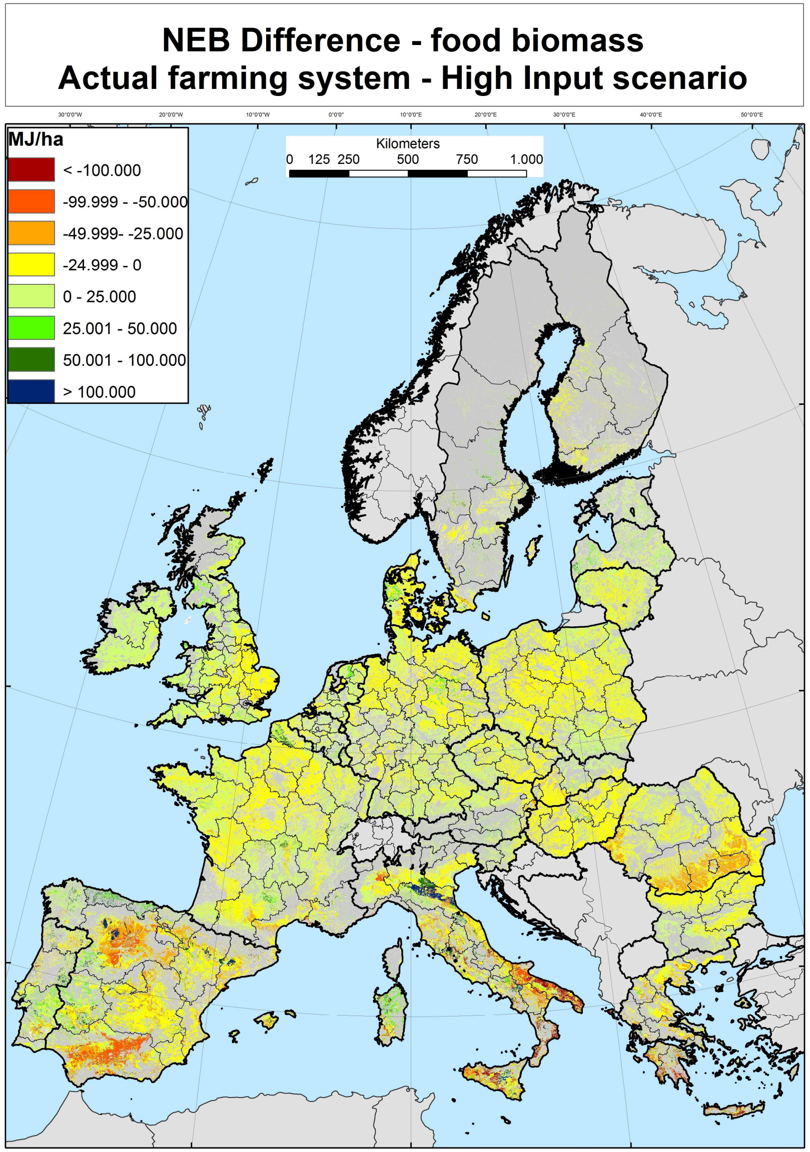
*Map 14: Ratio of per hectare EROI: High Input vs Low Input scenario*

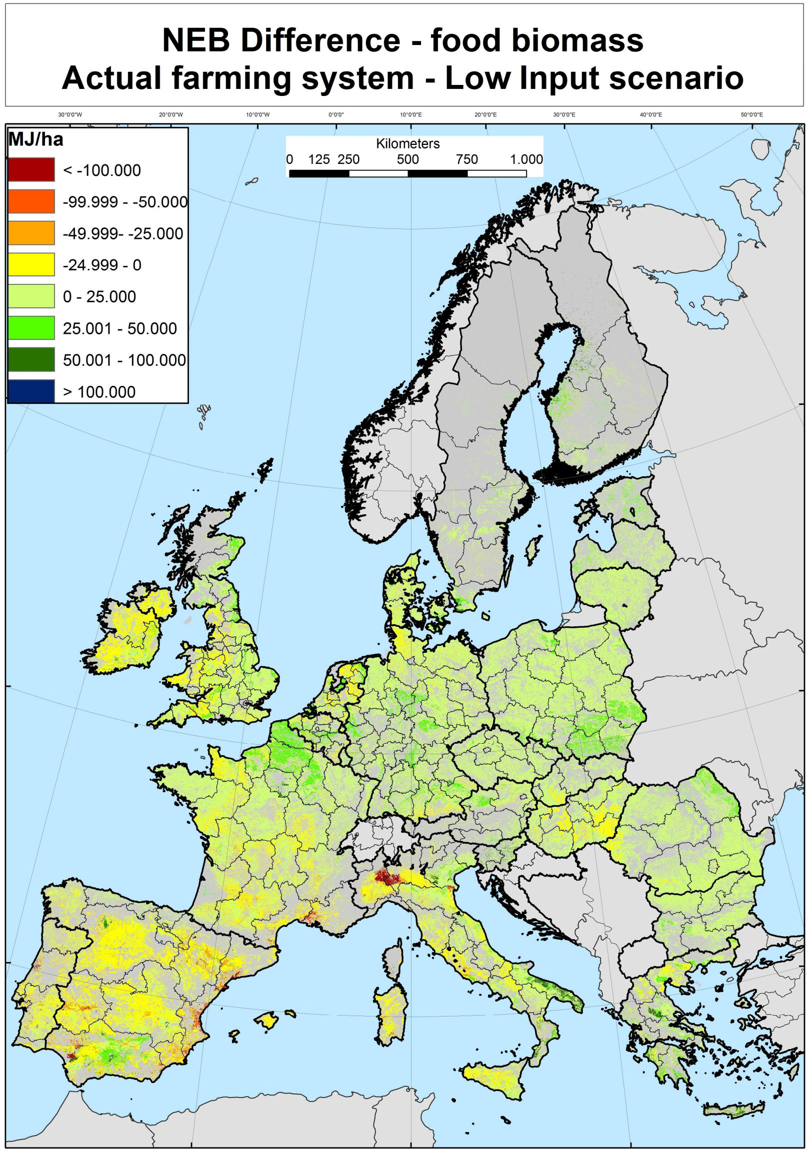


### 4.4.2 Comparison of EROI and NEB for actual farming situation and reference scenarios - food biomass

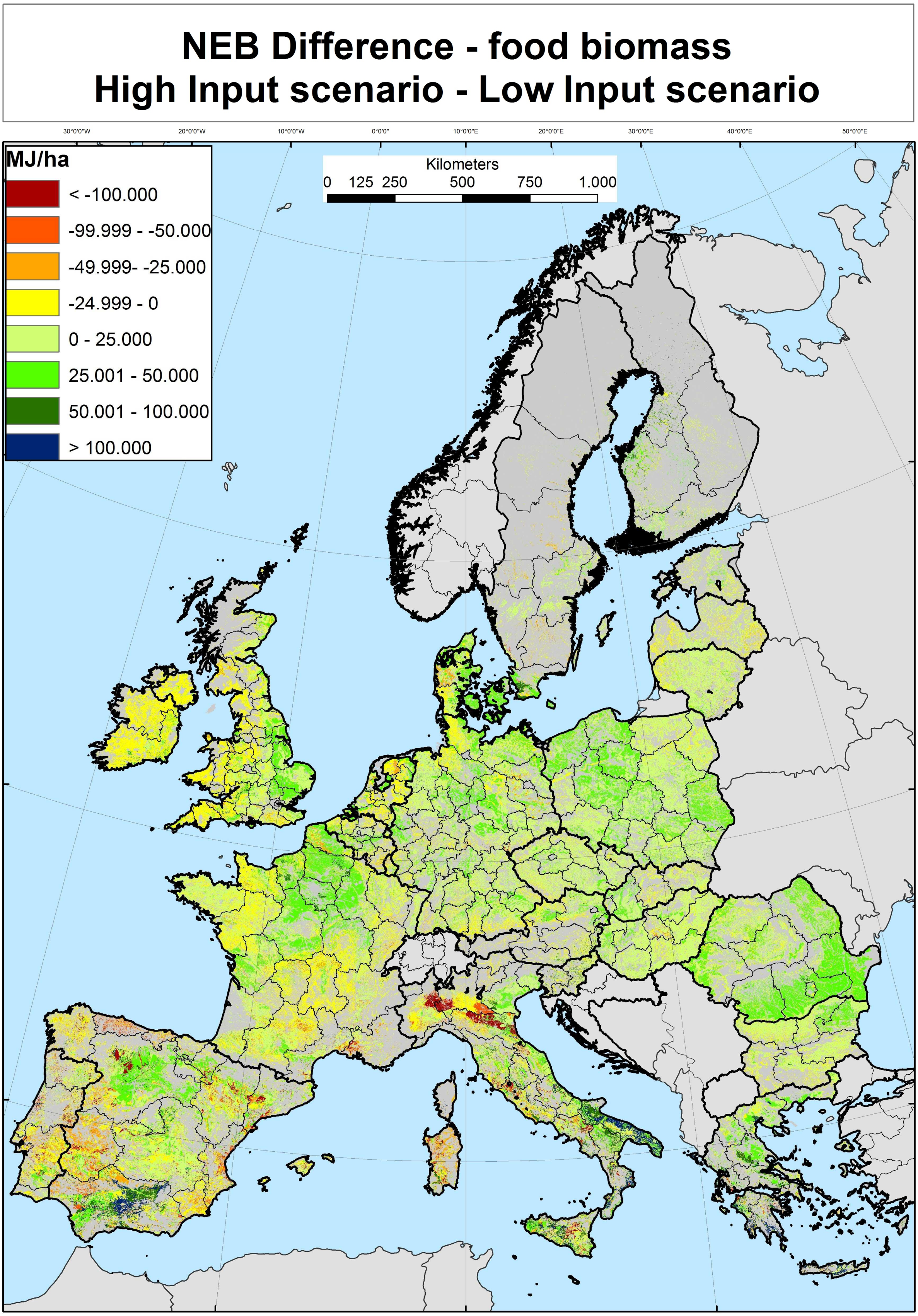
Maps 15-18 show the scenario comparison in terms of NEB and EROI when only the food biomass is taken into account (the Grassland scenario is therefore not considered).
Whilst mean output values of food biomass in the High Input scenario is significantly higher compared to the actual situation, NEB value is similar and even slightly lower(see Figure 8). The spatial pattern is mixed (Figure 15 left) with decreases in NEB scattered all over Europe. Again, some spots stand out with very high difference, as the olive groves in Apulia Region and Andalusia, for which increased input level would determine substantial increase in NEB, and some arable areas in the Po Plain and permanently irrigated arable land in Castilla y Leon (Spain), where the opposite is observed.
The average food NEB in Actual and High Input scenarios is also significantly higher than in the Low Input, but this difference is not uniformly distributed across Europe: Maps 15 (right) and 16 show in fact that areas where the lower input would deliver higher NEB are found in different regions and climatic zones, although with a certain prevalence in Southern Europe. The main differences with the observed patterns in total biomass' NEB differences (Maps 10 and 11) concern areas with significant presence of pastures and grassland, accounting for high-energy balances only when total biomass is considered. This is visible e.g. in Ireland, Western England or Normandy.
Similarly to the NEB comparison, the map showing EROI ratios between Actual and High Input scenarios (17 left) returns a mixed pattern, with values <1 found in prevalence, but not exhaustively, in Southern Europe (Italy, Spain and Greece), where water is a more significant limiting factor to crop growth. A geographical pattern emerges in a bit more pronounced way in Map 17 (right), comparing EROI of Actual situation and Low Input: here, EROI ratio values <1 are found – with very few exceptions - only South of latitude 48°N.
Finally, Map 18 depicts the EROI ratio between High and Low input scenarios: here the pattern is again mixed, with extreme values visible in already identified areas such as rice fields in the western Po Valley (Italy), Extremadura, Andalusia and Ebro delta (with High Input EROI significantly lower than Low Input) . Other areas with EROI ratio significantly <1 correspond to pastureland, e.g. in Auvergne, Normandy (Central and Northern France), Cornwall and Wales. In the High input scenario arable lands tend to have a higher EROI in central France, Eastern England, Germany, the Danube Plain (Bulgaria and Romania), whilst the opposite is observed in several arable areas in the Po Plain or central Hungary. This again is related to higher irrigation requirements in the latter two regions.

*Map 15Difference in food biomass NEB between Actual and High Input scenarios (left) and between Actual and Low Input scenarios (right)*

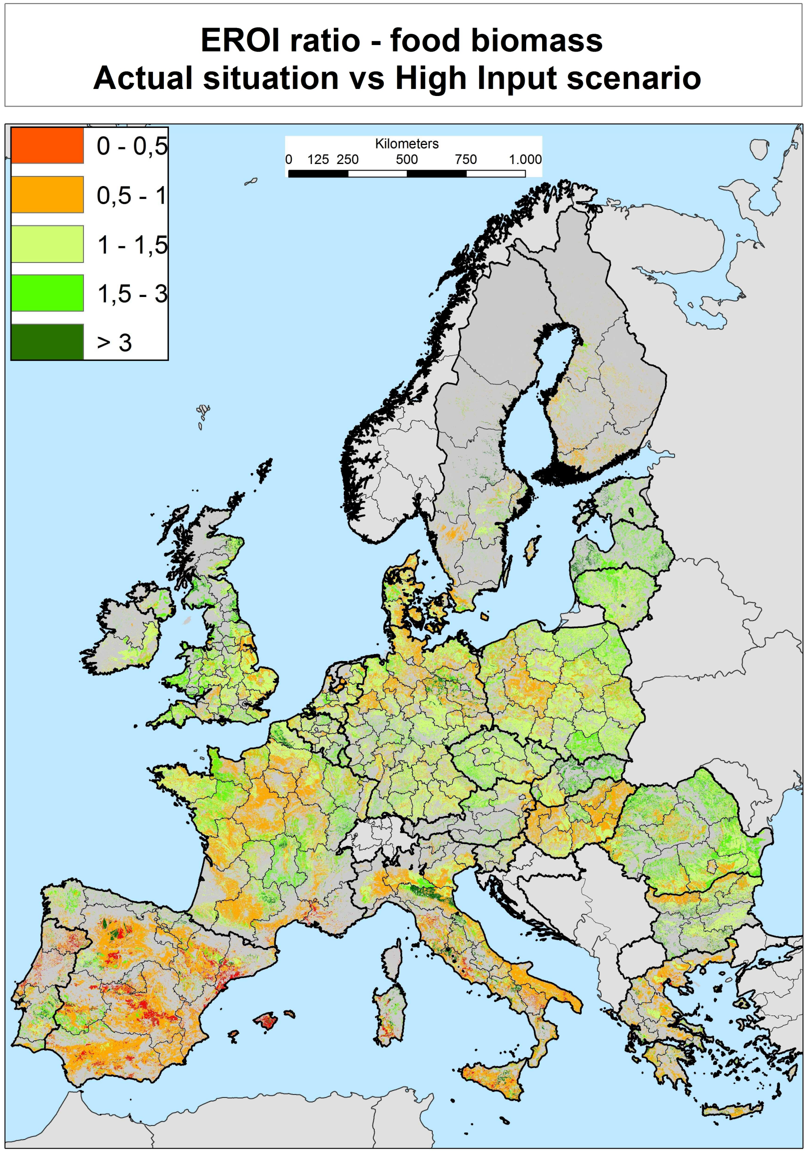


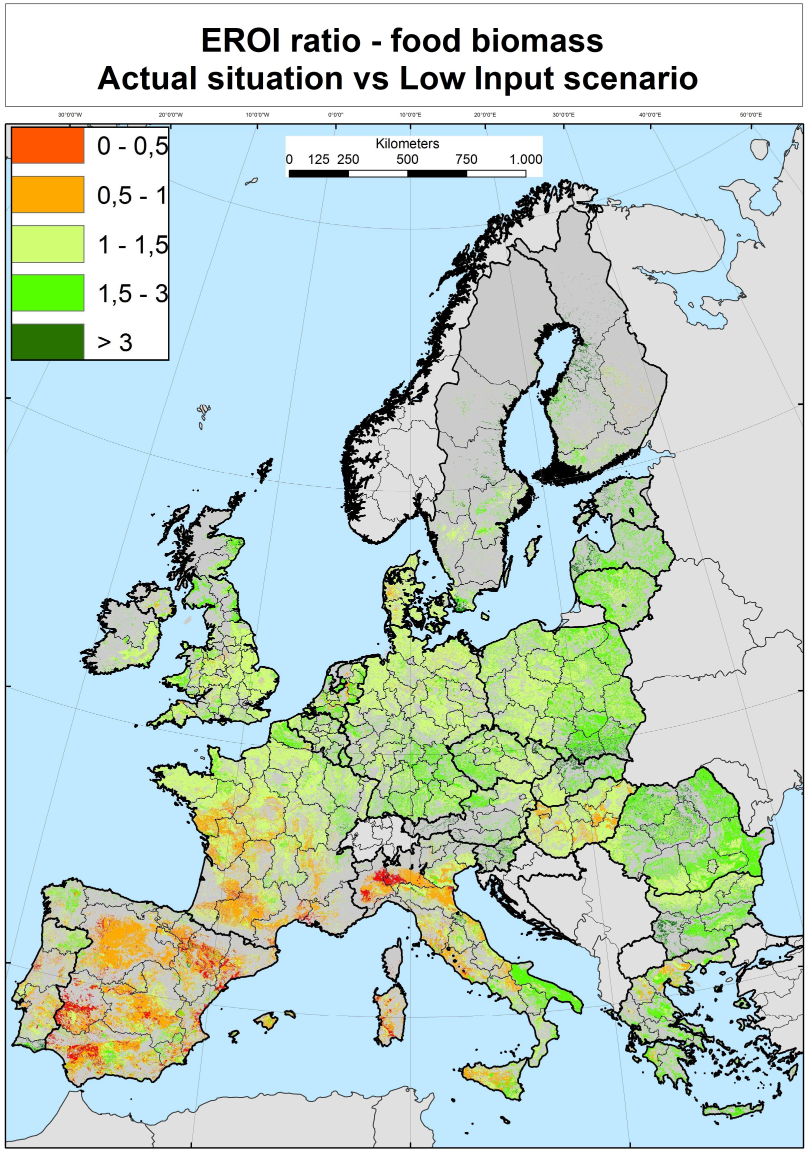



*Map 16: Difference in food biomass NEB between High Input and Low Input scenarios*

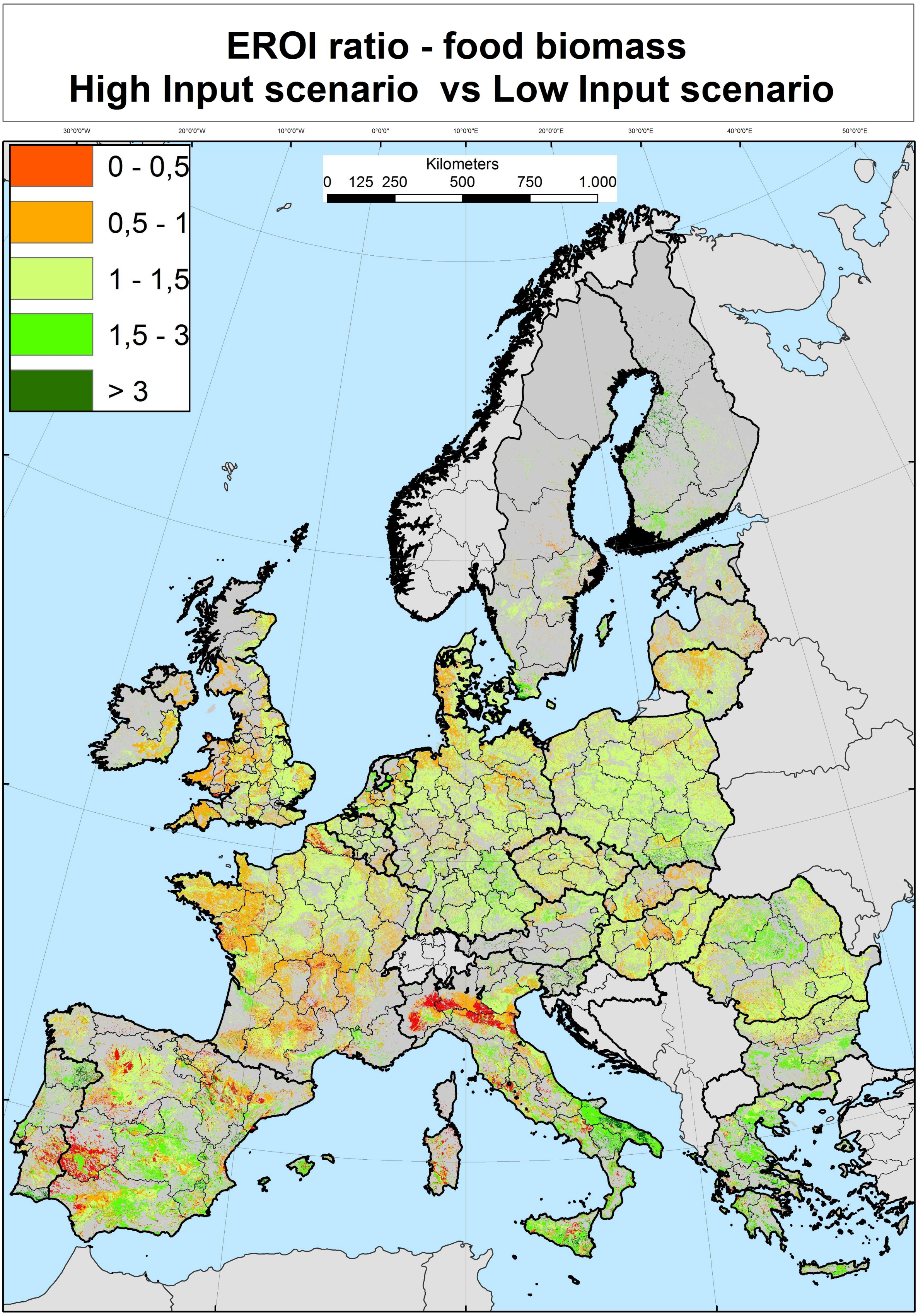


*Map 17: Ratio of per hectare EROI (food biomass): Actual situation vs High Input scenario (left) an d Actual vs Low input scenario (right)*



*Map 18 Ratio of per hectare EROI (food biomass): High Input vs Low Input scenario*



# 4. Discussion

In every ecosystem, whether partly influenced by humans or purely natural, there are flows of energy. These flow from ecological systems to human (or socio-economic) systems. In particular, in a provisioning ecosystem service such as agricultural biomass, the role of humans in managing the ecosystem, and particularly the use of fossil energy as input in the system, is crucial to reach current production levels. Because of this, EROI and NEB have been selected to provide further insights in the efficiency of the energy flow, in order to better understand its magnitude and spatial distribution across different European farming regions.

The energy input and output included in the balance are directly linked to the crop itself, and to the land management activities linked to its production, i.e. planting, establishment of the crop (e.g. root development), management during cultivation (e.g. weeding, spreading plant protection products and fertilizers and irrigating) and harvesting. The human labour input during all these activities is also included. To keep it as comparable as possible to a natural ecosystem, all secondary processes were excluded. Consequently, the processing of the harvest in further end-products for human consumption is excluded from the energy balance, as well as the production of meat or milk, or at least the modelisation stops after the cutting of grass, even though this grass may in fact be fed to animals to produce milk and meat.

*Input, output and net energy balance (NEB)*

When assessing the efficient use of resources in production of biomass by agro-ecosystems, it is important to distinguish between two ratios. Firstly, the *Total Energy Output/ Total Energy input*, which will always be < 1, because energy is lost as heat in transformation processes ($2^{nd}$ Law Thermodynamics). Secondly, the EROI i.e. the ratio between *Total Energy Output* and *Human (manipulated) Energy Input*, which should be > 1 to be considered efficient. In addition, the Capital Stock of the Soil (a fundamental part of the agro-ecosystem) should be maintained, for a sustainable supply of agricultural biomass as ecosystem service.

This study shows that EROI values that can be reached per crop system differ strongly. However, a clear trend is found, showing that arable and grassland systems have the highest efficiency of energy resources as input levels are generally lower than in permanent crops. Fruits and olives have overall energy input levels that are higher than in grassland and arable crops. However, their output levels are overall not higher but on the contrary lower, with some exceptions. This shows that several food services are not energy-efficient and show a negative ratio for two main reasons:

- (Human) input levels of energy are much higher than output levels of energy, so an important part of energy is lost;
- Only part of the biomass produced is used, thus the energy of the used output (the service) is lower than the total energy output

The highest average input levels per hectare in the EU-15 are found in the Netherlands and Belgium, Italy, Spain and Germany. In the EU-10, Slovenia stands out with a very high input per hectare, but overall input levels in EU-15 are higher than in EU-10. The categories taking the largest part of the input are mostly energy for cultivation and fertilizers. In the Mediterranean Countries, irrigation also adds significantly to the input side.

The highest output levels in provisioning of food, but in most cases also in total biomass provision are found in countries like Denmark, Poland, Finland, Germany, Czech Republic and Belgium. The EU-10 Countries have generally a lower input level and also a lower output level than the EU-15, at least when looking at food production. The highest net output in terms of total biomass is reached in Ireland, Belgium, Denmark, Netherlands, UK and Germany. Explanatory factors should clearly be sought in a combination of reasons, 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 which have generally been adapted in centuries of time to the optimal production the natural circumstances (climate and soil) can sustainably support.

The regions with high arable land shares often have high to very high output levels per hectare, particularly in relation to food output. Similarly, Countries with the highest grassland area shares, i.e. Ireland, UK, Slovenia and Netherlands, are also among those having the higher output levels, particularly in total biomass. Countries with a more mixed land use pattern, like most Southern EU Countries, generally show a lower output level, particularly when it goes together with high fallow land areas shares, as is the case for Portugal, Spain and Bulgaria.

Average input levels are lower in the Alpine, Boreal-Nemoral and Continental-Pannonian bio-geographical zones, where extensive agriculture is more dominant than in the other zones. On the contrary, in the Atlantic-Lusitanian zone and the Mediterranean, the input levels are higher. In the Atlantic zone, with the largest share of intensive agriculture in Europe, input levels are overall high and are particularly caused by high levels of energy input in cultivation and through mineral fertilizer application. However, in the Mediterranean zone extreme levels are also found, due to irrigation.

*Net Energy Balance (NEB) and economic value of the output*

To which extent agricultural production is valued by humans can be estimated by the market value of the output of agriculture. Overall, it can be concluded that although the NEB is generally higher in cereals and permanent grass such crops are least valued in economic terms. On the contrary, the lowest net energy producing system, fruits, has the highest economic value. This is because to produce fruits the plant makes a very high investment in "metabolic" energy, and therefore fruits have high "embodied energy", which is recognised in the market as valuable. Embodied energy refers to very specific fruit sugars and aromatic chemicals that are produced at the cost of burning calories in the production process. This is in contrast with cereals, which are straightforward glucose chains and have therefore much lower embodied energy.

*NEB and EROI in actual agriculture production systems as compared to natural and high and low input systems*

In order to compare the different land use intensity levels of agricultural ecosystems in terms of energy balance, the actual farming situation was compared to three reference situations:

- Natural permanent grassland, where all present agricultural land use per HSMU is permanent grassland;
- Minimum-input farming (extensive crop production);
- High-input farming (intensive crop production).

Comparison results show that when total biomass output is considered, high input systems would perform better than the actual one over the majority of European regions, not only in terms of total output, as it could be expected, but also as regards to the NEB. The Low input and the Grassland scenarios have comparable total outputs and NEB, significantly lower than the previous two scenarios.

However, the average EROI values in the Actual and High Input scenarios are very similar (actually values are slightly lower in the High Input scenario), meaning that most of current production in Europe is already highly intensive  and increasing the energy input would not improve the efficiency of the conversion of such additional energy into biomass.

EROI and NEB of the actual system are on average higher than those of the Low input scenario, however, there are several areas in Europe where the opposite is observed, as most of the Iberian Peninsula, Italy, Hungary, Bulgaria.

The natural permanent grassland shows the lowest net energy gains, but the highest EROI. Actual farming as compared to natural grasslands shows the highest gains in Ireland, UK, NW France and the Central European Plain. There are also some areas where actual farming has a lower net energy balance with respect to the grassland reference layers, as central Spain, some zones in the Po Plain and Hungary.

The picture changes when considering only the food biomass. In this case, the High input scenario still presents the highest average output (as expected), but its NEB is similar and in fact slightly lower than the actual one. Accordingly, the High Input EROI is lower than in the Actual scenario and even slightly lower than in the Low Input one. This is of course an aggregated figure, and there are several regions in Europe where increased input would deliver increased NEB or EROI, but with no emerging geographical pattern. The Low Input scenario has the lowest NEB and EROI also in this case, but the difference with the other scenario is less marked than for total biomass and its EROI falls in between the other two scenarios.

Further food for thought from the scenario exercise is provided by Table 6, where the available calories per person are calculated under the actual situation and the three analysed scenarios, taking as a reference a EU population of 2012. Since the scenarios refer to the present situation with changing inputs and not to a projection into the future, the population in the calculations is considered stable. Under these assumptions calories available per person would increase of 44% in the high input scenario, at the cost of a decreasing EROI for food of 23.8% but especially at the cost of an increase in the energetic input of 91%. The estimate of available calories per person concerns the mere agricultural output and therefore is a gross figure including losses characteristic of the processing chain from field to fork. This explains why values are high and greatly exceed the average requirement of 2500 Kcal/day. At this stage, though, it is not possible to estimate what the net figure would be. What is striking, though, is that the energy value of total biomass differs only by 13% between the Grassland and the Low Input scenario.

Ultimately, it would be interesting to know the curve of the relation of EROI and output with increasing input, to see if any breakpoint or threshold value can be identified, above which the amount of input required to get a higher output starts to diverge considerably.

*Table 6: Average values in the EU27 of the energy budget components*

| | Actual | High input | Low input | Grassland |
|---|---|---|---|---|
| Mean NEB -total biomass (GJ/ha) | 52.4 | 91.6 | 35.2 | 39.8 |
| Mean NEB - food (GJ/ha) | 14.9 | 14.3 | 7.5 | 0.0 |
| Mean Input (GJ/ha) | 16.0 | 30.5 | 12.7 | 1.8 |
| Mean output - total biomass (GJ/ha) | 68.4 | 122.2 | 47.9 | 41.6 |
| Mean output - food (GJ/ha) | 30.9 | 44.8 | 20.3 | 0.0 |
| Mean EROI total biomass | 4.27 | 4.00 | 3.76 | 24.6 |
| Mean EROI food | 1.93 | 1.47 | 1.59 | 0 |
| Kcal/person day (total biomass) | 16562 | 29556 | 11594 | 10074 |
| Kcal/person day (food) | 7480 | 10831 | 4904 | 0 |

*Limitations of the analysis*

The analysis in this study was performed using the best available data both on input factors and output levels in farming. The data that CAPRI uses for calculating the actual situation of farming refer to the years 2003-2005, and are contained in the COCO and Capreg database belonging to the CAPRI system. This database is 2-yearly up-dated according to same methodology and calibration approach. For the distribution of input and output factors to HSMU levels, very robust methodologies are used as well, which integrate statistical information at NUTS 2 and 3 level with more spatially detailed factors including the MARS-based CGMS yield levels which are available at Soil Mapping Unit level.

Despite these data are the best available ones, it should be noticed that the data on input levels have different quality. The best quality data at HSMU level, which have been tested and corrected in several former projects, are on fertilizer input, plant protection and process harvest. The distribution of N-inputs for manure and artificial fertilizers is based on extensive work done by CAPRI and JRC in several joined project in the last few years. The same applies for output levels as they are calibrated and compared against yield levels modelled in the MARS-CGMS. They are also based on yield statistics which have been carefully collected for several years at regional level by Eurostat.

In the cultivation input data, the estimates of ploughing energy input are still rough and do not consider the large differences in types of machinery used on different types of soils. This aspect could be improved, but no data is known to be available EU-wide so far.

The irrigation data from CAPRI were of lower quality and contained many rough disaggregation estimates. In addition, irrigation figures by Wriedt et al. (2009) were used, which were based on detailed irrigation data from regional and national sources and distributed spatially according to crop growth model estimates to 10*10 km grids to estimate irrigation shares per crops and total irrigation water consumption. These irrigation figures were rescaled to the cropping shares per HSMU in this project. The results show for some HSMUs, particularly in Spain and Portugal, very high levels of water consumption for irrigation. In this study, these figures were accepted, as they are the best available source at the required regional level. However, it is known that some Spanish regions (e.g. Castilla-la-Mancha) set maximum levels of irrigation water consumption per crop per hectare and the average water consumption data per crop in certain HSMUs in La Mancha exceed by far these levels. For the 2003-2005 time period, used as actual farming situation, which is also applicable to the data taken from Wriedt e al., 2009, these levels may have been exceeded. However, in more recent years, it is likely that water use consumption per hectare in several Spanish regions have decreased. This would also theoretically lead to a better performance on the net energy balance for some regions in Spain, as pumping energy for irrigation accounts for a large share of the energy input in many crops grown in the actual farming energy balance calculations. As for Portugal, it is also advisable to further improve and cross check irrigation water consumption levels in future updates of this study.

Labour energy was estimated based on German references. It only specifies an average energy input per working hour. The estimate of the working hours per farm activity were derived from assessments done in the SEAMLESS project which mainly built on the FADN labour hour estimates. The total labour investment per region was used as reconciliation factor to distribute over crops and activities in a region and this total was derived from Eurostat Regional statistics on total agricultural labour.

# 5 Conclusions and recommendations

Agro-ecosystems provide provisioning, regulating and cultural services to human society. This study focused on the agro-ecosystem provisioning services regarding food, feed, fibre and fuel. These services strongly respond to the socio-economic demands of human beings, but do not always consider the ecological demands of the ecosystem, i.e. the bio-physical structure and processes that take place during the agricultural production. Therefore, there is no clear agreement within the policy and scientific communities on whether all types of agricultural production should be seen as a provisioning ecosystem service and if so, how the ecological-socio-economic flow linked to the provisioning service should be better assessed. Several studies have provided qualitative assessments but no one, to the authors' knowledge, has done it in a quantitative way. This study attempts to answer the former questions by assessing quantitatively the degree of provisioning service by the agro-ecosystems by considering their energy balance and their different bio-physical structures and processes.

The first objective of this study was therefore to map the provisioning services delivered by EU agro-ecosystems at the highest possible spatial resolution, which is the Homogenous Spatial Mapping Unit (HSMU), considering the bio-physical characteristics, the net energy use of resources and the net economic benefits. Secondly, to compare the Energy Return on Investment (EROI) and the Net Energy Balance (NEB) of the actual farming situation against reference situations with higher and lower human interference.

The analytical framework considers the human handled input and output energy factors in the agricultural production. The results show that there are currently very large differences in input and output energy levels between crops, but also for the same crop group between EU regions. In addition, the net energy gain that can be reached per crop system differs strongly. These results show that the energy approach used in the study seems a useful tool to identify which are the factors in the agricultural production process that could be modified to improve the agricultural provisional services and the sustainability of their production.

The analytical framework considered also the economic value of the output, as a way to assess the last part of the ecosystem services flow – the market value reflecting the willingness to pay for agriculture benefits. Interestingly, the analysis makes evident the contrast between the crop energy outputs and their economic values, e.g. fruit production is the lowest net energy producing system, while fruits have the highest economic value. This indicates the need to consider other types of energy metrics in future studies, such as the crops' embodied energy.

The use of three reference layers considering different degree of human intervention (i.e. natural permanent grasslands, low input farming and high input farming) helps to identify how actual agricultural provision performs compared to the potential service (i.e. the ecological function), in terms of net energy gains for total biomass, and how this changes across Europe. In future works, it will be interesting to differentiate between the net energy gains of the different components of the total biomass (feed, fibre and fuel), and not only of food.

Overall, the largest uncertainty about quality of the input data in this study concerns labour and irrigation. No distinction was made between different categories of labour, such as heavy manual labour and light labour as driving a tractor. Consequently, for the use of the developed methodology worldwide, it would be recommendable to further elaborate on the labour categories and derive more detailed information on energy input in different types of labour. It should be emphasised that improvement in data quality and higher time and spatial resolution in data would certainly improve the results of the assessment carried out in this study, and would help improving the understanding of the relation between agro-ecosystem and their provisioning services, green infrastructure and resource efficiency.

In summary, the energy analysis (in terms of EROI and NEB) seems to be a useful approach to assess the efficiency of the use of natural and human resources in agro-ecosystems to deliver provisioning services. The approach can be used to operationalise the concept of provisioning ecosystem services in policies and management:

- Improving the resource efficiency in the provisioning service of the agro-ecosystem can be done in several ways: (i) diminishing human energy inputs; (ii) increasing energy output by choosing the most appropriate combination of plant-soil and bio-geographical region, maintaining the natural resources without causing more externalities; (iii) using not only part of the total biomass, but more of the output (e.g. energy residues);
- Whether agricultural ecosystems should be included as part of the Green Infrastructure could be based on energy efficiency in combination with externality effects. Therefore, those agricultural land uses in which the EROI is > 1 and that maintain the capital stock of the soil should be considered as sustainable and efficient provisioning ecosystems.
- The same argument could be considered regarding the restoration of certain agro-ecosystems in order to increase their energy efficiency.

Finally, this study can be considered as a first step in the assessment of the total energy balance of the agro-ecosystem. It only deals with the quantification of energy regarding human inputs and the corresponding output. Further analysis should address crucial issues such as the quality of the energy and the embodied energy in the plant production, which will help to understand the full complexity of the agro-ecosystem. In addition, the analysis of the externalities associated to the agricultural production, which are outside the scope of this study, will be fundamental to assess the inter-linkages (trade-offs and synergisms) between the provisioning services and the other ecosystem services provided by agriculture.

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## Annex 1 - Grouping of crop groups for presentation and analysis of final energy balance calculations

*Table 7 Mapping CAPRI crop activities to aggregates*

<table>
<tr><td>SWHE</td><td rowspan="8">Cereals</td><td rowspan="20">ARAB</td><td rowspan="22">ArabGras</td><td rowspan="29">ArabPermGras</td><td rowspan="34">ArabPermGrasFall</td><td rowspan="18">ArabFallNoVeg</td><td rowspan="18">ArabGrasFallNoVeg</td><td rowspan="18">ArabGrasNoVeg</td><td rowspan="42">AllCrops</td></tr>
<tr><td>DWHE</td></tr>
<tr><td>RYEM</td></tr>
<tr><td>BARL</td></tr>
<tr><td>OATS</td></tr>
<tr><td>MAIZ</td></tr>
<tr><td>OCER</td></tr>
<tr><td>PARI</td></tr>
<tr><td>RAPE</td><td rowspan="3">Oilseed</td></tr>
<tr><td>SUNF</td></tr>
<tr><td>SOYA</td></tr>
<tr><td>NONF</td><td rowspan="7">OtherArab</td></tr>
<tr><td>MAIF</td></tr>
<tr><td>ROOF</td></tr>
<tr><td>OFAR</td></tr>
<tr><td>PULS</td></tr>
<tr><td>POTA</td></tr>
<tr><td>SUGB</td></tr>
<tr><td>TOMA</td><td rowspan="2">Vegetab</td><td rowspan="11"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>OVEG</td></tr>
<tr><td>GRAE</td><td colspan="2" rowspan="2">Grass</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>GRAI</td></tr>
<tr><td>APPL</td><td rowspan="3">Fruits</td><td rowspan="7">Permanent</td><td rowspan="20"></td><td rowspan="7"></td><td rowspan="20"></td></tr>
<tr><td>OFRU</td></tr>
<tr><td>CITR</td></tr>
<tr><td>OLIV</td><td rowspan="2">Olives</td></tr>
<tr><td>TABO</td></tr>
<tr><td>TAGR</td><td rowspan="2">VINE</td></tr>
<tr><td>TWIN</td></tr>
<tr><td>FALL</td><td colspan="2" rowspan="5">Fallow</td><td rowspan="13"></td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>ISET</td></tr>
<tr><td>GSET</td></tr>
<tr><td>TSET</td></tr>
<tr><td>VSET</td></tr>
<tr><td>OOIL</td><td colspan="2" rowspan="8">NoClass</td><td rowspan="8"></td><td rowspan="8"></td><td rowspan="8"></td></tr>
<tr><td>OIND</td></tr>
<tr><td>NURS</td></tr>
<tr><td>FLOW</td></tr>
<tr><td>OCRO</td></tr>
<tr><td>NECR</td></tr>
<tr><td>TEXT</td></tr>
<tr><td>TOBA</td></tr>
</table>

# Annex 2 - Calculating energy input for spreading manure

Data used for estimating the energy input of manure spreading were based on German average figures (available at http://www.llh-essen.de/landwirtschaft/vtec/text63.htm).

According to these, it is assumed that a spreading tank contains on average 16m$^3$ of manure (average 11 – 22 m$^3$). It takes 30 minutes to drive, fill and spread the tank (own estimate). This means that 32m$^3$ are spread per hour which implies that 1.67 litres of diesel are used to spread 1 m$^3$ manure (32/19.2 = 1.67 l).

1 m$^3$ manure contains 12 kg Nitrogen, Phosphate and Potassium (NPK) in equal shares (based on "rough" average of nutrient content in different types of manure see e.g. http://www.lfl.bayern.de/iab/duengung/organisch/09556/).

To link the fuel input to the separate NPK contents the following formula is applied:

1.67 l/12 kg =0.139 l/kg NPK

Thus, 0.139 is the amount of diesel needed to spread 1 kg of nutrition. As the energy content of diesel is 45.71 MJ/l the energy consumption is 6.4 MJ/kg (nutrition).

When the calculation results on the energy input for manure spreading  is combined with the fertilizer spreading, the following coefficients for energy input for mineral and manure spreading are the result:

*Table 8 coefficients for energy inputs used for mineral and manure spreading*

| | mineral | manure |
|---|---|---|
| N | 58.99 | 6.4 |
| P | 40.06 | 6.4 |
| K | 9.25 | 6.4 |

# Annex 3 - Calculating energy input through labour

The labour input estimate builds on a German study[2], which is based on the average energy intake for a person (see Table 1) doing light physical work.

*Table 9 Overview of average energy in-take per day for males and females*

| Age | Males | Females |
|---|---|---|
| 15-18 years | 3100 kcal | 2500 kcal |
| 19 < 24 year | 3000 kcal | 2400 kcal |
| 25 -50 years | 2900 kcal | 2300 kcal |
| 51 - 64 years | 2500 kcal | 2000 kcal |
| >= 65 years | 2300 kcal | 1800 kcal |

Source: D-A-CH: Referenzwerte für die Nährstoffzufuhr

For heavier work, the following additional energy in-take is needed:

- Moderately heavy physical work: plus ca. 600 kcal
- Heavy physical work: plus ca. 1200 kcal
- Very heavy physical work: plus ca. 1600 kcal

Examples of these working categories are given in Table 2.

*Table 10 Examples of light to very heavy work categories*

| Light physical work | Moderately heavy physical work | Heavy physical work | Very heavy physical work |
|---|---|---|---|
| Clerk | Garage employee | Construction worker | Steel worker |
| Housewife/man | Painter | Sports instructor | Coal miner |
| Teacher | Gardener | Physiotherapist | Top sportsmen/women |
| Lorry driver | Salesman/women | Roofer | Forest worker |

[2] D-A-CH: Referenzwerte für die Nährstoffzufuhr. Available at: http://www.ernaehrung.de/tipps/allgemeine_infos/ernaehr10.php

In this study, we assume that a farmer operates at the same physical work level as a roofer or construction worker and that on average he is male and is in the age of 25-50 years.

This implies that his caloric needs are:

(2900 + 1200) Kcal = 4100 kcal.

Per working hour he needs:

4100 kcal / 8 hours of work = 500kcal per hour (approximately)

Conversion to MJ:

1kJ = 0.239 kcal; this implies that:

500 kcal/0.239= 2092kJ = 2.092 MJ per hour

In a follow up it could be considered to differentiate between different categories of labour (e.g. with machinery vs. manual labour), although data on which this differentiation can be made are scarce.

# Annex 4 - Energy content of output of food, feed and other biomass

As values are typically given per kg dry matter, all the coefficients had to be converted to fresh weight. For an overview of the energy content factors used for food products see Table 1. An overview of the energy contents of forage crops is given in Table 2.

*Table 11 Energy content of the food products*

| Product | MJ per kg fresh weight | Product | MJ per kg fresh weight |
|---|---|---|---|
| Soft wheat | 11,38 | Citrus fruits | 1,18 |
| Durum wheat | 11,38 | Table grapes | 2,86 |
| Reye and meslim | 12,06 | Tobacco | 4,07 |
| Barley | 11,46 | Wine | 2,85 |
| Oats | 10,19 | | |
| Grain maize | 11,02 | | |
| Other cereals | 11,46 | | |
| Rape (seed) | 15,28 | | |
| Sunflower (seed) | 15,28 | | |
| Soya (seed) | 10,19 | | |
| Other oil (seed) | 37,07 | | |
| Paddy rice | 15,88 | | |
| Olives | 36,81 | | |
| Pulses | 14,00 | | |
| Potatoes | 2,74 | | |
| Sugar beet | 2,38 | | |
| Tomatoes | 0,81 | | |
| Other vegetables | 1,12 | | |
| Apples | 1,70 | | |
| Other fruits | 1,75 | | |

*Table 12 Energy content of forage or biomass output*

| | Energy (MJ per kg dry matter) **** | Dry matter content (g/kg) | Energy (MJ per kg fresh weight) - approximately |
|---|---|---|---|
| Silage Maize* | 11,2 | 352 | 3,75 |
| Fodder root crops** | 7,9 – 8,3 | 140 - 190 | 2,00 |
| Other fodder from arable land* | 10.2 – 10.7 | 390 – 406 | 3,75 |
| Grass* | 10,0 - 10,6 | 423 – 431 | 3,75 |
| Straw*** | 18 | 890 | 16,00 |

* Taken from http://www.landwirtschaftskammer.de/landwirtschaft/tierproduktion/rinderhaltung/

** Taken from https://www.fibl-shop.org/shop/pdf/mb-futterrueben.pdf

*** Taken from Elbersen et al. (2012)

**** Heating value of biomass

To derive the potential biomass output of non-food (e.g. wood cuttings as by product of apple trees), specific biomass coefficient estimates were used first to estimate the total volume for cuttings and pruning from vineyards, citrus and other fruit trees, nuts and olives and for straw. These volumes were then converted to energy content according to their lower heating values and their dry matter content.

In order to estimate the residue potential the permanent cropping areas derived from CAPRI for 2004 the average harvest ratios per type of permanent crop. The harvest ratios were derived from several publications (see underneath) and their averages are summarised per crop category in Table 3.

*Table 13 Average residue harvest ratios per type of permanent crop*

| **Land use category** | **Residue yields Ton DM/HA/Year** |
|---|---|
| Fruit and berry plantations – total | 2.15 |
| Temperate climate fruit and berry plantations | |

| | |
|---|---|
| Subtropical climate fruit and berry plantations | |
| Nuts fruit and berry plantations | 2.15 |
| Citrus plantations | 2.75 |
| Olive plantations - table olives | 1.77 |
| Olive plantations - oil production | |
| Vineyards - quality wine | 2.81 |
| Vineyards - other wines | |
| Vineyards - table grapes | |
| Vineyards – raisins | |

Sources:

1) Di Blasi, C., Tanzi, V. and Lanzetta (1997), M. A study on the production of agricultural residues in Italy; Biomass and Bioenergy Vol 12 No 5 pp 321-331 (1997)
2) Iacopo Bernetti et. Al. (2004). A methodology to analyse the potential development of biomassenergy sector: an application in Tuscany; Forest Policy and Economics 6 (2004) 415-432
3) Figures taken from powerpoint presentation "Bioenergy market in Greece" by Despina Vamvuka (15/12/2006): http://www.enveng.tuc.gr/Downloads/ABES_LAB/05%20Vamvuka.pdf
4) Siemons, R., Mc Chesney, I., Nikolaou, N., Vis, M., Berg, van den D. & Whitelye M. (2004). Bioenergy's role in the EU energy market. A view of developments until 2020.http://ec.europa.eu/environment/etap/pdfs/bio_energy.pdf
5) Mladen Ilic, Borislav Grubor and Milos Tesic (2004). The state of biomass energy in Serbia; BIBLID: 0354-9836, 8 (2004), 2, 5-19; http://www.doiserbia.nb.rs/ft.aspx?id=0354-98360402005I

For the conversion of this biomass to energy, the following conversion factors were used:

Lower heating value: Energy (MJ per kg dry matter) = 11.7

Dry matter content (g/kg) = 890

Energy (MJ per kg fresh weight) = 10.41

A methodology for estimating the straw biomass potential is available from a JRC study (JRC and CENER, 2006 and Scarlat et al. 2009). In this work, the methodology for estimating a sustainable potential applies to a wide range of crops delivering straw including all cereals, rice, and maize, sunflower and oil seed rape. Based on a wide range of EU expertise, the straw yield ratios per type of crop are provided together with sustainable harvest levels. The latter relate to harvest practices aimed at maintaining the soil carbon levels in the soil. These were estimated to be at 40% for wheat, rye, oats and barley and at 50% for the other 4 crops. The JRC approach was applied to all crop area and yield levels in the CAPRI database to arrive at a final straw biomass energy output. For conversion of the straw biomass to energy, the figures provided in Table 2 for straw were used.

# Annex 5 - Allocation of input and output variables from region to HSMU

*Table 14 Overview of input and output factors and approach to how these have been allocated to HSMU level in CAPRI-Dynaspat*

| Factor | Linked to HSMU? | Description of allocation approach |
|---|---|---|
| Yield | Yes | Reconciliation of HSMU specific yields with regional production |
| Cultivation | No | *If needed it will be disaggregated using information at HSMU level on sand/clay content of soil* |
| Manure fertilizer | Yes | Derived from estimated spatial animal density (see Leip et al., 2008) |
| Mineral fertilizer | Yes | Derived from yield, manure application and soil characteristics (see Leip et al., 2008) |
| Irrigation | Yes/No | *Map of irrigation shares used in CAPRI-Dynaspat is already available. However, water consumption is not yet linked to HSMU. This will happen as part of this project. It will be done by combining the Wriedt et al. (2009) data providing irrigation water consumption and irrigation shares per crop at 10*10 km grid with the HSMU level* |
| Seed | No | *If needed it could be disaggregated proportional to yield* |
| Plant protection | No | *If needed it could be disaggregated proportional to yield* |
| Processing harvest | No | Take regional average. No allocation needed |
| Labour | No | Not clear if needed estimates of more or less manual labour input can be derived from the HSMU specific farm typology. |

Table A5-1 shows that important energy input factors like fertilisation levels and energy output as yield levels are already allocated to HSMU level.

For the allocation of irrigation water consumption per crop at HSMU, level the data from Wriedt et al. (2009) were used together with crop-region specific irrigation data from Mars-CGMS. For this purpose, the following steps were taken:

1. Data were extracted on irrigation shares and crop areas and total irrigation water consumption contained in the Wriedt et al. (2009) database for the EU-27 at the level of 10*10 km grids.

2. A spatial overlay was made between the 10*10 km grid with the HSMU polygons to transfer the irrigation shares per crop and the total irrigation water consumption to the level of HSMU.
3. Like for the allocation of the crops and the fertilisation levels, the existing Dynaspat allocation procedure (at the level of HSMU ) was further adapted and applied for the estimation of the irrigation water use levels per crop. This was done by using a Bayesian Highest Posterior Density method that distributes the total irrigation water to a crop in an HSMU within the totals of irrigation water consumption for the NUTS regions and taking account of prior information on total irrigation water consumption and irrigation crop shares. In the allocation, prior information from MARS-CGMS was also used on crop specific irrigation water consumption at NUTS level. This information is however only available for 8 arable crops and can therefore only improve the irrigation water consumption estimates on a selection of crops. The distribution aimed at creating an optimal consistency between scales, i.e. between the totals at NUTS2 and HSMU levels.

It was also decided that I was not necessary to make HSMU specific distributions of seed and plant protection within the scope of this study, since these inputs generally do not make up a large share of the total inputs per crop.

# Annex 6 - Preparation of the three reference layers with the MARS-CGMS system

The three reference layers were prepared with the CGMS. First a short description of the system is given, followed by a description of the preparation of the three reference layers.

*CGMS*

The Crop Growth Monitoring System (CGMS) as parts of the MARS Crop Yield Forecasting System (MARS-CYFS) of the European Commission Joint Research Centre consists of a meteorological, soil and crop data base, an agro-meteorological model and remote sensing information on Europe (including Russia, Turkey and Maghreb) and third countries. The system provides indicators of crop yield for specific crops with a resolution of 25x25 km for the whole Europe and several countries in Central Asia on a 0.25 DD resolution. The system runs on a daily basis to provide to the European Commission with near real time information on the status of arable crop development across Europe in terms of delays and biomass production in the current year and in comparison to the past (1975-2011). The crop biomass production is first simulated using biophysical environmental factors (weather, soil, crops) and agronomic knowledge, and in a second step an analysis is carried out to relate the simulation results to agricultural statistics. Estimates distinguish total biomass production and harvestable yield of 11 arable crops (winter wheat, grain maize, spring barley, rye, field beans, winter rapeseed, sunflower, permanent grassland, temporary grassland, sugar beet and potato).

The components of the system run on computers at three locations (Wageningen (NL), Mol (B) and Berlin (D)), while a copy of it is maintained at JRC, Ispra, Italy by remote control. The MARSOP Consortium acts as data provider, the final analysis and forecasts are done by MARS Unit of JRC at Ispra, Italy. For further information on MARS see: www.marsop.info

CGMS is based on a number of crop physiological responses to weather and soil conditions which is the case for a family of crop growth models, of which SUCROS, WOFOST and ORYZA are the best known members. These models are used to explain or predict the potential and attainable yields of crops under the environmental and management conditions, and to compare these yields against actual yields in a field, farm, or a region, to quantify the yield gap and to identify the constraints limiting crop production. The WOFOST model (see Van Keulen and Wolf, 1986; van Diepen et al., 1989; Supit et al., 1994; Vossen and Rijks, 1995) is the weather driven crop engine of CGMS. In WOFOST, instantaneous photosynthesis (calculated at three depths in the canopy for three moments of the day) is first integrated over the depth of the canopy and over the light period to arrive at daily total canopy photosynthesis. After subtracting maintenance respiration, assimilates are partitioned over roots, stems, leaves and grains as a function of the development stage, which is calculated by integrating the daily development rate, described as a function of temperature and photoperiod. Assimilates are then converted into structural plant material taking into account growth respiration. Leaf area growth is driven by temperature and limited by assimilate availability.

Above-ground dry matter accumulation and its distribution over leaves, stems and grains on a hectare basis are simulated from sowing to maturity on the basis of physiological processes as determined by the crop's response to daily weather: (rainfall, solar radiation, photoperiod, minimum and maximum temperature and air humidity), soil moisture status (i.e. $T_a/T_p$, alike the FAO models) and management practices (i.e. sowing density, planting date, etc.). Water supply to the roots, infiltration, runoff, percolation, capillary rise and redistribution of water in a one-dimensional profile are derived from hydraulic characteristics and moisture storage capacity of the soil.

A detailed physiological information is also included, such as heat sums to reach various phonological stages, energy conversion, portioning of assimilates over various plant organs. For specific crop varieties grown in certain regions, some parameters in the crop files have been modified. Since new crop varieties are constantly introduced, crop parameters that describe crop growth and development, such as the temperature sums to reach the flowering stage, are regularly updated and calibrated as new information becomes available.

The need for soil data is twofold. Rooting depth and water retention characteristics determine the maximum available water that can be stored by the soil. Important system aspects like initial available water at the start of the growing season and the soil capacity to buffer infiltrated rainfall are influenced by these soil properties. Further, soil data are used to define whether a crop has to be included in the simulation for a given soil type. For instance, shallow soil types are excluded, as these soils are not cropped in reality. The current CGMS is based on the Soil Geographical Database of Europe (SGDBE) version 4 covering pan Europe. The resolution available for geographical representation is 1:1,000,000 for most countries. The SGDBE contains list of Soil Typologic Units (**STU**), characterizing distinct soil types that have been identified and described. The STU are described by attributes specifying the nature and properties of the soils, for example texture, the moisture regime, the stoniness etc. Because it is not technically feasible to delineate each STU on the map, the STUs are grouped into Soil Mapping Units (**SMU**) to form soil associations. Soil attributes like rooting depth and water retention required in the crop water model of CGMS have been derived from basic properties like soil name and texture applying so-called pedotransfer rules.

CGMS-Europe contains a database with historic daily meteorological data from weather stations. For the EU15 and neighbouring countries, data from approximately 380 stations operating since 1976 are available, in some cases back to 1930. Since about 1990, the data set was extended with stations from Eastern Europe, western Russia, Maghreb and Turkey, while the station density increased over the entire area. Presently, data from about 7000 stations is available. Of these stations, about 3000 receive daily meteorological information. The historic data were converted into consistent units and scanned for inconsistencies and non-realistic values. Variables covered are global radiation, air temperature, dew-point temperature (humidity), pressure at sea level, wind speed, amounts of precipitation, clouds, and sunshine duration.

Although CGMS can be applied at station level, CGMS runs on a 25 by 25 km grid for the following reasons: irregular spatial distribution of the meteorological stations, spatial variability of the crop and land use, crop and soil information. The weather variables needed as input are: precipitation, minimum and maximum temperature, global radiation, wind speed and vapour pressure. The data interpolation is based on the averaging of values from weather stations surrounding a given grid cell, with a preference for similar stations. Similarity is expressed as a score based on distance between grid centre and station, difference in altitude and distance to the coast, position relative to a climatic barrier and the distribution of the used stations around the grid cell.

The interpolation is executed in two steps: first, from the list of suitable stations a sub-et is selected that is most suitable for the interpolation. Second, a simple average is calculated for most of the meteorological parameters, with a correction for the altitude difference between the station and grid cell centre in case of temperature and vapour pressure. As an exception, rainfall data are taken directly from the most similar station. This empirical interpolation method is robust and accurate.

*Natural grassland*

The natural grassland layer assumes a situation in which the present agricultural land area of the EU is covered by grassland that is maintained under grass by grazing with wild animals. No external inputs are assumed in terms of nitrogen or irrigation water. The nitrogen availability is restricted to the nitrogen base supply per soil type, which is maintained by the nitrogen fixation of the vegetation. This fixation is very low as under purely natural circumstances there is practically no nitrogen deposition resulting from intensive livestock systems and other sources. The base nitrogen supply is estimated per STU based on its texture class (Figure 1). It was also assumed that the N-base in the soil remains stable, as there is a balance between nitrogen fixation by the grassland and nitrogen removal by natural grazing. The nitrogen base supply was used in to correct CGMS results for possible nitrogen shortage in natural grassland systems.

*Figure 9 Base nitrogen levels per STU in purely natural grassland conditions with extensive grazing by wild fauna*


1 Course: 30kg/ha

2 Medium: 45kg/ha

3 Medium fine: 50kg/ha

4 Fine: 40kg/ha

5 Very fine: 30kg/ha

Climate and soil conditions together determine the biomass yield in combination with the very extensive grazing of wild animals. To calculate the natural grassland yield, the CGMS water-limited permanent grassland yield was taken as a basis (YIELD_CGMS_WYB). This water-limited yield assumes no irrigation water application and unlimited nitrogen availability. In order to correct for nitrogen limitation, the following calculation steps were applied in a post model assessment.

Two situations are considered. If the nitrogen requirement needed for YIELD_CGMS_WYB can be provided by the base nitrogen availability, there is no nitrogen limitation and N_CORRECTION is set to 1. If the base nitrogen availability is smaller than the nitrogen requirement needed for YIELD_CGMS_WYB, a linear relation between the amount of nitrogen and yield was assumed. Therefore, N_CORRECTION is equal to the base nitrogen availability divided by the nitrogen requirement. The nitrogen requirement was calculated by multiplying YIELD_CGMS_WYB by the average nitrogen fraction in the crop (0.015). Finally, a correction factor was applied to account for the loss of biomass via natural grazing which was set at 25%. To summarize:

- If nitrogen base supply >= nitrogen requirement:

→Natural grassland yield = 0.75 * YIELD_CGMS_WYB

- If nitrogen base supply < nitrogen requirement:

→Natural grassland yield = 0.75 * YIELD_CGMS_WYB * N_BASE_SUPPLY / N_REQUIRED

*Low input farming*

In the low input farming situation, it was assumed that land use is the same as in the actual situation; that the nitrogen supply to all crops is reduced by 50% of the actual supply and that there is no irrigation. This implies that the yield is always considered water-limited, but compared to the maximum water-limited yield there is an extra post processing reduction. It is assumed that 20% of the CMGS_YIELD_WYB is supplied by the soil and not influenced by the reduced nitrogen supply. For the remaining production (80%), a linear relation is used to account for the 50% nitrogen supply reduction. Finally, a 0.7 harvest share is applied:

Low input yield = 0.7 * (CGMS_YIELD_WYB*0.2 + CGMS_YIELD_WYB *0.8*0.5)

By using nitrogen fractions from table 1, nitrogen shares can be derived:

Low input base nitrogen = CGMS_YIELD_WYB * 0.2* N_MEAN

Low input nitrogen = CGMS_YIELD_WYB *0.8*0.5* N_MEAN

*Table 15 Mean nitrogen fractions per crop*

| *CROP* | *HI* | *N_MIN_STO* | *N_MIN_STE* | *N_MIN* | *N_MEAN* |
|---|---|---|---|---|---|
| Barley | 0.44 | 1.10 | 0.35 | 0.680 | 0.010200 |
| Maize | 0.50 | 0.95 | 0.40 | 0.675 | 0.010125 |
| Potato | 0.80 | 0.85 | 1.50 | 0.980 | 0.014700 |
| Rapeseed | 0.50 | 1.50 | 0.55 | 1.025 | 0.015375 |
| Sugerbeet | 0.70 | 0.60 | 1.80 | 0.960 | 0.014400 |
| Sunflower | 0.56 | 1.80 | 0.70 | 1.316 | 0.019740 |
| Wheat | 0.50 | 1.10 | 0.30 | 0.700 | 0.010500 |

Where:

| | |
|---|---|
| HI | = Harvest index |
| N_MIN_STO | = minimum % N of dry weight storage organs |
| N_MIN_STE | = minimum % N of dry weight stems and straw |
| N_MIN | = HI * N_MIN_STO + (1-HI) * N-MIN_STE |
| N_MEAN | = 1.5 * (N_MIN) / 100 |

HI, N_MIN_STO and N_MIN_STE have been derived from Nijhof, 1987; Van Heemst, 1988; Boons-Prins, 1993; and literature review.

*High input farming*

The high input layer assumes a similar land use pattern as the actual land use pattern but a maximum yield. This implies that crop growth is simulated with the MARS CGMS assuming no water, nor nitrogen limitation. In CGMS, this maximum yield level is already calculated for all crops included in the system. It is the potential above ground biomass yield (CGMS_YIELD_PYB), corrected with a 30% management correction fraction:

High input yield = 0.7 * CGMS_YIELD_PYB

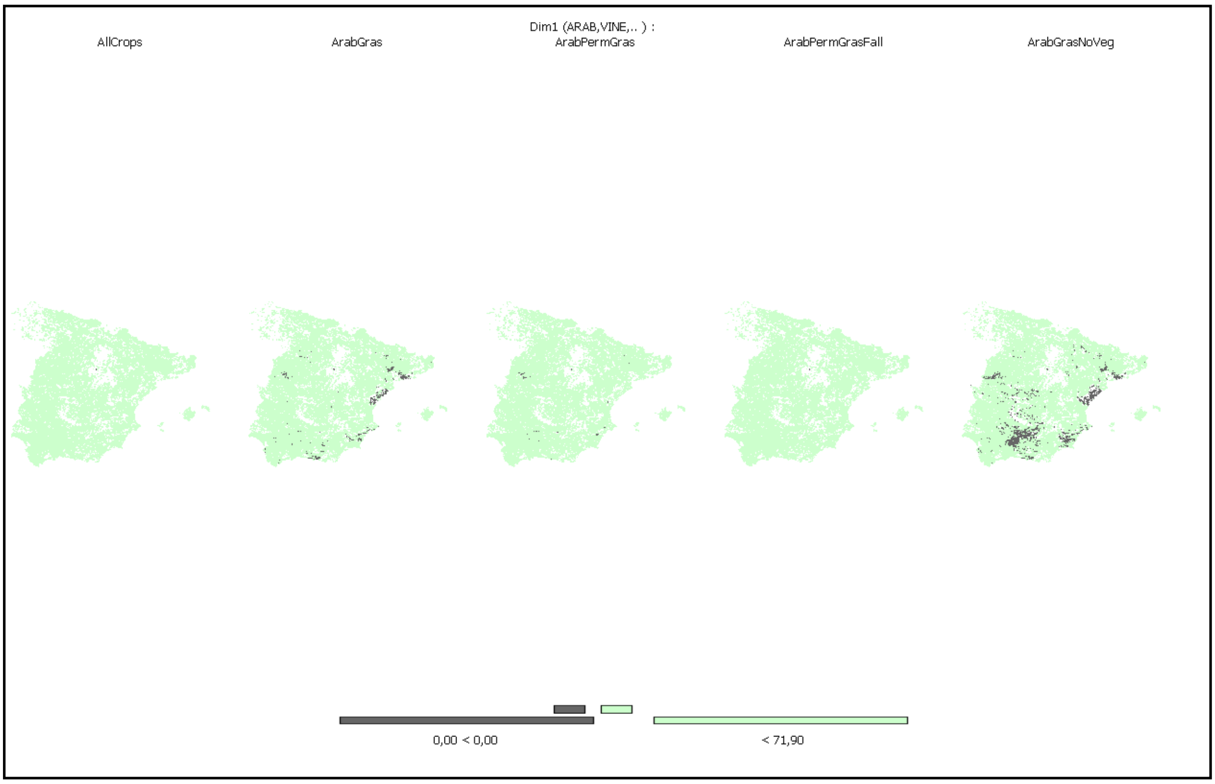
Also in this case the nitrogen shares can be derived using the nitrogen fractions from table 1. The base nitrogen is equal to the low input situation and High input accounts for the remaining part:

| | |
|---|---|
| High input base nitrogen | = CGMS_YIELD_WYB * 0.2* N_MEAN |
| High input nitrogen | = (CGMS_YIELD_PYB - CGMS_YIELD_WYB * 0.2) * N_MEAN |

# Annex 7 - Analysis of most suitable crop aggregates for presentation of results

To understand which crop aggregates are most suitable to be used for presenting the final results of EROI and Net Energy Balance, an analysis was carried out for Spain. Spain is a very diverse country in terms of crop, farming types and agro-environmental characteristics; therefore, it is very suited to test the coverage of crop type aggregates for HSMUs. It has been investigated with which crop groups the largest number of HSMUs are covered with energy balance calculation results. After all, if certain crop groups are excluded from the analysis, this could also lead to exclusion of HSMUs from the analysis. An overview of where HSMUs are no longer covered per crop group is presented in Figure 1. The results show that, as it was expected, full coverage is reached when all crops are included (left picture), but if the crops belonging to NoClass (see Annex 1) are excluded from the analysis (fourth map from the left, including the categories arable, vegetables, grasslands, permanent crops and fallow), a practically full coverage of all HSMUs is still provided. In conclusion, it means that this class is the most suitable one to present the final results.

*Figure 10 Coverage of HSMUs per crop group (grey = not available, green = available)*



# Annex 8 - Land use, input and output information per country and environmental zone

In the Tables 1 and 2 below, land use (as of 2004) for different crops are provided, respectively, per Member State and Environmental Zones.

*Table 16 Land use 2004 per country (*1000 ha)*

| | arable | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | Cereals | Oilseeds | Other arables | total arable | Fallow | Vegetables | Grass | Fruits | Olives | Vineyards | total |
| Austria | 796 | 77 | 384 | 1270 | 148 | 13 | 1754 | 10 | | 48 | 3242 |
| Bulgaria | 1726 | 649 | 193 | 2628 | 516 | 55 | 1730 | 66 | | 135 | 5130 |
| Belgium-Luxe | 358 | 11 | 434 | 854 | 32 | 52 | 584 | 20 | | 1 | 1544 |
| Czech Rep | 1558 | 309 | 838 | 2724 | 92 | 19 | 904 | 28 | | 19 | 3787 |
| Germany | 6874 | 1329 | 2898 | 11208 | 1318 | 106 | 4945 | 73 | | 101 | 17752 |
| Denmark | 1454 | 113 | 716 | 2293 | 224 | 11 | 187 | 8 | | | 2722 |
| Estonia | 280 | 49 | 222 | 555 | 30 | 3 | 250 | 4 | | 0 | 842 |
| Greece | 1113 | 19 | 426 | 1702 | 403 | 121 | 1339 | 161 | 746 | 112 | 4584 |
| Spain | 6498 | 681 | 1829 | 9522 | 4290 | 393 | 8562 | 1052 | 2515 | 1132 | 27467 |
| Finland | 1243 | 94 | 703 | 2051 | 384 | 10 | 78 | 7 | | | 2531 |
| France | 9197 | 2022 | 5909 | 17425 | 1642 | 275 | 9427 | 184 | 18 | 882 | 29853 |
| Hungary | 2852 | 619 | 455 | 4028 | 197 | 99 | 956 | 100 | | 89 | 5469 |
| Ireland | 318 | 14 | 814 | 1154 | 39 | 7 | 3052 | 2 | | | 4254 |
| Italy | 3903 | 352 | 2449 | 7423 | 641 | 485 | 3866 | 660 | 1006 | 788 | 14869 |
| Lithuania | 990 | 98 | 585 | 1694 | 213 | 21 | 944 | 35 | | | 2908 |
| Latvia | 473 | 56 | 486 | 1029 | 118 | 14 | 661 | 16 | | | 1838 |
| Netherlands | 219 | 2 | 693 | 992 | 32 | 77 | 847 | 20 | | 0 | 1969 |
| Poland | 8497 | 527 | 1981 | 11192 | 1480 | 187 | 3499 | 360 | | 0 | 16718 |
| Portugal | 439 | 214 | 580 | 1307 | 378 | 48 | 1174 | 143 | 358 | 218 | 3627 |
| Romania | 5646 | 1214 | 1165 | 8257 | 420 | 231 | 4516 | 208 | | 220 | 13853 |
| Sweden | 1206 | 152 | 1114 | 2486 | 507 | 13 | 487 | 4 | | | 3496 |
| Slovenia | 91 | 2 | 82 | 178 | 1 | 3 | 299 | 6 | 2 | 20 | 508 |
| Slovakia | 798 | 195 | 354 | 1359 | 8 | 11 | 677 | 8 | | 14 | 2079 |
| UK | 3091 | 580 | 1954 | 5738 | 561 | 112 | 9979 | 33 | | 1 | 16423 |

*Table 17 Land use 2004 per aggregate Environmental Zone (*1000 ha)*

| | Arable | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Environmental zone | Cereals | Oil- seeds | Other arables | total arable | Fallow | Vege-tables | Grass | Fruits | Olives | Vine-yards | total |
| Alpine | 654 | 64 | 579 | 1297 | 100.5 | 19 | 2050 | 35 | 2 | 68 | 3572 |
| Boreal - Nemoral | 4842 | 454 | 3133 | 8429 | 1292.9 | 76 | 2838 | 71 | | 0 | 12707 |
| Continental - Pannonian | 18959 | 3230 | 13787 | 35976 | 3343.3 | 647 | 34423 | 317 | 232 | 657 | 75594 |
| Atlantic - Lusitanian | 26424 | 4726 | 8142 | 39292 | 3837.1 | 692 | 17258 | 819 | | 638 | 62536 |
| Mediterranean | 12629 | 1562 | 6892 | 21082 | 5810.2 | 1062 | 15882 | 2010 | 4411 | 2464 | 52721 |

The following Tables shows the average values of input, output, EROI and Net Energy Balance for all crops in EU-27 first per MS and subsequently per aggregate Environmental Zones.

*Table 18 Average input, output, EROI and Net Energy Balance for all crops in EU-27 per MS*

| Allcrops | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Energy | | | Net balance: $Mj_{out}$-$MJ_{in}$ | | |
| Country | Cultivation | Irrigation | Labour | Manure Fertilizer | Mineral Fertilizer | Plant Protection | Process Harvest | Seed | total input | Food | Feed | biomass | Food | Food+ Feed | Total | Food | Food+ Feed | Total |
| Austria | 6526 | 6 | 90 | 860 | 2411 | 193 | 2896 | 260 | 13242 | 24637 | 23628 | 5190 | 1.86 | 3.64 | 4.04 | 11395 | 35023 | 40213 |
| Bulgaria | 4560 | 16 | 494 | 230 | 1597 | 0 | 505 | 831 | 8233 | 24752 | 7916 | 5936 | 3.01 | 3.97 | 4.69 | 16518 | 24434 | 30370 |
| Belgium-Luxemburg | 8785 | 34 | 73 | 2801 | 8014 | 1206 | 2847 | 380 | 24139 | 39251 | 64377 | 5750 | 1.63 | 4.29 | 4.53 | 15111 | 79489 | 85239 |
| Czech Rep | 5439 | 12 | 22 | 517 | 5052 | 219 | 797 | 377 | 12436 | 40900 | 22185 | 10174 | 3.29 | 5.07 | 5.89 | 28465 | 50649 | 60823 |
| Germany | 7963 | 126 | 86 | 1132 | 6775 | 320 | 1235 | 353 | 17991 | 41484 | 38181 | 12330 | 2.31 | 4.43 | 5.11 | 23493 | 61674 | 74004 |
| Denmark | 7210 | 222 | 56 | 1454 | 5243 | 222 | 586 | 439 | 15434 | 45924 | 40095 | 15852 | 2.98 | 5.57 | 6.60 | 30491 | 70586 | 86438 |
| Estonia | 5310 | 0 | 164 | 423 | 2397 | 79 | 457 | 419 | 9250 | 31812 | 21539 | 4923 | 3.44 | 5.77 | 6.30 | 22562 | 44101 | 49024 |
| Greece | 9105 | 125 | 343 | 505 | 3890 | 431 | 0 | 880 | 15278 | 32586 | 16477 | 10498 | 2.13 | 3.21 | 3.90 | 17308 | 33786 | 44284 |
| Spain | 6516 | 9029 | 79 | 468 | 3100 | 277 | 3 | 258 | 19729 | 19213 | 15208 | 9691 | 0.97 | 1.74 | 2.24 | -515 | 14693 | 24384 |
| Finland | 8672 | 0 | 51 | 545 | 4703 | 93 | 166 | 468 | 14699 | 41760 | 12866 | 8873 | 2.84 | 3.72 | 4.32 | 27061 | 39927 | 48801 |
| France | 5926 | 1480 | 91 | 844 | 5755 | 544 | 2633 | 465 | 17738 | 33851 | 39952 | 10032 | 1.91 | 4.16 | 4.73 | 16112 | 56064 | 66096 |
| Hungary | 5555 | 13 | 331 | 356 | 4199 | 141 | 6278 | 430 | 17304 | 29861 | 10251 | 8436 | 1.73 | 2.32 | 2.81 | 12557 | 22807 | 31243 |
| Ireland | 4752 | 0 | 37 | 1911 | 6137 | 90 | 0 | 115 | 13041 | 10125 | 93471 | 17 | 0.78 | 7.94 | 7.95 | -2916 | 90555 | 90571 |
| Italy | 9679 | 7158 | 271 | 757 | 4310 | 899 | 1 | 378 | 23453 | 32882 | 23719 | 10058 | 1.40 | 2.41 | 2.84 | 9428 | 33147 | 43205 |
| Lithuania | 5445 | 0 | 188 | 382 | 2916 | 43 | 14 | 494 | 9483 | 30085 | 17479 | 5729 | 3.17 | 5.02 | 5.62 | 20602 | 38081 | 43811 |
| Latvia | 5295 | 0 | 256 | 279 | 1557 | 0 | 505 | 365 | 8257 | 25793 | 20992 | 3716 | 3.12 | 5.67 | 6.12 | 17536 | 38528 | 42244 |
| Netherlands | 9466 | 261 | 217 | 3367 | 9404 | 776 | 783 | 713 | 24986 | 28728 | 76056 | 2234 | 1.15 | 4.19 | 4.28 | 3742 | 79797 | 82031 |
| Poland | 6899 | 6 | 411 | 506 | 4441 | 104 | 1442 | 571 | 14379 | 44083 | 10771 | 9057 | 3.07 | 3.82 | 4.44 | 29705 | 40476 | 49533 |
| Portugal | 8209 | 2936 | 163 | 604 | 2286 | 614 | 0 | 262 | 15075 | 11657 | 13210 | 8698 | 0.77 | 1.65 | 2.23 | -3418 | 9792 | 18490 |
| Romania | 5610 | 27 | 613 | 0 | 0 | 128 | 24 | 342 | 6744 | 31963 | 11524 | 4202 | 4.74 | 6.45 | 7.07 | 25220 | 36744 | 40946 |
| Sweden | 6691 | 20 | 36 | 625 | 3622 | 97 | 418 | 361 | 11871 | 23536 | 40202 | 7875 | 1.98 | 5.37 | 6.03 | 11666 | 51868 | 59743 |
| Slovenia | 10579 | 11 | 401 | 1375 | 8644 | 486 | 345 | 317 | 22158 | 21242 | 38852 | 4267 | 0.96 | 2.71 | 2.90 | -916 | 37936 | 42203 |
| Slovakia | 4331 | 41 | 51 | 333 | 2924 | 281 | 1887 | 418 | 10264 | 30178 | 18724 | 6795 | 2.94 | 4.76 | 5.43 | 19914 | 38638 | 45432 |
| UK | 3752 | 53 | 32 | 955 | 4674 | 413 | 286 | 239 | 10403 | 22321 | 57601 | 5941 | 2.15 | 7.68 | 8.25 | 11917 | 69518 | 75459 |
| EU-10 | 6161 | 9 | 298 | 460 | 4102 | 128 | 1971 | 492 | 13620 | 37718 | 14270 | 8195 | 2.77 | 3.82 | 4.42 | 24098 | 38368 | 46563 |
| EU-15 | 6789 | 3071 | 108 | 884 | 4819 | 440 | 924 | 364 | 17399 | 28832 | 35072 | 9191 | 1.66 | 3.67 | 4.20 | 11432 | 46504 | 55695 |

*Table 19 Average input, output, EROI and Net Energy Balance for all crops per aggregate Environmental Zone*

| Allcrops | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results: Energy | | | Energy balance results: Net balance: Mjout- | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Country** | **Cultivation** | **Irrigation** | **Labour** | **Manure Fertilizer** | **Mineral Fertilizer** | **Plant Protection** | **Process Harvest** | **SEED** | **total input** | **Food** | **Feed** | **biomass** | **Food** | **Food+ Feed** | **Total** | **Food** | **Food+ Feed** | **Total** |
| Alpine | 6392 | 318 | 163 | 862 | 3371 | 277 | 1510 | 219 | 13113 | 18285 | 23653 | 3564 | 1.39 | 3.20 | 3.47 | 5173 | 28825 | 32389 |
| Boreal Nemoral | 6447 | 2 | 162 | 496 | 3313 | 64 | 329 | 444 | 11257 | 31515 | 21991 | 6715 | 2.80 | 4.75 | 5.35 | 20258 | 42249 | 48964 |
| Atlantic Lusitanian | 5374 | 409 | 67 | 1139 | 5523 | 436 | 1233 | 293 | 14473 | 29050 | 52345 | 7938 | 2.01 | 5.62 | 6.17 | 14577 | 66922 | 74860 |
| Continental, Pannonian, | 6324 | 29 | 329 | 490 | 3602 | 172 | 1494 | 447 | 12886 | 36080 | 18274 | 8134 | 2.80 | 4.22 | 4.85 | 23193 | 41467 | 49601 |
| Mediterranean | 7575 | 7206 | 156 | 534 | 3488 | 516 | 240 | 435 | 20150 | 23871 | 18206 | 9692 | 1.18 | 2.09 | 2.57 | 3721 | 21927 | 31619 |

*Table 20 Average input, output, EROI and Net Energy Balance for cereals in EU-27 per MS*

| Cereals | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Eeney | | | Net balance: $Mj_{out}$-$MJ_{in}$ | | |
| Country | Cultivation | Irrigation | Labour | Manure Fertilizer | Miniral Fertilizer | Plant Protection | Process Harvest | Seed | total input | Food | Feed | biomass | Food | Food+ Feed | Total | Food | Food+ Feed | Total |
| Austria | 9761 | 14 | 104 | 572 | 6630 | 162 | 11942 | 504 | 29688 | 70173 | 0 | 18243 | 2.36 | 2.36 | 2.98 | 40485 | 40485 | 58729 |
| Bulgaria | 5423 | 4 | 567 | 273 | 3270 | 0 | 1544 | 566 | 11647 | 60452 | 0 | 13261 | 5.19 | 5.19 | 6.33 | 48806 | 48806 | 62066 |
| Belgium-Luxemburg | 8555 | 10 | 74 | 1128 | 13054 | 536 | 12370 | 611 | 36339 | 94896 | 0 | 22830 | 2.61 | 2.61 | 3.24 | 58558 | 58558 | 81388 |
| Czech Rep | 6229 | 1 | 28 | 483 | 6707 | 205 | 1988 | 571 | 16212 | 76608 | 0 | 24211 | 4.73 | 4.73 | 6.22 | 60396 | 60396 | 84607 |
| Germany | 8819 | 49 | 97 | 764 | 9658 | 263 | 3197 | 541 | 23387 | 81006 | 0 | 30861 | 3.46 | 3.46 | 4.78 | 57618 | 57618 | 88479 |
| Denmark | 7010 | 222 | 50 | 1170 | 5942 | 233 | 1095 | 524 | 16248 | 72672 | 0 | 29427 | 4.47 | 4.47 | 6.28 | 56425 | 56425 | 85852 |
| Estonia | 6361 | 0 | 183 | 99 | 3997 | 120 | 1372 | 544 | 12676 | 77895 | 0 | 14245 | 6.15 | 6.15 | 7.27 | 65219 | 65219 | 79464 |
| Greece | 6272 | 129 | 146 | 328 | 8916 | 310 | 0 | 682 | 16783 | 45113 | 0 | 7227 | 2.69 | 2.69 | 3.12 | 28330 | 28330 | 35557 |
| Spain | 5393 | 5533 | 65 | 293 | 6025 | 173 | 11 | 660 | 18153 | 34424 | 0 | 10447 | 1.90 | 1.90 | 2.47 | 16271 | 16271 | 26718 |
| Finland | 7913 | 0 | 58 | 144 | 5953 | 108 | 341 | 602 | 15118 | 73190 | 0 | 18030 | 4.84 | 4.84 | 6.03 | 58072 | 58072 | 76102 |
| France | 6632 | 1725 | 75 | 479 | 11490 | 522 | 8555 | 507 | 29985 | 78668 | 0 | 27445 | 2.62 | 2.62 | 3.54 | 48683 | 48683 | 76128 |
| Hungary | 5529 | 7 | 340 | 372 | 6232 | 121 | 12393 | 561 | 25555 | 45724 | 0 | 14011 | 1.79 | 1.79 | 2.34 | 20170 | 20170 | 34181 |
| Ireland | 7483 | 0 | 125 | 953 | 10283 | 232 | 0 | 468 | 19545 | 111959 | 0 | 0 | 5.73 | 5.73 | 5.73 | 92414 | 92414 | 92414 |
| Italy | 6581 | 6631 | 201 | 451 | 8530 | 603 | 4 | 444 | 23445 | 56911 | 0 | 10347 | 2.43 | 2.43 | 2.87 | 33467 | 33467 | 43813 |
| Lithuania | 6042 | 0 | 231 | 296 | 5044 | 52 | 42 | 637 | 12344 | 69062 | 0 | 16024 | 5.59 | 5.59 | 6.89 | 56717 | 56717 | 72742 |
| Latvia | 6398 | 0 | 369 | 50 | 2834 | 0 | 1984 | 634 | 12269 | 78192 | 0 | 13463 | 6.37 | 6.37 | 7.47 | 65923 | 65923 | 79386 |
| Netherlands | 8939 | 167 | 120 | 1207 | 14177 | 276 | 6939 | 705 | 32529 | 88722 | 0 | 16604 | 2.73 | 2.73 | 3.24 | 56193 | 56193 | 72797 |
| Poland | 5964 | 0 | 406 | 333 | 6298 | 65 | 2836 | 631 | 16533 | 67960 | 0 | 16333 | 4.11 | 4.11 | 5.10 | 51427 | 51427 | 67761 |
| Portugal | 5715 | 7382 | 166 | 171 | 5458 | 315 | 0 | 569 | 19775 | 31745 | 0 | 608 | 1.61 | 1.61 | 1.64 | 11970 | 11970 | 12578 |
| Romania | 5848 | 25 | 757 | 0 | 0 | 101 | 59 | 351 | 7141 | 55580 | 0 | 7164 | 7.78 | 7.78 | 8.79 | 48440 | 48440 | 55604 |
| Sweden | 7977 | 9 | 52 | 449 | 5619 | 122 | 1218 | 629 | 16074 | 54259 | 0 | 22840 | 3.38 | 3.38 | 4.80 | 38184 | 38184 | 61025 |
| Slovenia | 12300 | 8 | 591 | 1863 | 16462 | 429 | 1947 | 636 | 34236 | 81673 | 0 | 11148 | 2.39 | 2.39 | 2.71 | 47437 | 47437 | 58585 |
| Slovakia | 5162 | 48 | 68 | 317 | 4495 | 368 | 5077 | 586 | 16121 | 58829 | 0 | 17104 | 3.65 | 3.65 | 4.71 | 42708 | 42708 | 59812 |
| UK | 5732 | 24 | 57 | 551 | 11330 | 769 | 1524 | 523 | 20510 | 87029 | 0 | 31315 | 4.24 | 4.24 | 5.77 | 66519 | 66519 | 97834 |
| EU-10 | 5932 | 4 | 323 | 348 | 6067 | 105 | 4384 | 609 | 17772 | 64919 | 0 | 16561 | 3.65 | 3.65 | 4.58 | 47147 | 47147 | 63708 |
| EU-15 | 6929 | 2231 | 91 | 526 | 9017 | 382 | 3389 | 551 | 23115 | 67185 | 0 | 21711 | 2.91 | 2.91 | 3.85 | 44069 | 44069 | 65780 |

*Table 21 Average input, output, EROI and Net Energy Balance for cereals per aggregate Environmental Zone*

| Cereals | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Energy balance: $Mj_{out}/MJ_{in}$ | | | Net balance: $Mj_{out}-MJ_{in}$ | | |
| **Country** | **Cultivation** | **Irrigation** | **Labour** | **Manure Fertilizer** | **Mineral Fertilizer** | **Plant Protection** | **Process Harvest** | **Seed** | **total input** | **Food** | **Feed** | **biomass** | **Food** | **Food+ Feed** | **Total** | **Food** | **Food+ Feed** | **Total** |
| Alpine | 9196 | 940 | 212 | 823 | 9587 | 398 | 8282 | 443 | 29881 | 74631 | | 12779 | 2.50 | 2.50 | 2.93 | 44750 | 44750 | 57529 |
| Boreal Nemoral | 6978 | 1 | 194 | 262 | 5253 | 80 | 872 | 625 | 14264 | 68124 | | 17286 | 4.78 | 4.78 | 5.99 | 53859 | 53859 | 71145 |
| Atlantic Lusitanian | 6748 | 643 | 74 | 633 | 11021 | 545 | 4919 | 520 | 25103 | 82980 | | 28969 | 3.31 | 3.31 | 4.46 | 57877 | 57877 | 86846 |
| Continental, Pannonian, | 6503 | 14 | 378 | 349 | 5323 | 133 | 3563 | 533 | 16795 | 64567 | | 17214 | 3.84 | 3.84 | 4.87 | 47773 | 47773 | 64987 |
| Mediterranean | 5926 | 5464 | 113 | 342 | 7118 | 336 | 1005 | 588 | 20892 | 44352 | | 10522 | 2.12 | 2.12 | 2.63 | 23459 | 23459 | 33982 |

*Table 22 Average input, output, EROI and Net Energy Balance for grain maize in EU-27 per MS*

| Grain Maize | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results: Eeney balance:Mjout/MJin | | | Energy balance results: Net balance: Mjout-MJin | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | Cultivation | Irrigation | Labour | Manure Fertilizer | Mineral Fertilizer | Plant Protection | Process Harvest | SEED | total input | Food | Feed | biomass | Food | Food+ Feed | Total | Food | Food+ Feed | Total |
| Austria | 11025 | 56 | 127 | 962 | 11299 | 298 | 53550 | 247 | 77564 | 71111 | 0 | 0 | 0.92 | 0.92 | 0.92 | -6453 | -6453 | -6453 |
| Bulgaria | 5082 | 8 | 798 | 197 | 4586 | 0 | 0 | 318 | 10989 | 46526 | 0 | 0 | 4.23 | 4.23 | 4.23 | 35538 | 35538 | 35538 |
| Belgium-Luxemburg | 8763 | 62 | 95 | 2267 | 10591 | 474 | 54398 | 424 | 77073 | 76484 | 0 | 0 | 0.99 | 0.99 | 0.99 | -589 | -589 | -589 |
| Czech Rep | 6049 | 12 | 40 | 456 | 8648 | 329 | 31132 | 243 | 46909 | 65805 | 0 | 0 | 1.40 | 1.40 | 1.40 | 18896 | 18896 | 18896 |
| Germany | 10935 | 331 | 122 | 994 | 11435 | 378 | 42643 | 508 | 67346 | 78228 | 0 | 0 | 1.16 | 1.16 | 1.16 | 10882 | 10882 | 10882 |
| Denmark | | | | | | | | | | | | | | | | | | |
| Estonia | | | | | | | | | | | | | | | | | | |
| Greece | 5940 | 298 | 268 | 539 | 20494 | 751 | 0 | 265 | 28553 | 100411 | 0 | 0 | 3.52 | 3.52 | 3.52 | 71857 | 71857 | 71857 |
| Spain | 5317 | 35377 | 149 | 929 | 20582 | 644 | 0 | 147 | 63144 | 106067 | 0 | 0 | 1.68 | 1.68 | 1.68 | 42922 | 42922 | 42922 |
| Finland | | | | | | | | | | | | | | | | | | |
| France | 6935 | 7512 | 108 | 479 | 9652 | 548 | 39845 | 413 | 65492 | 90060 | 0 | 0 | 1.38 | 1.38 | 1.38 | 24568 | 24568 | 24568 |
| Hungary | 5557 | 12 | 442 | 320 | 7042 | 155 | 30960 | 470 | 44956 | 40374 | 0 | 0 | 0.90 | 0.90 | 0.90 | -4582 | -4582 | -4582 |
| Ireland | | | | | | | | | | | | | | | | | | |
| Italy | 7406 | 19576 | 268 | 857 | 12484 | 1083 | 0 | 80 | 41755 | 97049 | 0 | 0 | 2.32 | 2.32 | 2.32 | 55293 | 55293 | 55293 |
| Lithuania | 5081 | 0 | 378 | 268 | 3332 | 70 | 15576 | 424 | 25129 | 43629 | 0 | 0 | 1.74 | 1.74 | 1.74 | 18500 | 18500 | 18500 |
| Latvia | | | | | | | | | | | | | | | | | | |
| Netherlands | 9829 | 1564 | 79 | 2156 | 14839 | 340 | 42544 | 508 | 71860 | 73363 | 0 | 0 | 1.02 | 1.02 | 1.02 | 1504 | 1504 | 1504 |
| Poland | 4954 | 0 | 640 | 253 | 9587 | 136 | 27830 | 196 | 43597 | 71584 | 0 | 0 | 1.64 | 1.64 | 1.64 | 27988 | 27988 | 27988 |
| Portugal | 5680 | 15024 | 332 | 383 | 10434 | 599 | 0 | 424 | 32875 | 22456 | 0 | 0 | 0.68 | 0.68 | 0.68 | -10419 | -10419 | -10419 |
| Romania | 5395 | 44 | 919 | 0 | 0 | 127 | 0 | 75 | 6560 | 54078 | 0 | 0 | 8.24 | 8.24 | 8.24 | 47517 | 47517 | 47517 |
| Sweden | 8588 | 0 | 82 | 530 | 3690 | 156 | 32943 | 424 | 46412 | 74439 | 0 | 0 | 1.60 | 1.60 | 1.60 | 28027 | 28027 | 28027 |
| Slovenia | 12525 | 23 | 756 | 2388 | 29663 | 825 | 0 | 508 | 46689 | 62437 | 0 | 0 | 1.34 | 1.34 | 1.34 | 15747 | 15747 | 15747 |
| Slovakia | 5199 | 149 | 97 | 271 | 5497 | 510 | 27304 | 329 | 39356 | 46437 | 0 | 0 | 1.18 | 1.18 | 1.18 | 7082 | 7082 | 7082 |
| UK | | | | | | | | | | | | | | | | | | |
| EU-10 | 5550 | 21 | 440 | 345 | 7929 | 201 | 29438 | 390 | 44314 | 49113 | 0 | 0 | 1.11 | 1.11 | 1.11 | 4799 | 4799 | 4799 |
| EU-15 | 7379 | 12179 | 175 | 725 | 12505 | 687 | 22247 | 293 | 56189 | 89658 | 0 | 0 | 1.60 | 1.60 | 1.60 | 33469 | 33469 | 33469 |

*Table 23 Average input, output, EROI and Net Energy Balance for grain maize per aggregate Environmental Zone*

| Grain Maize | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Energy balance:Mjout/MJin | | | Net balance: Mjout-MJin | | |
| Country | Cultivation | Irrigation | Labour | Manure Fertilizer | Mineral Fertilizer | Plant Protection | Process Harvest | Seed | total input | Food | Feed | biomass | Food | Food+ Feed | Total | Food | Food+ Feed | Total |
| Alpine | 9541 | 2305 | 289 | 1015 | 14103 | 673 | 19737 | 228 | 47891 | 76051 | | | 1.59 | 1.59 | 1.59 | 28159 | 28159 | 28159 |
| Boreal Nemoral | | | | | | | | | | | | | | | | | | |
| Atlantic Lusitanian | 7310 | 5583 | 130 | 652 | 10069 | 529 | 38643 | 423 | 63340 | 84407 | | | 1.33 | 1.33 | 1.33 | 21067 | 21067 | 21067 |
| Continental, Pannonian, | 5890 | 43 | 687 | 180 | 3780 | 156 | 13687 | 216 | 24638 | 53727 | | | 2.18 | 2.18 | 2.18 | 29089 | 29089 | 29089 |
| Mediterranean | 6723 | 20323 | 214 | 781 | 14545 | 871 | 5703 | 177 | 49337 | 97150 | | | 1.97 | 1.97 | 1.97 | 47813 | 47813 | 47813 |

*Table 24 Average input, output, EROI and Net Energy Balance for oilseeds in EU-27 per MS*

| Oilseeds | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Eeney | | | Net balance: Mjout-MJin | | |
| Country | Cultivation | Irrigation | Labour | Manure Fertilizer | Mineral Fertilizer | Plant Protection | Process Harvest | Seed | total input | Food | Feed | biomass | Food | Food+ Feed | Total | Food | Food+ Feed | Total |
| Austria | 7969 | 10 | 85 | 247 | 5778 | 178 | 72 | 1 | 14340 | 47324 | 0 | 0 | 3.30 | 3.30 | 3.30 | 32984 | 32984 | 32984 |
| Bulgaria | 4738 | 16 | 400 | 303 | 2510 | 0 | 56 | 1 | 8024 | 29330 | 0 | 0 | 3.66 | 3.66 | 3.66 | 21306 | 21306 | 21306 |
| Belgium-Luxemburg | 7689 | 0 | 66 | 522 | 15636 | 610 | 49 | 1 | 24573 | 56686 | 0 | 0 | 2.31 | 2.31 | 2.31 | 32113 | 32113 | 32113 |
| Czech Rep | 5500 | 3 | 24 | 255 | 10882 | 282 | 49 | 1 | 16996 | 46774 | 0 | 0 | 2.75 | 2.75 | 2.75 | 29778 | 29778 | 29778 |
| Germany | 7289 | 3 | 86 | 385 | 12932 | 271 | 49 | 1 | 21017 | 54422 | 0 | 0 | 2.59 | 2.59 | 2.59 | 33405 | 33405 | 33405 |
| Denmark | 6385 | 143 | 63 | 597 | 15878 | 243 | 53 | 1 | 23363 | 53500 | 0 | 0 | 2.29 | 2.29 | 2.29 | 30137 | 30137 | 30137 |
| Estonia | 5814 | 0 | 166 | 22 | 5197 | 178 | 49 | 1 | 11426 | 37400 | 0 | 0 | 3.27 | 3.27 | 3.27 | 25973 | 25973 | 25973 |
| Greece | 6503 | 195 | 81 | 228 | 3243 | 230 | 56 | 1 | 10536 | 17819 | 0 | 0 | 1.69 | 1.69 | 1.69 | 7283 | 7283 | 7283 |
| Spain | 4858 | 15717 | 50 | 104 | 5275 | 109 | 67 | 1 | 26181 | 20027 | 0 | 0 | 0.76 | 0.76 | 0.76 | -6153 | -6153 | -6153 |
| Finland | 7500 | 0 | 55 | 237 | 3616 | 94 | 49 | 1 | 11551 | 104505 | 0 | 0 | 9.05 | 9.05 | 9.05 | 92954 | 92954 | 92954 |
| France | 6212 | 849 | 64 | 280 | 10039 | 442 | 56 | 1 | 17943 | 46074 | 0 | 0 | 2.57 | 2.57 | 2.57 | 28131 | 28131 | 28131 |
| Hungary | 5262 | 1 | 228 | 278 | 5111 | 140 | 73 | 1 | 11094 | 35852 | 0 | 0 | 3.23 | 3.23 | 3.23 | 24758 | 24758 | 24758 |
| Ireland | 6970 | 0 | 102 | 650 | 15144 | 390 | 49 | 1 | 23306 | 75972 | 0 | 0 | 3.26 | 3.26 | 3.26 | 52666 | 52666 | 52666 |
| Italy | 5991 | 12202 | 216 | 348 | 5611 | 478 | 135 | 1 | 24982 | 30444 | 0 | 0 | 1.22 | 1.22 | 1.22 | 5462 | 5462 | 5462 |
| Lithuania | 5703 | 0 | 210 | 142 | 2005 | 77 | 49 | 1 | 8186 | 39855 | 0 | 0 | 4.87 | 4.87 | 4.87 | 31668 | 31668 | 31668 |
| Latvia | 6334 | 0 | 335 | 23 | 1892 | 0 | 56 | 1 | 8640 | 43194 | 0 | 0 | 5.00 | 5.00 | 5.00 | 34554 | 34554 | 34554 |
| Netherlands | 9016 | 0 | 168 | 747 | 14535 | 369 | 49 | 1 | 24886 | 58072 | 0 | 0 | 2.33 | 2.33 | 2.33 | 33186 | 33186 | 33186 |
| Poland | 5723 | 0 | 379 | 78 | 8286 | 130 | 49 | 1 | 14647 | 49110 | 0 | 0 | 3.35 | 3.35 | 3.35 | 34463 | 34463 | 34463 |
| Portugal | 6144 | 2851 | 31 | 8 | 1947 | 174 | 56 | 1 | 11213 | 499 | 0 | 0 | 0.04 | 0.04 | 0.04 | -10714 | -10714 | -10714 |
| Romania | 4969 | 58 | 469 | 0 | 0 | 69 | 69 | 1 | 5635 | 56420 | 0 | 0 | 10.01 | 10.01 | 10.01 | 50785 | 50785 | 50785 |
| Sweden | 7282 | 0 | 46 | 193 | 4210 | 134 | 59 | 1 | 11924 | 38446 | 0 | 0 | 3.22 | 3.22 | 3.22 | 26522 | 26522 | 26522 |
| Slovenia | 10716 | 11 | 444 | 1400 | 12254 | 333 | 55 | 1 | 25214 | 43482 | 0 | 0 | 1.72 | 1.72 | 1.72 | 18269 | 18269 | 18269 |
| Slovakia | 4717 | 21 | 50 | 192 | 5072 | 401 | 66 | 1 | 10519 | 40022 | 0 | 0 | 3.80 | 3.80 | 3.80 | 29502 | 29502 | 29502 |
| UK | 5540 | 0 | 53 | 445 | 7061 | 820 | 49 | 1 | 13969 | 61191 | 0 | 0 | 4.38 | 4.38 | 4.38 | 47222 | 47222 | 47222 |
| EU-10 | 5452 | 3 | 219 | 188 | 6719 | 182 | 59 | 1 | 12823 | 42358 | 0 | 0 | 3.30 | 3.30 | 3.30 | 29535 | 29535 | 29535 |
| EU-15 | 6301 | 3067 | 74 | 298 | 9054 | 370 | 60 | 1 | 19226 | 44679 | 0 | 0 | 2.32 | 2.32 | 2.32 | 25453 | 25453 | 25453 |

*Table 25 Average input, output, EROI and Net Energy Balance for oilseeds per aggregate Environmental Zone*

| Oilseeds | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results: Energy | | | Energy balance results: Net balance : $MJ_{out}$-$MJ_{in}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | Cultivation | Irrigation | Labour | Manure Fertilizer | Mineral Fertilizer | Plant Protection | Process Harvest | Seed | total input | Food | Feed | biomass | Food | Food+ Feed | Total | Food | Food+ Feed | Total |
| Alpine | 6797 | 2286 | 175 | 439 | 6887 | 362 | 131 | 1 | 17078 | 40347 | | | 2.36 | 2.36 | 2.36 | 23270 | 23270 | 23270 |
| Boreal Nemoral | 6609 | 0 | 165 | 138 | 3720 | 99 | 52 | 1 | 10785 | 54171 | | | 5.02 | 5.02 | 5.02 | 43386 | 43386 | 43386 |
| Atlantic Lusitanian | 6104 | 134 | 61 | 379 | 9432 | 566 | 51 | 1 | 16727 | 53968 | | | 3.23 | 3.23 | 3.23 | 37241 | 37241 | 37241 |
| Continental, Pannonian, | 5640 | 20 | 270 | 196 | 6172 | 154 | 60 | 1 | 12512 | 47080 | | | 3.76 | 3.76 | 3.76 | 34567 | 34567 | 34567 |
| Mediterranean | 5703 | 10743 | 87 | 174 | 5203 | 247 | 79 | 1 | 22237 | 21868 | | | 0.98 | 0.98 | 0.98 | -369 | -369 | -369 |

*Table 26 Average input, output, EROI and Net Energy Balance for permanent grassland in EU-27 per MS*

| Grass | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Eeney | | | Net balance: $MJ_{out}$-$MJ_{in}$ | | |
| Country | Cultivation | Irrigation | Labour | Manure Fertilizer | Mineral Fertilizer | Plant Protection | Process Harvest | Seed | total input | Food | Feed | biomass | Food | Food+ Feed | Total | Food | Food+ Feed | Total |
| Austria | 2865 | 0 | 74 | 973 | 512 | 38 | 1 | 0 | 4464 | 0 | 31557 | 0 | | 7.07 | 7.07 | | 27094 | 27094 |
| Bulgaria | 1358 | 26 | 72 | 207 | 83 | 0 | 1 | 0 | 1747 | 0 | 18868 | 0 | | 10.80 | 10.80 | | 17121 | 17121 |
| Belgium-Luxemburg | 2402 | 68 | 41 | 3434 | 6161 | 503 | 1 | 0 | 12609 | 0 | 94336 | 0 | | 7.48 | 7.48 | | 81727 | 81727 |
| Czech Rep | 1702 | 22 | 4 | 319 | 2024 | 47 | 1 | 0 | 4120 | 0 | 33819 | 0 | | 8.21 | 8.21 | | 29698 | 29698 |
| Germany | 3112 | 103 | 49 | 1525 | 3737 | 149 | 1 | 0 | 8675 | 0 | 79884 | 0 | | 9.21 | 9.21 | | 71208 | 71208 |
| Denmark | 2012 | 265 | 28 | 1320 | 4230 | 78 | 1 | 0 | 7934 | 0 | 123272 | 0 | | 15.54 | 15.54 | | 115338 | 115338 |
| Estonia | 1522 | 0 | 28 | 380 | 1357 | 0 | 1 | 0 | 3288 | 0 | 32290 | 0 | | 9.82 | 9.82 | | 29002 | 29002 |
| Greece | 1542 | 68 | 8 | 981 | 2082 | 131 | 1 | 0 | 4813 | 0 | 47766 | 0 | | 9.93 | 9.93 | | 42953 | 42953 |
| Spain | 1591 | 5821 | 9 | 881 | 1865 | 60 | 1 | 0 | 10227 | 0 | 41580 | 0 | | 4.07 | 4.07 | | 31353 | 31353 |
| Finland | 2266 | 0 | 7 | 745 | 2534 | 39 | 1 | 0 | 5592 | 0 | 31805 | 0 | | 5.69 | 5.69 | | 26213 | 26213 |
| France | 1945 | 1387 | 30 | 908 | 2262 | 173 | 1 | 0 | 6705 | 0 | 74561 | 0 | | 11.12 | 11.12 | | 67856 | 67856 |
| Hungary | 1530 | 32 | 38 | 297 | 1004 | 24 | 1 | 0 | 2926 | 0 | 33680 | 0 | | 11.51 | 11.51 | | 30754 | 30754 |
| Ireland | 2291 | 0 | 15 | 1884 | 5116 | 56 | 1 | 0 | 9363 | 0 | 99556 | 0 | | 10.63 | 10.63 | | 90194 | 90194 |
| Italy | 1319 | 2579 | 20 | 1062 | 1318 | 103 | 1 | 0 | 6402 | 0 | 45512 | 0 | | 7.11 | 7.11 | | 39110 | 39110 |
| Lithuania | 1522 | 0 | 37 | 461 | 1902 | 14 | 1 | 0 | 3937 | 0 | 35681 | 0 | | 9.06 | 9.06 | | 31744 | 31744 |
| Latvia | 1522 | 0 | 55 | 355 | 1012 | 0 | 1 | 0 | 2946 | 0 | 34475 | 0 | | 11.70 | 11.70 | | 31530 | 31530 |
| Netherlands | 2558 | 418 | 112 | 3682 | 7842 | 159 | 1 | 0 | 14771 | 0 | 103116 | 0 | | 6.98 | 6.98 | | 88345 | 88345 |
| Poland | 1519 | 13 | 63 | 866 | 1553 | 18 | 1 | 0 | 4033 | 0 | 32348 | 0 | | 8.02 | 8.02 | | 28316 | 28316 |
| Portugal | 1630 | 1130 | 9 | 929 | 1678 | 69 | 1 | 0 | 5448 | 0 | 24524 | 0 | | 4.50 | 4.50 | | 19076 | 19076 |
| Romania | 1497 | 27 | 87 | 0 | 0 | 50 | 1 | 0 | 1661 | 0 | 27851 | 0 | | 16.77 | 16.77 | | 26190 | 26190 |
| Sweden | 2156 | 78 | 2 | 632 | 1683 | 35 | 1 | 0 | 4588 | 0 | 73920 | 0 | | 16.11 | 16.11 | | 69332 | 69332 |
| Slovenia | 4068 | 11 | 75 | 747 | 6304 | 98 | 1 | 0 | 11303 | 0 | 45292 | 0 | | 4.01 | 4.01 | | 33989 | 33989 |
| Slovakia | 1481 | 32 | 8 | 299 | 455 | 68 | 1 | 0 | 2343 | 0 | 28860 | 0 | | 12.32 | 12.32 | | 26517 | 26517 |
| UK | 1820 | 0 | 16 | 1077 | 2655 | 78 | 1 | 0 | 5647 | 0 | 80127 | 0 | | 14.19 | 14.19 | | 74479 | 74479 |
| EU-10 | 1631 | 15 | 45 | 585 | 1614 | 27 | 1 | 0 | 3917 | 0 | 33404 | 0 | | 8.53 | 8.53 | | 29487 | 29487 |
| EU-15 | 1983 | 1627 | 25 | 1169 | 2607 | 108 | 1 | 0 | 7520 | 0 | 66666 | 0 | | 8.86 | 8.86 | | 59146 | 59146 |

*Table 27 Average input, output, EROI and Net Energy Balance for permanent grasslands per aggregate Environmental Zone*

| Grass | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results: Energy | | | Net balance: $MJ_{out}$-$MJ_{in}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | Cultivation | Irrigation | Labour | Manure Fertilizer | Mineral Fertilizer | Plant Protection | Process Harvest | Seed | total input | Food | Feed | biomass | Food | Food+ Feed | Total | Food | Food+ Feed | Total |
| Alpine | 2886 | 62 | 65 | 786 | 1449 | 50 | 1 | 0 | 5300 | | 26185 | | | 4.94 | 4.94 | | 20884 | 20884 |
| Boreal Nemoral | 1633 | 6 | 40 | 560 | 1589 | 14 | 1 | 0 | 3843 | | 39957 | | | 10.40 | 10.40 | | 36114 | 36114 |
| Atlantic Lusitanian | 2033 | 236 | 23 | 1257 | 3003 | 107 | 1 | 0 | 6662 | | 81948 | | | 12.30 | 12.30 | | 75286 | 75286 |
| Continental, Pannonian, | 1953 | 28 | 61 | 658 | 1361 | 63 | 1 | 0 | 4125 | | 40684 | | | 9.86 | 9.86 | | 36559 | 36559 |
| Mediterranean | 1459 | 4207 | 14 | 874 | 1705 | 87 | 1 | 0 | 8347 | | 42959 | | | 5.15 | 5.15 | | 34611 | 34611 |

*Table 28 Average input, output, EROI and Net Energy Balance for fruits in EU-27 per MS*

| Fruits | Input (GJ/Ha) | | | | | | | | Output (GJ/Ha) | | | Energy balance results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Eeney balance: $Mj_{out}/MJ_{in}$ | | | Net balance: $Mj_{out}-MJ_{in}$ | | |
| Country | Cultivation | Irrigation | Labour | Manure Fertilizer | Mineral Fertilizer | Plant Protection | Process Harvest | Seed | total input | Food | Feed | biomass | Food | Food+ Feed | Total | Food | Food+ Feed | Total |
| Austria | 38017 | 94 | 783 | 1213 | 5347 | 5426 | 0 | 1 | 50881 | 137665 | 0 | 34830 | 2.71 | 2.71 | 3.39 | 86784 | 86784 | 121614 |
| Bulgaria | 19713 | 36 | 2410 | 139 | 1003 | 0 | 0 | 1 | 23301 | 3933 | 0 | 34830 | 0.17 | 0.17 | 1.66 | -19368 | -19368 | 15462 |
| Belgium-Luxemburg | 23031 | 28 | 467 | 694 | 1984 | 9086 | 0 | 1 | 35291 | 50779 | 0 | 34830 | 1.44 | 1.44 | 2.43 | 15489 | 15489 | 50319 |
| Czech Rep | 22839 | 17 | 148 | 134 | 4768 | 836 | 0 | 1 | 28744 | 35933 | 0 | 34830 | 1.25 | 1.25 | 2.46 | 7189 | 7189 | 42019 |
| Germany | 38896 | 363 | 617 | 307 | 2217 | 2529 | 0 | 1 | 44929 | 32045 | 0 | 34830 | 0.71 | 0.71 | 1.49 | -12884 | -12884 | 21946 |
| Denmark | 33433 | 532 | 227 | 17 | 2245 | 808 | 0 | 1 | 37262 | 15052 | 0 | 34830 | 0.40 | 0.40 | 1.34 | -22210 | -22210 | 12620 |
| Estonia | 19567 | 0 | 1094 | 46 | 1227 | 953 | 0 | 1 | 22888 | 1694 | 0 | 34830 | 0.07 | 0.07 | 1.60 | -21194 | -21194 | 13636 |
| Greece | 23687 | 204 | 988 | 265 | 2814 | 1892 | 0 | 1 | 29852 | 21667 | 0 | 37788 | 0.73 | 0.73 | 1.99 | -8185 | -8185 | 29603 |
| Spain | 21801 | 26520 | 318 | 169 | 2803 | 808 | 0 | 1 | 52418 | 7379 | 0 | 37602 | 0.14 | 0.14 | 0.86 | -45039 | -45039 | -7437 |
| Finland | 40875 | 0 | 432 | 228 | 1087 | 1293 | 0 | 1 | 43916 | 3838 | 0 | 34830 | 0.09 | 0.09 | 0.88 | -40078 | -40078 | -5248 |
| France | 24884 | 18072 | 986 | 381 | 2128 | 5470 | 0 | 1 | 51921 | 33312 | 0 | 34933 | 0.64 | 0.64 | 1.31 | -18608 | -18608 | 16325 |
| Hungary | 19120 | 109 | 2118 | 175 | 693 | 429 | 0 | 1 | 22645 | 15432 | 0 | 34830 | 0.68 | 0.68 | 2.22 | -7214 | -7214 | 27616 |
| Ireland | 41670 | 0 | 497 | 40 | 2274 | 2468 | 0 | 1 | 46950 | 13868 | 0 | 34830 | 0.30 | 0.30 | 1.04 | -33083 | -33083 | 1747 |
| Italy | 29296 | 5253 | 933 | 128 | 3533 | 3394 | 0 | 1 | 42539 | 21999 | 0 | 37343 | 0.52 | 0.52 | 1.39 | -20541 | -20541 | 16803 |
| Lithuania | 17148 | 0 | 1368 | 186 | 1259 | 43 | 0 | 1 | 20006 | 4144 | 0 | 34830 | 0.21 | 0.21 | 1.95 | -15862 | -15862 | 18968 |
| Latvia | 16792 | 0 | 2043 | 0 | 1890 | 0 | 0 | 1 | 20727 | 9292 | 0 | 34830 | 0.45 | 0.45 | 2.13 | -11435 | -11435 | 23395 |
| Netherlands | 25960 | 824 | 1089 | 471 | 3058 | 2113 | 0 | 1 | 33517 | 51908 | 0 | 34830 | 1.55 | 1.55 | 2.59 | 18391 | 18391 | 53221 |
| Poland | 19014 | 3 | 2018 | 334 | 964 | 746 | 0 | 1 | 23080 | 15095 | 0 | 34830 | 0.65 | 0.65 | 2.16 | -7984 | -7984 | 26846 |
| Portugal | 24805 | 6226 | 743 | 24 | 1978 | 1448 | 0 | 1 | 35225 | 3249 | 0 | 36607 | 0.09 | 0.09 | 1.13 | -31976 | -31976 | 4631 |
| Romania | 19711 | 26 | 3391 | 0 | 0 | 1009 | 0 | 1 | 24138 | 15017 | 0 | 34830 | 0.62 | 0.62 | 2.07 | -9121 | -9121 | 25709 |
| Sweden | 29895 | 0 | 261 | 128 | 1258 | 1562 | 0 | 1 | 33105 | 14476 | 0 | 34830 | 0.44 | 0.44 | 1.49 | -18629 | -18629 | 16201 |
| Slovenia | 35076 | 144 | 2693 | 902 | 4826 | 7689 | 0 | 1 | 51330 | 44599 | 0 | 34830 | 0.87 | 0.87 | 1.55 | -6731 | -6731 | 28099 |
| Slovakia | 18407 | 185 | 395 | 77 | 4007 | 1417 | 0 | 1 | 24488 | 30607 | 0 | 34830 | 1.25 | 1.25 | 2.67 | 6119 | 6119 | 40949 |
| UK | 21142 | 1464 | 509 | 125 | 819 | 7474 | 0 | 1 | 31535 | 15939 | 0 | 34830 | 0.51 | 0.51 | 1.61 | -15595 | -15595 | 19235 |
| EU-10 | 19218 | 26 | 1879 | 277 | 1241 | 715 | 0 | 1 | 23357 | 15830 | 0 | 34830 | 0.68 | 0.68 | 2.17 | -7527 | -7527 | 27303 |
| EU-15 | 25181 | 15024 | 633 | 186 | 2854 | 2249 | 0 | 1 | 46128 | 16345 | 0 | 37070 | 0.35 | 0.35 | 1.16 | -29783 | -29783 | 7287 |

*Table 29 Average input, output, EROI and Net Energy Balance for fruits per aggregate Environmental Zone*

| **Fruits** | **Input (GJ/Ha)** | | | | | | | | | **Output (GJ/Ha)** | | | **Energy balance results** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | **Energy balance:Mjout/MJin** | | | **Net balance: Mjout-MJin** | | |
| **Country** | **Cultivation** | **Irrigation** | **Labour** | **Manure Fertilizer** | **Mineral Fertilizer** | **Plant Protection** | **Process Harvest** | **Seed** | **total input** | **Food** | **Feed** | **biomass** | **Food** | **Food+ Feed** | **Total** | **Food** | **Food+ Feed** | **Total** |
| Alpine | 37675 | 729 | 1162 | 598 | 3352 | 3686 | 0 | 1 | 47204 | 3838 | | 34830 | 0.08 | 0.08 | 0.82 | -43366 | -43366 | -8536 |
| Boreal Nemoral | 20020 | 0 | 1513 | 162 | 1338 | 322 | 0 | 1 | 23358 | 47676 | | 35374 | 2.04 | 2.04 | 3.56 | 24318 | 24318 | 59692 |
| Atlantic Lusitanian | 26209 | 2904 | 773 | 260 | 1904 | 4230 | 0 | 1 | 36280 | 6707 | | 34830 | 0.18 | 0.18 | 1.14 | -29573 | -29573 | 5257 |
| Continental, Pannonian | 20654 | 44 | 2231 | 213 | 986 | 927 | 0 | 1 | 25056 | 23987 | | 35524 | 0.96 | 0.96 | 2.38 | -1069 | -1069 | 34455 |
| Mediterranean | 24425 | 17319 | 607 | 166 | 2985 | 1992 | 0 | 1 | 47495 | 17883 | | 34830 | 0.38 | 0.38 | 1.11 | -29612 | -29612 | 5218 |

*Table 30 Average input, output, EROI and Net Energy Balance for olives in EU-27 per MS*

| Olives | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Eeney balance:$Mj_{out}/MJ_{in}$ | | | Net balance: $Mj_{out}$-$MJ_{in}$ | | |
| Country | Cultivation | Irrigation | Labour | Manure Fertilizer | Mineral Fertilizer | Plant Protection | Process Harvest | Seed | total input | Food | Feed | biomass | Food | Food+ Feed | Total | Food | Food+ Feed | Total |
| Austria | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Bulgaria | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Belgium-Luxemburg | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Czech Rep | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Germany | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Denmark | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Estonia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Greece | 25740 | 105 | 1021 | 126 | 2234 | 446 | 0 | 1 | 29672 | 95420 | 0 | 42880 | 3.22 | 3.22 | 4.66 | 65748 | 65748 | 108627 |
| Spain | 24271 | 21270 | 194 | 101 | 2313 | 833 | 0 | 1 | 48984 | 79851 | 0 | 43497 | 1.63 | 1.63 | 2.52 | 30868 | 30868 | 74364 |
| Finland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| France | 40560 | 640 | 331 | 170 | 1010 | 1290 | 0 | 1 | 44002 | 39632 | 0 | 42113 | 0.90 | 0.90 | 1.86 | -4369 | -4369 | 37743 |
| Hungary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Ireland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Italy | 30934 | 1016 | 475 | 54 | 2478 | 920 | 0 | 1 | 35878 | 135915 | 0 | 44257 | 3.79 | 3.79 | 5.02 | 100037 | 100037 | 144294 |
| Lithuania | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Latvia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Netherlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Poland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Portugal | 30058 | 559 | 311 | 30 | 1913 | 251 | 0 | 1 | 33124 | 22170 | 0 | 44079 | 0.67 | 0.67 | 2.00 | -10954 | -10954 | 33126 |
| Romania | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Sweden | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Slovenia | 69076 | 0 | 1628 | 516 | 1546 | 313 | 0 | 1 | 73079 | 86232 | 0 | 44550 | 1.18 | 1.18 | 1.79 | 13153 | 13153 | 57703 |
| Slovakia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| UK | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| EU-10 | 69076 | 0 | 1628 | 516 | 1546 | 313 | 0 | 1 | 73079 | 86232 | 0 | 44550 | 1.18 | 1.18 | 1.79 | 13153 | 13153 | 57703 |
| EU-15 | 26461 | 11803 | 397 | 90 | 2300 | 746 | 0 | 1 | 41799 | 89889 | 0 | 43602 | 2.15 | 2.15 | 3.19 | 48089 | 48089 | 91691 |

*Table 31 Average input, output, EROI and Net Energy Balance for olives per aggregate Environmental Zone*

| Olives | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Energy | | | Net balance: Mj$_{out-}$ | | |
| **Country** | **Cultivation** | **Irrigation** | **Labour** | **Manure Fertilizer** | **Mineral Fertilizer** | **Plant Protection** | **Process Harvest** | **Seed** | **total input** | **Food** | **Feed** | **biomass** | **Food** | **Food+ Feed** | **Total** | **Food** | **Food+ Feed** | **Total** |
| Alpine | 64916 | 9 | 1535 | 499 | 1486 | 422 | 0 | 1 | 68867 | 90765 | | 44550 | 1.32 | 1.32 | 1.96 | 21898 | 21898 | 66448 |
| Boreal Nemoral | | | | | | | | | | | | | | | | | | |
| Atlantic Lusitanian | 30657 | 717 | 424 | 56 | 1809 | 318 | 0 | 1 | 33984 | 26306 | | 43992 | 0.77 | 0.77 | 2.07 | -7677 | -7677 | 36315 |
| Continental, Panonian | | | | | | | | | | | | | | | | | | |
| Mediterranean | 26240 | 12387 | 396 | 91 | 2326 | 769 | 0 | 1 | 42210 | 93229 | | 43581 | 2.21 | 2.21 | 3.24 | 51019 | 51019 | 94600 |

*Table 32 Average input, output, EROI and Net Energy Balance for vineyards in EU-27 per MS*

| Vineyards | Input (GJ/Ha) | | | | | | | | | Output (GJ/Ha) | | | Energy balance results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Energy | | | Net balance: $Mj_{out}$-$MJ_{in}$ | | |
| Country | Cultivation | Irrigation | Labour | Manure Fertilizer | Mineral Fertilizer | Plant Protection | Process Harvest | Seed | total input | Food | Feed | biomass | Food | Food+ Feed | Total | Food | Food+ Feed | Total |
| Austria | 34419 | 35 | 314 | 345 | 582 | 1768 | 0 | 1 | 37463 | 15108 | | 45522 | 0.40 | 0.40 | 1.62 | -22355 | -22355 | 23167 |
| Bulgaria | 11859 | 31 | 2688 | 137 | 336 | 0 | 0 | 1 | 15052 | 4874 | | 45522 | 0.32 | 0.32 | 3.35 | -10178 | -10178 | 35344 |
| Belgium-Luxemburg | 34516 | 135 | 374 | 743 | 4212 | 7679 | 0 | 1 | 47660 | 33203 | | 45522 | 0.70 | 0.70 | 1.65 | -14458 | -14458 | 31064 |
| Czech Rep | 26494 | 0 | 151 | 197 | 939 | 408 | 0 | 1 | 28191 | 2462 | | 45522 | 0.09 | 0.09 | 1.70 | -25729 | -25729 | 19793 |
| Germany | 43746 | 672 | 389 | 486 | 2343 | 2714 | 0 | 1 | 50351 | 26247 | | 45522 | 0.52 | 0.52 | 1.43 | -24104 | -24104 | 21418 |
| Denmark | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | | | | | |
| Estonia | 24206 | 0 | 1185 | 141 | 2598 | 4636 | 0 | 1 | 32766 | 42097 | | 45522 | 1.28 | 1.28 | 2.67 | 9331 | 9331 | 54853 |
| Greece | 15683 | 133 | 1015 | 385 | 2844 | 1119 | 0 | 1 | 21179 | 25007 | | 45522 | 1.18 | 1.18 | 3.33 | 3827 | 3827 | 49349 |
| Spain | 12749 | 16765 | 325 | 172 | 1931 | 661 | 0 | 1 | 32604 | 10660 | | 45522 | 0.33 | 0.33 | 1.72 | -21944 | -21944 | 23578 |
| Finland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | | 0 | 0.00 | 0.00 | 0.00 | -1 | -1 | -1 |
| France | 19699 | 1772 | 453 | 238 | 1837 | 3945 | 0 | 1 | 27944 | 17248 | | 45522 | 0.62 | 0.62 | 2.25 | -10696 | -10696 | 34826 |
| Hungary | 14996 | 7 | 1504 | 219 | 825 | 552 | 0 | 1 | 18105 | 13698 | | 45522 | 0.76 | 0.76 | 3.27 | -4408 | -4408 | 41114 |
| Ireland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | | | | | |
| Italy | 21617 | 3825 | 1086 | 325 | 2543 | 3711 | 0 | 1 | 33109 | 22919 | | 45522 | 0.69 | 0.69 | 2.07 | -10190 | -10190 | 35332 |
| Lithuania | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | | | | | |
| Latvia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | | | | | |
| Netherlands | 38127 | 0 | 1177 | 459 | 1881 | 3825 | 0 | 1 | 45470 | 20312 | | 45522 | 0.45 | 0.45 | 1.45 | -25157 | -25157 | 20365 |
| Poland | 24206 | 0 | 2109 | 265 | 1017 | 1874 | 0 | 1 | 29471 | 12651 | | 45522 | 0.43 | 0.43 | 1.97 | -16820 | -16820 | 28702 |
| Portugal | 15136 | 2399 | 598 | 83 | 1989 | 3066 | 0 | 1 | 23273 | 10552 | | 45522 | 0.45 | 0.45 | 2.41 | -12721 | -12721 | 32801 |
| Romania | 12989 | 27 | 2789 | 0 | 0 | 416 | 0 | 1 | 16221 | 7314 | | 45522 | 0.45 | 0.45 | 3.26 | -8908 | -8908 | 36614 |
| Sweden | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | | | | | |
| Slovenia | 41815 | 23 | 2142 | 704 | 1947 | 2989 | 0 | 1 | 49620 | 12672 | | 45522 | 0.26 | 0.26 | 1.17 | -36948 | -36948 | 8574 |
| Slovakia | 14955 | 36 | 293 | 118 | 894 | 579 | 0 | 1 | 16875 | 8749 | | 45522 | 0.52 | 0.52 | 3.22 | -8126 | -8126 | 37396 |
| UK | 21220 | 493 | 259 | 149 | 441 | 1781 | 0 | 1 | 24344 | 6728 | | 45522 | 0.28 | 0.28 | 2.15 | -17615 | -17615 | 27907 |
| EU-10 | 12559 | 28 | 2751 | 52 | 128 | 258 | 0 | 1 | 15777 | 6386 | | 45522 | 0.40 | 0.40 | 3.29 | -9391 | -9391 | 36131 |
| EU-15 | 20226 | 11 | 1291 | 273 | 1007 | 886 | 0 | 1 | 23694 | 11669 | | 45522 | 0.49 | 0.49 | 2.41 | -12025 | -12025 | 33497 |

*Table 33 Average input, output, EROI and Net Energy Balance for vineyards per aggregate Environmental Zone*

| **Cereals** | **Input (GJ/Ha)** | | | | | | | | | **Output (GJ/Ha)** | | | **Energy balance results** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | **Energy** | | | **Net balance: $Mj_{out}$-$MJ_{in}$** | | |
| **Country** | **Cultivation** | **Irrigation** | **Labour** | **Manure Fertilizer** | **Mineral Fertilizer** | **Plant Protection** | **Process Harvest** | **Seed** | **total input** | **Food** | **Feed** | **biomass** | **Food** | **Food+ Feed** | **Total** | **Food** | **Food+ Feed** | **Total** |
| Alpine | 35470 | 1610 | 1374 | 622 | 1725 | 2725 | 0 | 1 | 43526 | 18267 | | 45522 | 0.42 | 0.42 | 1.47 | -25259 | -25259 | 20263 |
| Boreal Nemoral | 24206 | 0 | 1185 | 141 | 2598 | 4636 | 0 | 1 | 32766 | 42097 | | 45522 | 1.28 | 1.28 | 2.67 | 9331 | 9331 | 54853 |
| Atlantic Lusitanian | 21928 | 467 | 578 | 312 | 1281 | 3082 | 0 | 1 | 27648 | 15111 | | 45522 | 0.55 | 0.55 | 2.19 | -12537 | -12537 | 32985 |
| Continental, Pannonian, | 19128 | 91 | 1832 | 166 | 572 | 812 | 0 | 1 | 22602 | 10756 | | 45522 | 0.48 | 0.48 | 2.49 | -11846 | -11846 | 33676 |
| Mediterranean | 16215 | 9618 | 590 | 206 | 2322 | 2389 | 0 | 1 | 31341 | 16412 | | 45522 | 0.52 | 0.52 | 1.98 | -14929 | -14929 | 30593 |

## Annex 9 - Variation in input levels per crop

*Figure 11 Average level and regional variation in inputs for all crops in EU-27*

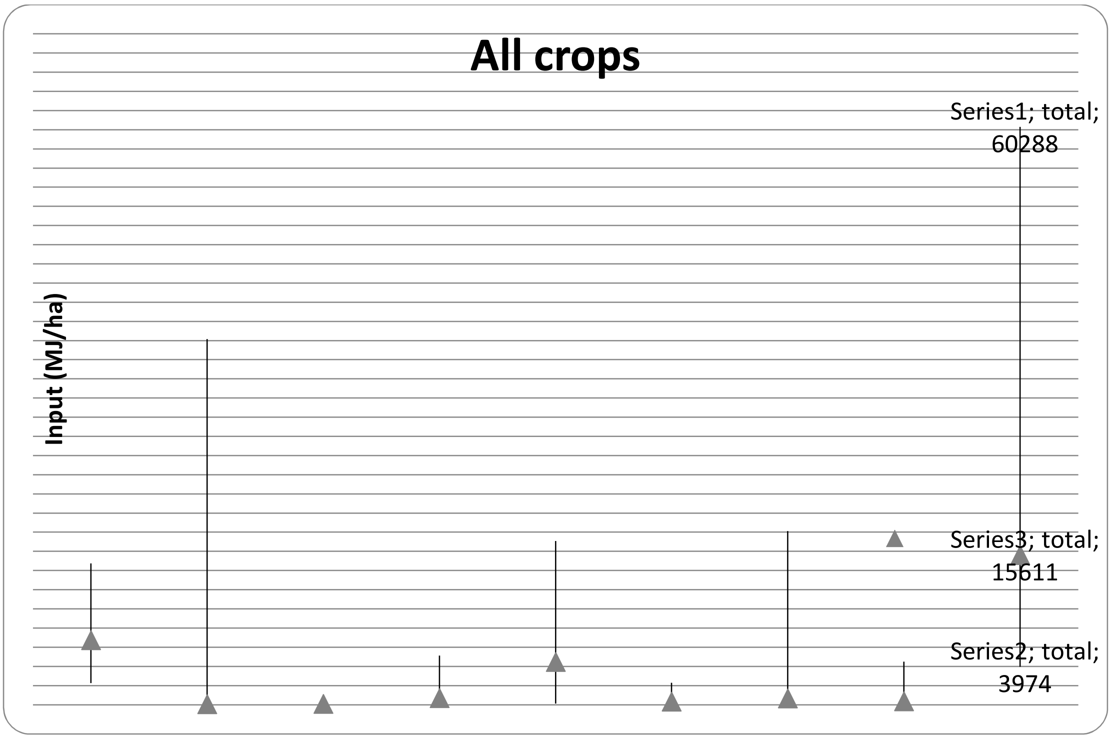



*Figure 12 Average level and regional variation in inputs for all crops in the Alpine Zone*

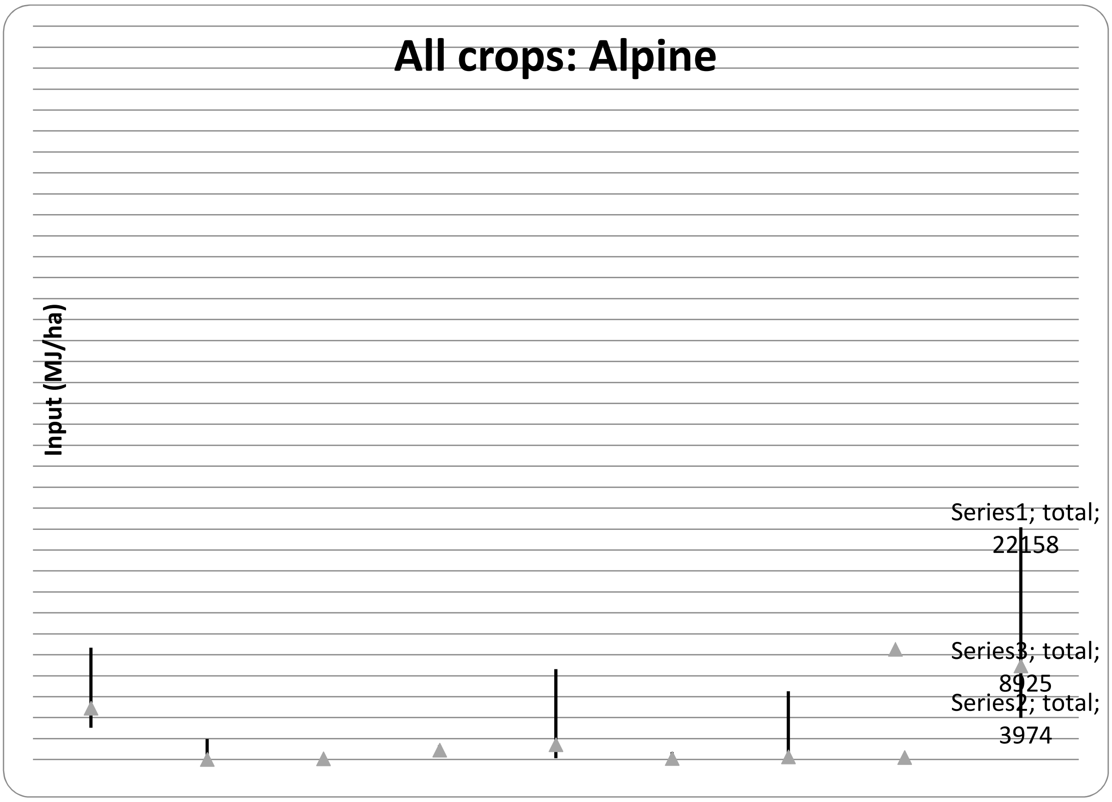


*Figure 13 Average level and regional variation in inputs for all crops in the Boreal-Nemoral zone*

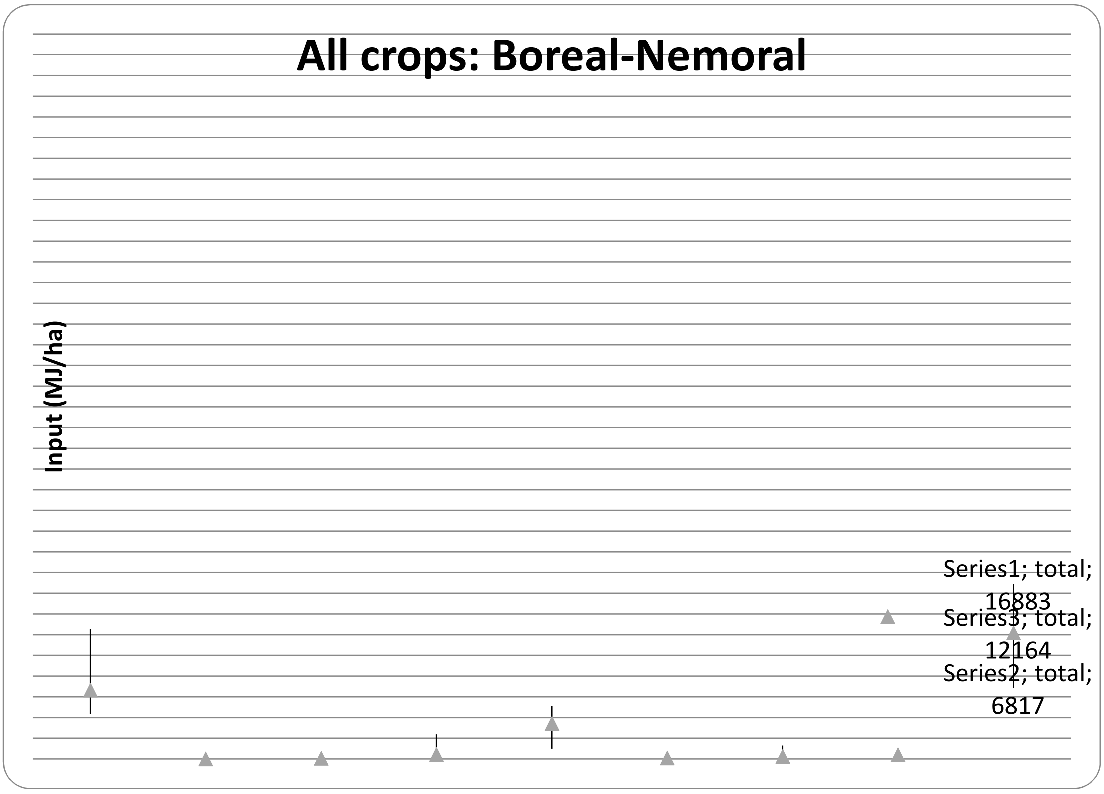



*Figure 14 Average level and regional variation in inputs for all crops in the Atlantic-Lusitanian zone*

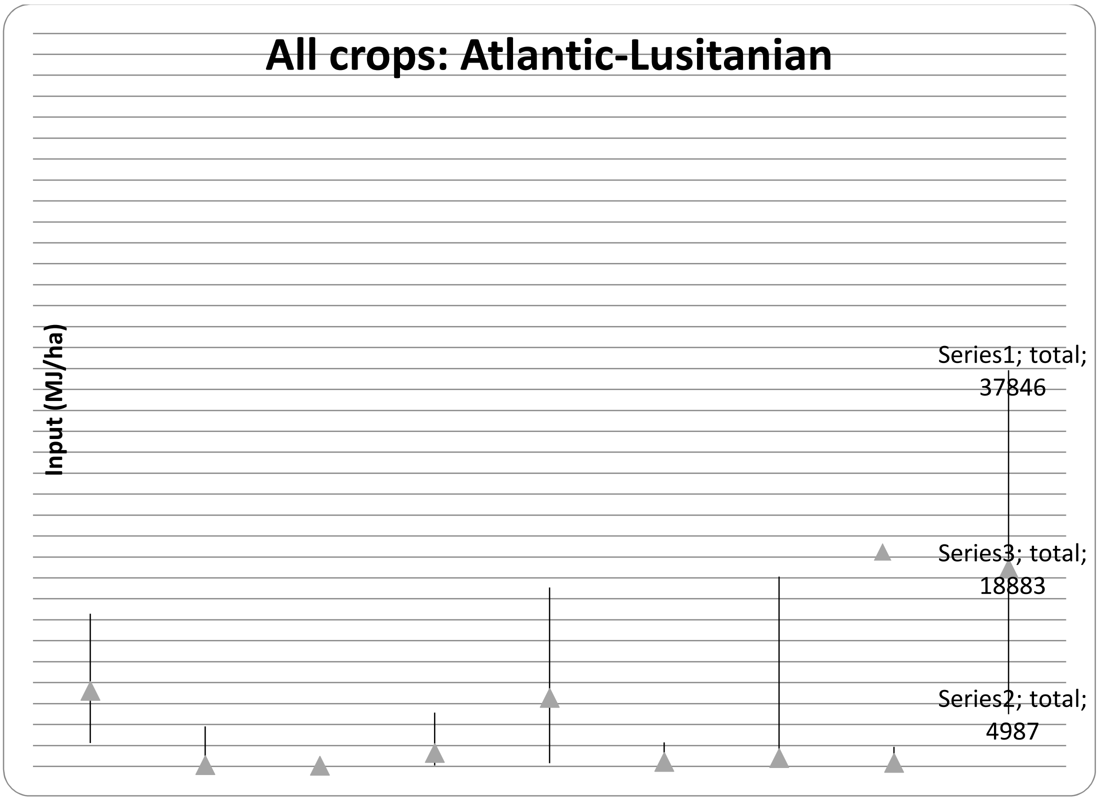


*Figure 15 Average level and regional variation in inputs for all crops in the Continental-Pannonian zone*

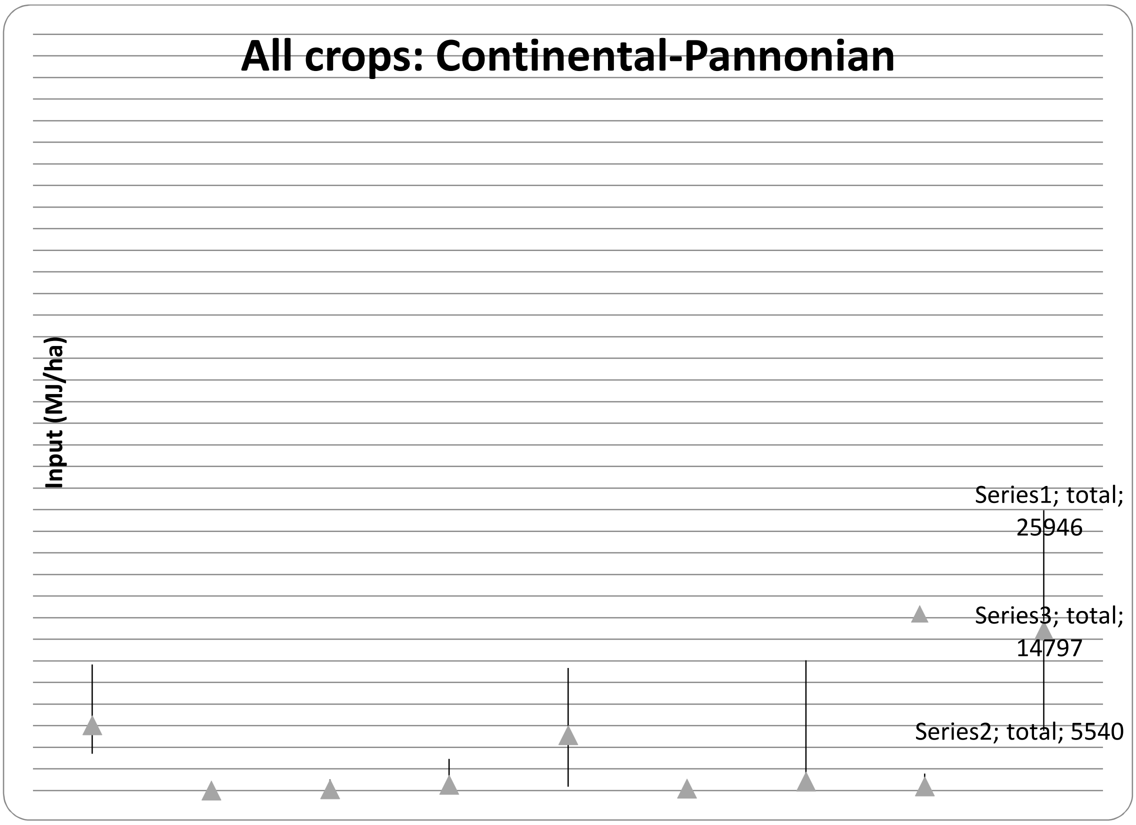



*Figure 16 Average level and regional variation in inputs for all crops in the Mediterranean zone*

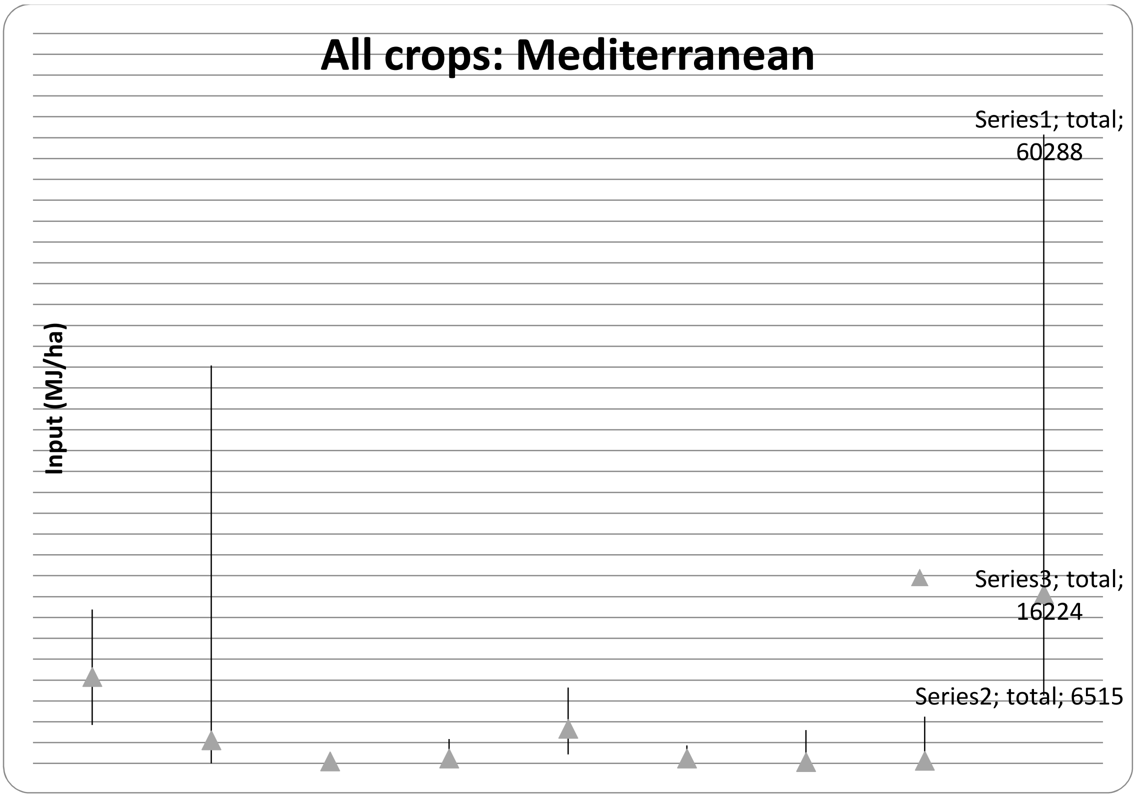


*Figure 17 Average level and regional variation in inputs for permanent crops in EU-27 (MJ/ha)*

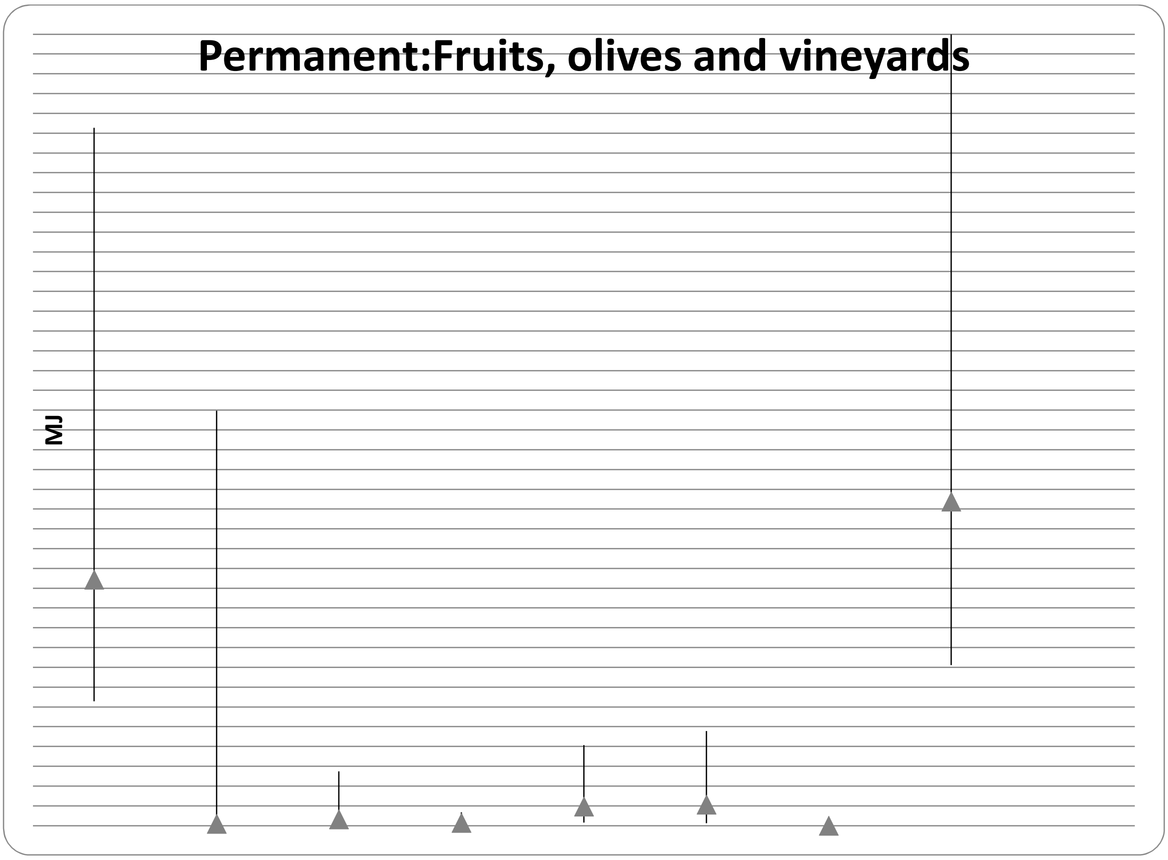
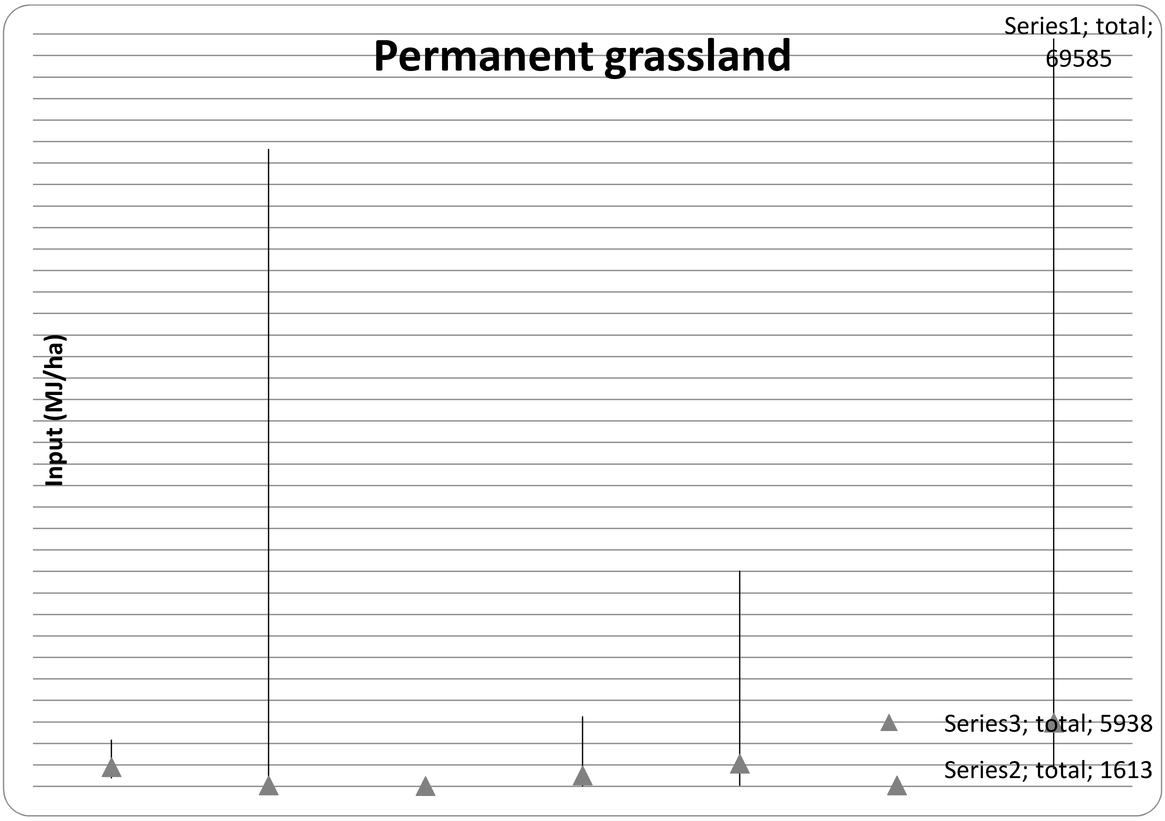


*Figure 18 Average level and regional variation in inputs for grass in EU-27 (MJ/ha)*



## List of abbreviations and definitions

EC: European Commission

EROI: Energy return on investment

EU: European Union

HSMU: Homogeneous Spatial Mapping Unit

MJ: Mega Joule

NEB: Net Energy Balance

## List of figures

## List of tables

LB-NA-27538-EN-N

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*Serving society*
*Stimulating innovation*
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Publications Office

doi:10.2788/679096

ISBN 978-92-79-52771-5