Deutsches BiomasseForschungsZentrum
gemeinnützige GmbH

German Biomass Research Centre

Report

Global Biomass Potentials

Investigation and assessment of data
Remote sensing in biomass potential research
Country-specific energy crop potentials

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1 Background and aim

Within the development of the “Energy [R]evolution scenarios 2008” Greenpeace placed an order with the German Biomass Research Centre, the former Institute for Energy and Environment, to compile world wide energy crop potentials in different scenarios till 2050. Additionally, information about the scientific literature status quo of worldwide potential studies and the state of the art of remote sensing for investigation of biomass potentials are brought together. The background and aim of this study is briefly discussed in following.

Caused by different legislations and other political instruments (e.g. subsidies), as well as a massive price increase for fossil energy, the energetic biomass-utilization increasingly gains importance in european and world-wide context. Not only a clear increase of biomass utilization for energy recovery in the recent years can be recognized, but also the biomass utilization may reinforce in the future. Specific characteristics like transportability, suitability for storage as well as the utilization with established technologies. Biomasses for energy recovery are usually classified in the groups of residues, organic wastes and energy crops. Residues can be wood from thinning and harvesting as well as agricultural residues like excrements and harvest-remains (e.g. straw). The production of energy crops takes place almost exclusively in agricultural production systems. This type of biomass production has on the one hand high growth opportunities, gives the possibility of flexible reaction to the demand side and the production of specific feedstock; on the other hand the danger of conflicts about land use, negative environmental influences and the competition with food and fodder production is especially high.

Expecting a world wide rising biomass utilization energy recovery, the question about the current and future biomass potentials has to be answered. Thereby theoretical, technical, deducible and economical potentials can be described. These different potentials are affected by agriculturally, energy-economically or waste-management factors. Furthermore, the currently available production and utilization technologies can be influence the biomass potentials. Therefore, the estimation of future biomass potentials represents a very complex question.

Against the described background, one goal of this study is to summarize and analyse the current state of knowledge about global biomass potentials in scientific literature in chapter 2.

Although, a discussion of different driver-factors (e.g. population development and food consumption) that have a strong influence on biomass potentials and their future development will occur. Summarized data of world wide residue potentials are given in chapter 3.

The main part of this study is the calculation and representation of agricultural energy crop potentials. With regard to the biomass potentials in agriculture, energy crops are expected to become much more important in the near future. Hence, the focus of the analysis will be given to them. Energy crops are produced on agricultural land, so land availability is the key factor for the energy crops potential. The potentials of cultivable land for energy crop production are calculated for 133 countries with self-developed methodologies. These methodologies are described in chapter 4.1.4. On the surplus area of agricultural land different energy crops can be produced that generates the energy crop potential. The monitored years are 2010, 2015, 2020 and 2050. In chapter 4.2.2 cultivable land areas and energy crop potentials are calculated country specific. These results are put into world maps in chapter 4.2.2 and the annex.

Due to current activities using satellite based remote sensing technologies for biomass potential studies, an overview about current research activities in this area is given. Thereby, the methodical development and current results of biomass potential investigations based on remote sensing are represented in chapter 5.

2 Investigation and assessment of biomass potential studies

Comparability among potential studies is generally hard to achieve. In order be able to draw reasonable conclusions out of the literature review it was aimed to restrict the literature research to utilisable studies which were selected based on the criteria described in the following.

Berndes /1/ analysed 17 studies that reported bioenergy potentials, all published in the 1990s except the one from Fischer and Schrattenholzer /3/ which became available in 2001. The analysed studies differ in the complexity of the approach, the observed timeframe, analysed type of potential and the geographic aggregation. Beyond that one can distinguish between demand-driven and resource-focused assessments. The latter can be described as feedstock analyses of different biomass resources with consideration of competing uses while demand-driven assessments rather focus on the possible contribution of bioenergy within the overall energy system. In the context of this project we are more interested in the supply of biomass than its part in the energy system. Demand-driven assessment will therefore be neglected in the following.

The scope of this project is on technical potentials expressed in units of primary energy. Therefore only studies were included that analysed potentials consistent with the given definition. Furthermore it was aimed to include a variety of different methodologies to show the whole range of how potential estimates were derived in the past and what will be the most promising and reproducible approach for future assessments. Referring to the regional aggregation within the studies only those were analysed that reported that used a global perspective. Research undertaken on regional levels always follows other guidelines as the purpose of such assessments often differs from that done on a global scale. The literature research was further conducted with concentration on studies that report potentials for biomass residues. The overall number of existing biomass potential studies is relatively large. Particularly in recent times the emphasis was put on analysing the potential of energy crops while residues were more or less neglected /4/. In the context of this thesis only few studies were analysed that solely focussed on energy crops in order to draw conclusions about relation between energy crops and residues.

2.1 Reported bioenergy potentials

The collection and presentation of the bioenergy potentials as published in various articles and studies forms a major part of the literature review. In total data from 18 studies could be made available. Among these there are ten comprehensive potential assessments with more or less detailed documentations on how the specific potentials were derived. The remaining studies are either collections of literature values or citations of the results calculated in other potential assessments that could not be made available. Another form of studies are those that seem to have calculated a potential themselves but do only give insufficient information on the underlying methodology so that they can not be grouped together with the potential assessments. Table 1 shows the distribution of studies according to evaluation period, their regional disaggregation, and the general types of resources considered. A regional split is of interest as the development of some important parameters, e.g. population growth, will show widely varying future trends among regions. Observing different resource categories is also of significance as the differing characteristics determine the conversion option and the possible form of usage. The majority of publications concentrate on the long-term energy potential of biomass. The best information base exists for 2050 and also for 2100 several publications could be found. Relatively little information however is available for the short and mid-term until 2020 and 2030. Most of the observed studies were published within the last ten years. Two studies were analysed that originate from 1993 as both made important contributions to the methodical discussion related with potential assessments.

Table 1: Overview of studies in literature review

Evaluation period	**No year**	**2020-30**	**2050**	**2100**
Number of studies	2	3	11	6
Studies with regional disaggregation	2	1 (2)	4 (5)	1
Studies considering both residues and energy crops	2	2	6	2
Studies considering only energy crops	0	0	4	4
Studies considering only residues	0	1[a]	1[b]	0
Studies with regional disaggregation and consider both energy crops and residues	2	1(2)	2	0

numbers in brackets also include partially disaggregated studies

a: the referred study was only available in form of a secondary source

b: this study only considers the potential from annual forest growth

The total potentials as reported in the literature are presented in Figure 1:. The dashed lines represent potential estimates that made no hint on the observed time horizon. What is striking is that most studies see biomass potentials to be substantially higher than their current level of use. The most optimistic study outcomes even project the potential to be several times the present global primary energy production. For example /8/ in its most favourable scenario projects a potential of roughly 1550 EJ/yr equalling more than three times the present global primary energy supply (480 EJ/yr in 2005). However it also has to be pointed out that there some assessments came out with a bioenergy potential below the current use of about 50 EJ. Assuming an increasing energy demand in the future, that would mean a substantial decline of the significance of biomass as a source of energy. There are two studies did not give information on the evaluation period. These are illustrated as solid lines in the diagram. Compared to previous estimates as presented in Figure 1: more recent research came out with substantially higher maximum values. The highest potential estimate shown here exceeds the previous one by 3.5 times.

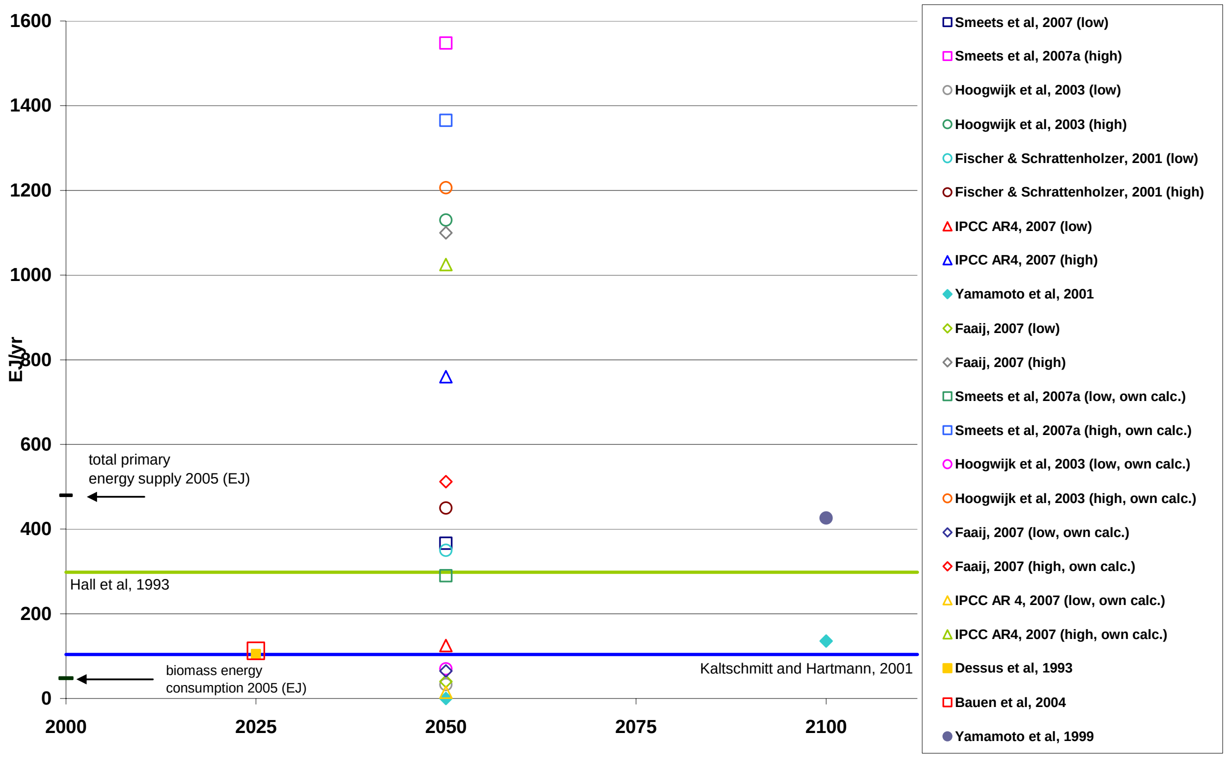


Figure 1: Global biomass potentials from 18 studies (data of /3/, /5/, /8/, /9/, /10/, /11/, /12/, /13/, /14/, /16/, /17/, /18/, /19/, /20/, /21/, /22/, /23/, /24/)

2.1.1 Potential of different resource fractions

Looking at the contribution of individual resources to the total biomass potential the majority of studies agrees that the most promising resource is given with energy crops from dedicated plantations. Figure 2 shows the ranges of individual resource potentials. These ranges are determined by the minimum and maximum amount out of all studies analysed. As there are only a few studies available that consider the years 2020/2030 the significance referring to the reported potentials may be impaired. The same holds for estimates that do not consider any year. Reliable and comprehensive information is therefore only available for 2050 and in a restricted way for 2100. What is obvious however from Figure 2 is that the size of the potential of energy crops is much more a subject of uncertainty than that resulting from residues. Projections for the potential of energy crops for 2050 range from 0 to 1272 EJ/yr. The major residue resource is given with forestry derived biomass for energy production. The largest variation of a residue fraction, forest residues, takes on 150 EJ/yr. According to /1/ the most crucial parameters when assessing the potential of energy crops are the available land area and attainable crop yields. Both factors are highly dependent on underlying assumptions made by the respective study which explains the widely differing estimates. The reason for the relatively large difference for forest derived biomass is based on a disagreement among studies referring to the definition of forest residues. Often studies do not differentiate between the quantities obtained from surplus forest growth and the residues released through harvesting and processing.

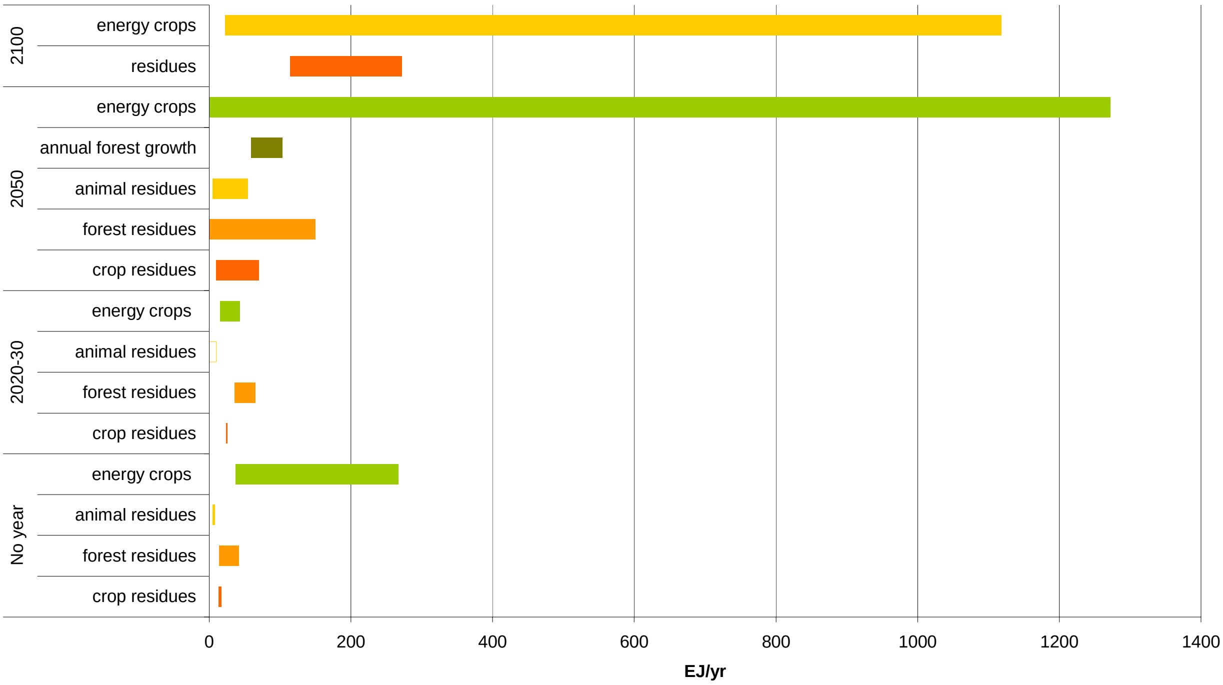


Figure 2: Ranges of potentials for different resource categories (data of /3/, /5/, /8/, /9/, /10/, /11/, /12/, /13/, /14/, /16/, /17/, /18/, /19/, /20/, /21/, /22/, /23/, /24/)

The potential of residues is differently handled in the referred studies. Some just calculated an overall residue potential and gave information on the included residue streams; others calculated independent potentials for different resource fractions. However there are only very few studies, that calculated all residue categories separately. Most studies concentrated on the potential of crop and forest residues as these are considered to be most significant. Quantifying the potential of minor fractions such as animal residues and organic wastes is difficult as the data situation is relatively poor.

The reported potentials for energy crops were further analysed by applying some statistical means. The visualization was done in form of a boxplot which is presented in Figure 3:. Before analysing this diagram it has to be noted that the significance of such statistical means is limited in this case as the basis data taken as an input is far beyond from everything like an objective series of measurements. In fact there are numerous parameters with different levels of uncertainty that determine the potential of energy crops. But for all that some conclusions on the expectable potentials can be made. Most estimates came out with a number between 162 and 297 EJ/yr, which is less than one quarter the total range. This boosts the impression that the higher values are some kind of optimum estimates and are only feasible under extraordinarily favourable conditions.

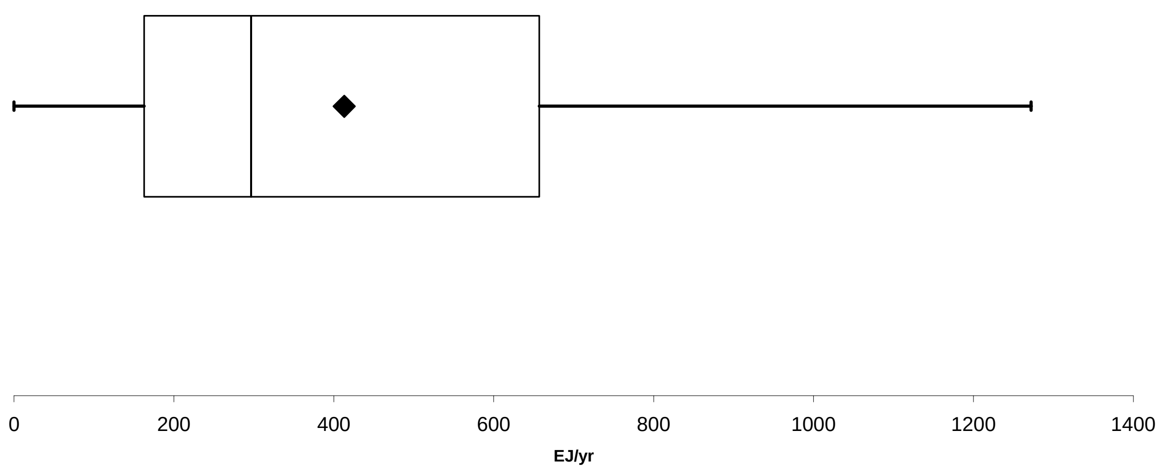


Figure 3: Boxplot for energy crops potentials reported for 2050 (data of /3/, /5/, /8/, /9/, /10/, /11/, /12/, /13/, /14/, /16/, /17/, /18/, /19/, /20/, /21/, /22/, /23/, /24/)

2.1.2 Bioenergy potential in different world regions

Among the scanned studies there are six that give bioenergy potentials with a regional disaggregtion. Two studies used a scenario approach and hence came out with different potentials for each calculated scenario. For reasons of better comparability only the minimum and maximum outcomes are presented in Figure 4:. The higher estimate of /16/ sticks out. All studies have in common that they expect significant contributions to the potential from Africa, Asia and South America. The contribution of OECD countries in comparison is minor. Out of the industrialised countries North America offers the largest potential. The global potential however is highly dependent on the future development of developing countries. This does not come as a surprise as a previous comprehensive literature review on the biomass potentials drew the same conclusions. /1/ also mentions that the importance of developing countries is particularly significant in the longer term. The establishment of large scale energy plantations in developing countries is often discussed in the literature as one of the most promising alternatives of bioenergy production. The potential in these countries might be substantial, but their estimation also comes along with a high degree of uncertainty. The political and economic development in a number of developing countries is very uncertain. Assessments of the existing potentials in these countries are furthermore confronted with severe problems concerning data obtaining. This results in widely varying estimates of the bioenergy potential.

/1/ made a comparison of the supply potential and bioenergy demand projections. According to their findings the potential of many developing countries exceeds by far the regional demand and is hence only realizable if well functioning trade relations were established with potential import countries.

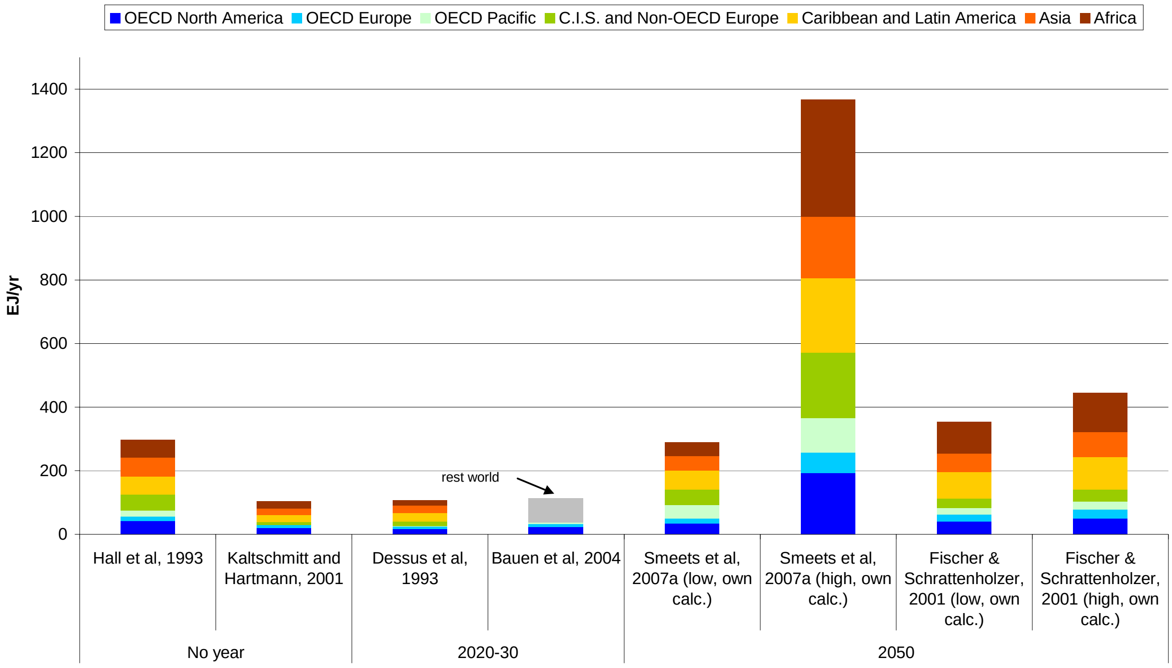


Figure 4: Total bioenergy potential in different world regions (data of /3/, /5/, /8/, /9/, /10/, /11/, /12/, /13/, /14/, /16/, /17/, /18/, /19/, /20/, /21/, /22/, /23/, /24/)

2.2 Discussion of methodical approaches

The first biomass potential assessments were carried out in the early 1990s. The first scientific contributions were made by Hall whose potential estimates were derived through bottom-up calculations based on literature reviews associated with an expert judgment on some factors. During the 1990s studies published showed a trend towards top-down approaches based on the biomass net primary production (NPP) or the future energy demand. In this context complex integrated models were built like the Global Land Use and Energy Model (GLUE) or the Integrated Model to Assess the Global Environment (IMAGE) /6/. The latest comprehensive potential estimates published by /5/ concentrated on deriving bottom-up methodologies to calculate potentials of different resource categories with a high degree of transparency. Most studies have in common that they designed scenarios with different storylines. Such a scenario approach seems to be the most adequate mean to address the complexity associated with assessing biomass potentials /7/.

Only very few studies give detailed documentations on their applied methodologies. First to mention is the study from /5/. This publication sticks out as nearly every step during the calculation process is made transparent could possibly be reproduced. Apart from that a number of other studies could be identified that also made some useful descriptions about their general calculation procedure.

The following studies were hence selected based on their usability in terms of methodical approaches.

- /8/ Smeets et al, 2007
- /9/, /10/ Hoogwijk et al, 2003 and 2005
- /3/ Fischer and Schrattenholzer 2001
- /11/, /12/ Yamamoto et al, 1999 and 2001
- /13/ Dessus et al, 1993
- /14/ Hall et al, 1993

2.2.1 Scenario drivers and scenario design

Scenarios are considered to be one of the best means to adequately assess bioenergy potentials. The reason is that the degree of complexity is relatively high with numerous parameters existing that influence the potential. Most of these factors are also subject to variations and their future development is everything but certain. Addressing this complexity and uncertainty a scenario approach seems to be indispensable.

Creating scenarios requires the definition of so-called scenario drivers that have an impact on the target value. One could differentiate between exogenous and endogenous drivers, where exogenous drivers describe independent variables that are not altered within the scenario context. They have effects on the endogenous drivers which can also be referred to as dependent variables. A distinction of exogenous drivers and endogenous drivers in the context of bioenergy potential assessments is rather difficult. Some publications even claim that for instance food and material demand were taken as exogenously defined variables in previous assessment studies. The bioenergy sector was assumed to evolve in parallel to the food or material sector, neglecting potential interactions /1/. The choice of scenario drivers is closely linked to the scenario design and its objective. Consequently each study identified different parameters resulting in difficulties when it comes to assess those that are most relevant.

/7/ figured out six fundamental drivers mainly affecting the available land for energy crop production and hence the energy crop potential. Three of them are also considered to influence the potential supply of residues. The referring drivers and the way they are addressed by different studies are listed in Table 2:. Additionally a corridor, expressed in percent, is given for each driver, representing the range of its variation against a fictitious average. These corridors should not be taken as an indicator for the sensitivity of the result to the respective parameter. They can however provide information on the level of uncertainty associated with the development of each driver.

Table 2: Parameters affecting the potential use of biomass for energy (adapted from /7/)

Parameter	affects[a]	corridor (in %)	Scale of parameter in 2050			
			Hookwijk et al., 2003	Hookwijk et al., 2005	Smeets et al., 2007a	Fischer und Schrattenholzer, 2001
Population growth (in billion)	E, R	+25 - +70	8.7-11.3	8.7-11.3	8.8	10
Per capita consumption (in MJ d^{-1})	E, R	+18 - +28	10.1-11.5	n. s.	13.8	n. s.
Yield increase through breeding	E	+30 - +130	n. s.	taken into account	taken into account	taken into account
State of the art of food production	E	+80 - +160	varying	varying	varying	constant
Impact of climate change on available land area	E, W, R	0 – (-7)	excluded in all scenarios			
Reduction of agricultural land	E, (W)	(-2) – (-9)	Partial consideration of single aspects (e.g. reforestation), however disregard of the important driver „soil degradation“			

[a] E: Energy crops, W: Wood from forests, R: Residues

A major part of the work of /8/ consisted of determining the parameters affecting the bioenergy potential. In the end the authors came up with a complex structure of influential factors and their interrelations. An illustration of this concept is presented in Figure 5:. For all these key factors data sets were obtained and included in the applied model. This process contained the analysis of past developments and based upon that the development of future trends. The authors considered the animal production system but also the advancement of agricultural technology to be the most important drivers of the potential. Hence they built their scenarios upon these findings and varied the scale of these parameters.

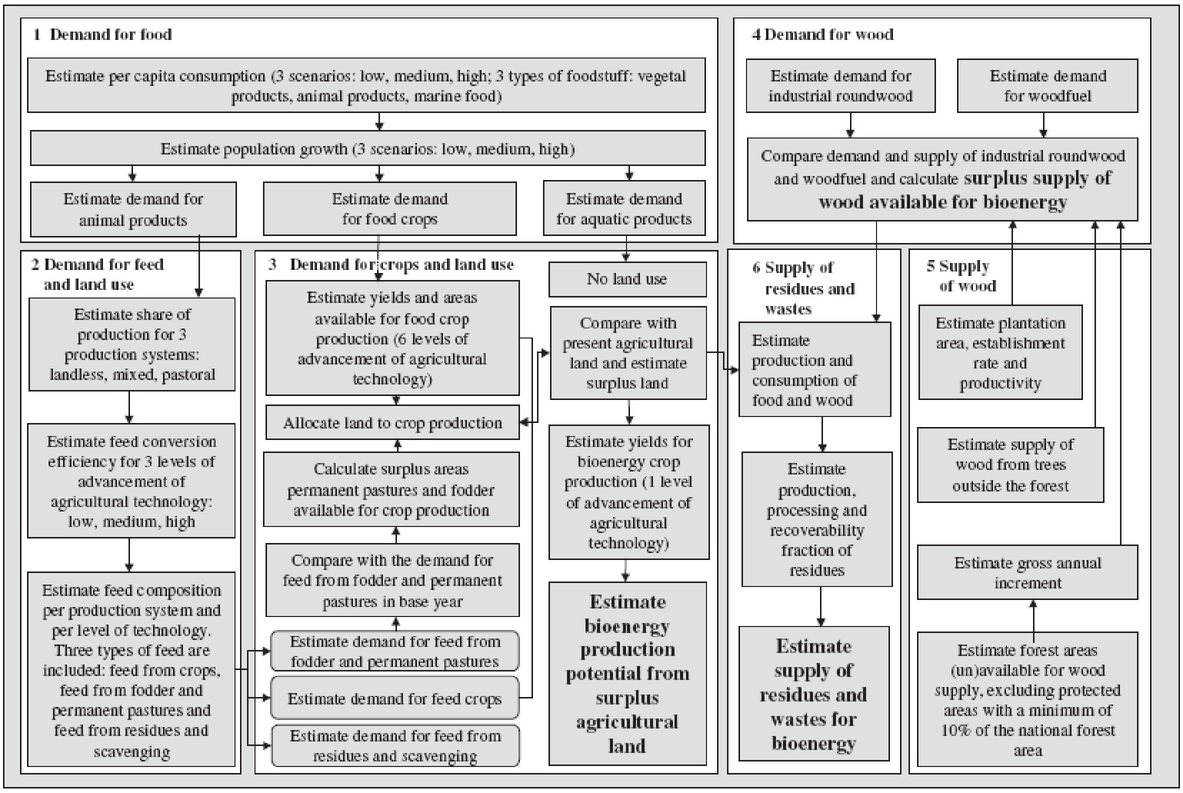


Figure 5: Key parameters for assessing the biomass potential /8/

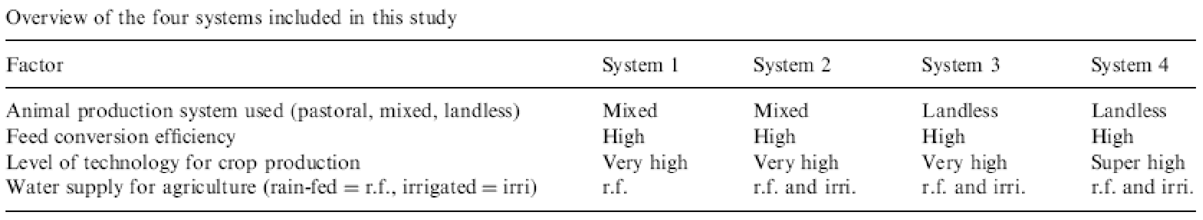
2.2.2 Energy crops

Most studies that cover bioenergy potentials mainly concentrate on potential contribution of energy crops. This resource category is regarded to be the most important source of energy derived from biomass in the future. In consequence much effort is spent on identifying the quantity of this resource. Estimating the potential of energy crops is a complex task as there are various uncertain parameters that can possibly have an effect on the resulting potential.

Approaches pursued by different studies show widely varying sets of parameters. The most crucial parameters when considering the potential of energy crops are land availability and assumed yields of energy crops /1/. Land types considered to be suitable for energy crop plantations mainly include surplus agricultural land and degraded or marginal land. Surplus agricultural land is basically defined as the remainder after subtracting the land required for food and feed production from the total existing agricultural land. The available land for energy production is hence primarily dependent on the food production. A major guideline when estimating energy potentials of dedicated crops is that sufficient supply of food may not be hampered by energy production. Most studies focussed solely on energy crop potentials from surplus agricultural land. Only two studies also observed potentials from degraded land (i.e. /9/, /10/). The transformation of degraded land into arable land requires great efforts in order to overcome financial and technical constraints /15/.

/8/ calculated the potential of dedicated energy crops on surplus agricultural land based on modelling three major input factors. These are demand for food, demand for feed and associated land use and the demand for crops and associated land use. These parameters were identified to primarily affect land use patterns and hence the resulting area to grow energy crops. For each of the factor a detailed description of the calculation procedure is given together with the main sources of data. In order to address uncertainties associated with the animal and agricultural production system four scenarios were designed. Their structure is presented in Table 3:. The chosen animal production system is a main determinant of the available land area. Animal production is far more land intensive than crop production. The caloric intake of animal products however only reached one sixth of the total intake. The required land for food crop production and production of animal products as calculated for 2050 was compared to the agricultural area in the base year (1998). Different food crop types were then allocated on the available land according to the soil quality. The crops are characterized by different yields and also potential future yield increases were included.

Table 3: Scenarios calculated by /8/



Overview of the four systems included in this study

Factor	System 1	System 2	System 3	System 4
Animal production system used (pastoral, mixed, landless)	Mixed	Mixed	Landless	Landless
Feed conversion efficiency	High	High	High	High
Level of technology for crop production	Very high	Very high	Very high	Super high
Water supply for agriculture (rain-fed = r.f., irrigated = irri)	r.f.	r.f. and irri.	r.f. and irri.	r.f. and irri.

/3/ followed a different approach. They distinguished four land use categories and allocated bioenergy resource categories to different land types. In order to meet the increasing food demand, additional 12.5 % of land needs to be transferred into crop land. The additional land is assumed to originate in equal shares from forests and grassland. The referring land use categories and allocated bioenergy categories are presented in Table 4:.

Table 4: Land use categories according to /3/

Land category	**Biomass category**
Arable land	Crop residues
Grassland	All kinds of biomass, e. g. energy crops
Forests	Forest residues
Other land	None
None	Animal waste
None	Municipal waste

/14/ assumes that in tropical regions bioenergy production will mainly take place on degraded land while in more temperate regions relatively high quality crop land will be used. The choice of the plantation location and the type of land has an immediate effect on the attainable yields. Land availabilities differ widely among world regions. A meaningful assessment of the global energy crop potentials therefore requires taking into account detailed regional assessments /14/.

/9/ created scenarios based on varying compositions of diets, different population projections and two different systems of agricultural production. The diets considered comprise a vegetarian, a moderate and an affluent diet. Population projections were taken from the literature. The agricultural production systems distinguished are first a system with high external input (HEI) and second a system with low external input (LEI). The HEI system aims to achieve highest possible yields by using fertilizers and “best technical means”. The LEI system represents a form of agricultural production that wants to minimize the environmental impacts of agriculture. The use of fertilizers for example is only allowed under special circumstances and only through biological fixation. The general calculation procedure also involves the comparison of global food supply and demand to identify surplus agricultural land. Additionally the potential from degraded land was estimated. In this context studies were analysed that reported potential areas for reforestation. Yield levels were taken from the crop growth model IMAGE 2.1 and adjusted on the specific land types meaning that yield levels between surplus land and degraded land differ.

/10/ concentrated on deriving potentials of energy crops until 2100 for four IPCC SRES scenarios. The scenario storylines are presented in Figure 6:. The “A”-scenarios are more economically oriented while the “B”-scenarios are more environmentally and socially focused. The scenario number, either 1 or 2, indicates the level of globalization. Energy crop potentials are calculated for three different land types: abandoned agricultural land, low-productive land and rest land. The rest land category is defined as the remaining area corrected by forest land, grassland, urban area and bioreserves. Additionally a land-claim exclusion factor was introduced to address potential land-use change in the future, i.e. transformation of land into urban area. In order to respond to the potential impact of farming practices on the attainable yields, a management factor was introduced.

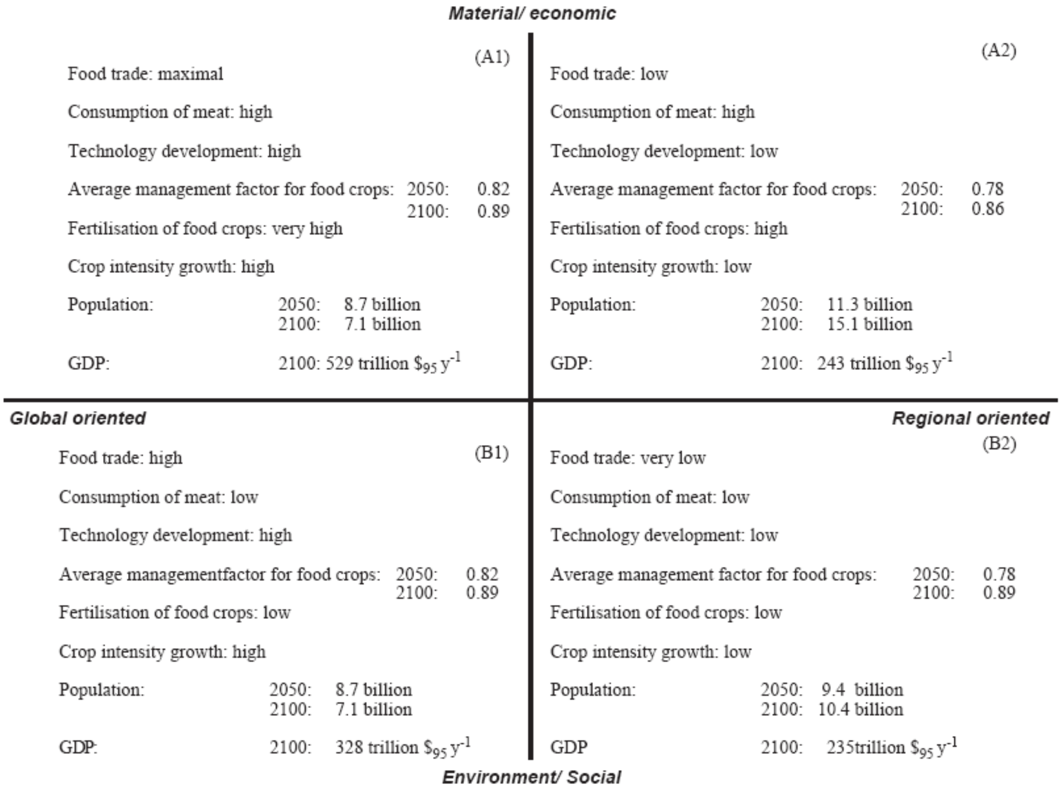


Figure 6: Scenarios calculated by /10/

Yield levels in most studies were derived by applying an external crop growth model, for example the IMAGE model. Such models basically work with a function of soil conditions and climatic aspects. Another approach followed for instance by /14/ includes the calculation of yields based on previous experience with energy plantations, breeding achievements on test fields and developments of food crop yields.

2.2.3 Residues

Residue potentials are differently treated among the surveyed studies. In some cases only a potential for residues in total is provided while others estimated potentials for different types of residues. The potential of forest-derived biomass is particularly uncertain. This has to do with differing assumptions on what are forest residues. /8/ for example defined forest residues as the quantities released during harvesting and processing of wood as well as the discharged amounts of wood. An additional forest derived resource is the surplus forest growth that is defined by the difference of supply and demand of forests. /13/ in contrast just included “commercial wood” and “non-commercial wood” potentials. The underlying methodology of the derivation of these potentials is largely consistent with the methodology used by /8/ to calculate the potential of surplus forest growth. Forest residue potentials according to the definition from /8/ are not included in the analysis of /13/. Understanding and comparing residue potentials therefore also requires an analysis of the definitions applied.

The general approach of deriving residue potentials involves estimating the production quantities of food and wood and multiplying these with a residue generation factor and further an energy recovery factor. All three parameters are critical for the expectable residue potential. The development of the food and wood production is associated with uncertainties as well as the development of residue generation factors. It is assumed that in the future yield increases achieved in the food production will result in a decreasing residue production relative to the production of the primary purpose-grown product. The recoverability fraction of the produced residues depends on the amounts of residues required for competing uses. Different uses for residues other than efficient energy production are for instance material use, animal feed, animal bedding and traditional fuels. Furthermore a share of residues has to remain on the field for reasons of erosion prevention and soil quality conservation.

In previous studies as analysed in /1/ most often residue generation rates were assumed to stay constant over the scenario period. The same holds for the applied recoverability ratios. /8/ at least addresses future developments in crop productivity. They derived independent yield increases for each world region according to the specific scenario design, i.e. a system with a higher level of technology shows higher yield increases. Whether this has an impact on the harvest index is not further specified. The same study also subtracted animal feed obtained from residues from the resulting potentials and therefore at least included one option of competing use.

No specific hint was made on the possible role of cascading and recycling ratios in any study. Cascading describes the multiple use of biomass resource for different utilizations. A residue can for instance be used for material recovery and later the waste product is available for bioenergy production. Sometimes a residue resource can be recycled several times before there remains no other usage possibility than energy recovery which is defined as cascading use. Cascading if existing has an impact on the primary biomass production as less primary residues are necessary to satisfy the demand for materials /9/. In the future increasing recycling rates are assumed to be developed, particularly in the paper industry /8/.

The residue factors assumed in five studies are presented in Table 5: The ratios are presented for different types of residues released at different stages from the biomass production chain. There can be seen kind of an agreement among studies because in most cases the same ratios were applied. In some cases however differences occur which basically have to do with the methodology applied. For instance /13/ only assumed a recoverability rate of 0.1 for organic wastes while others took a factor of 0.75. The number presented by /13/ however takes the total waste production as a base while others apply solely to the organic parts of municipal waste. Referring to wood ratios some studies make distinctions between developing and industrialised countries and further roundwood production of industrial applications and for woodfuel. Different recoverability rates reflect these assumptions.

Table 5: Residue recoverability factors as assumed in different studies

Stage of release	Residue type	Residue recoverability factors as applied in studies				
		Smeets et al, 2007	Hoogwijk et al, 2003	Yamamoto et al, 2001	Hall et al, 1993	Dessus et al, 1993
harvest	crops	0.25	0.25	0.25 - 0.67	0.25	0.3 - 0.5
	wood	0.25	0.25 - 0.5	0.5	0.25	0.5 - 0.7
process	crops	1	1	1	1	
	wood	0.75	0.33 - 0.75	0.42 - 0.75	0.75	
	animal		0.125 - 0.25	0.25	0.125	0.3
waste	crops	1				
	wood	0.75				
	organic waste		0.75	0.75		0.1

2.2.4 Evaluation

Various studies analysed the bioenergy potential and came out with widely differing assumptions on the size of the potentials. The reasons for that are manifold so that a deeper look on how these potentials were estimated is required to understand the outcome.

First of all the comparison of different potentials as reported in studies involves certain difficulties. Among other things studies refer to different definitions of some biomass resource fractions. The identification of the resource type considered includes itself an understanding of the respectively applied methodology to be sure to reach comparability. This problem is particularly significant referring to forest derived biomass.

A special problematic occurred related to the publication of /8/. This publication reported potentials for residue streams and energy crops. The total biomass potential is hence the sum of both resource fractions. The reported total potential from the study however does not correspond to the number calculated by adding the two numbers. Instead the lower value as derived from own calculations is about 21 % below the reported number, and also the upper limit deviates by -11 % from the published value. Such difficulties makes it of course even harder to rank potential estimates.

The analysis of methodologies also involves some difficulties. First of all only a limited number of studies made detailed and transparent documentations of their approaches.

Important parameters directly affecting the scale of the potential are in most cases given, however some studies only hinted to the model they used and presented the generated output rather than giving the sources they obtained their data from and the calculation procedures applied.

Referring to residues many studies stress that there are substantial data gaps concerned with particularly the recoverable amounts of residues and the required residue quantities for material use /8/. The analysis of residue potentials often plays a minor role within the reviewed studies. Most research activities focus on energy crops as their development is considered to be more significant for satisfying the bioenergy demand. However residue potentials should not be neglected as they can make a substantial contribution to the energy supply. Many publications mention that the residue potential is mostly based on conservative assumptions and tends to be underestimated.

A conclusion of /1/ was the formulation of further research demand related to land-use based mitigation options as well as other environmental and socioeconomic goals. /8/ but also /10/ address at least partially some of these former weaknesses of approaches by building different scenarios in which they varied for instance food demand, population growth and agricultural production systems. Furthermore /8/ defined sustainability criteria in their assessment, such as the avoidance of deforestation for the sake of bioenergy production.

Another review of bioenergy potential studies, like /4/, concentrated on recently published research outcomes. The analysed studies focussed mainly on the economic potential of energy crops. Several critical aspects were included but no study considered all controversial issues. /4/ discovered further demand for research activities related to the availability of water and irrigation, the impacts of the animal production system, the demand for wood and bio-materials, the effects of large-scale biomass production on prices and finally the impact of biodiversity objectives on biomass potentials.

Furthermore improvements were made relating to defining the scope of analyses. In particular, clear definitions of different types of potentials were established and followed, that allow a better interpretation and comparability of results.

Referring to the applied methodologies it has to be noted that integrated model seem to be useful tool as they can include a variety of parameters and interrelationships between factors can be illustrated. Such models however also seem to be relatively complex and unique so that comparability among studies is hard to achieve. The choice of scenario drivers for instance is crucial for the generated output and the set-up of drivers differs significantly among the models. It also seems to be that each model stands independent for itself and that further research based on these models is linked with several difficulties. This is due to the fact that the algorithms used in such model are only partially documented so that full traceability is not given. From the methodological point of view the approach followed by /8/ offers the highest level of transparency and traceability and seems be an appropriate basis for further assessments.

3 Potentials of residues for Greenpeace' "Energy [R]evolution 2008"

Within the previous chapter, several potential studies were described and analysed. The part of each residue fraction can vary in different regions and is mainly dependent on the population, the living standard and the methods and intensity of the agricultural and forestal production in the particular region. As mentioned in the previous chapter, several studies analysing the long term residue potential in a more or less detailed way are available. A direct comparability of the studies is difficult, since the baseline assumptions are different. Although, residue potentials for the Greenpeace' „Energy [R]evolution 2008" are estimated in this project. The following data are calculated on the basis of two studies /13/ (Dessus et al 1993) and /8/ (Smeets et al 2007). Study /13/ is used, since it is the only study with region-specific residue potentials for 2020. Study /8/ takes the year 2050 into consideration and is used because the authors have defined sustainability criteria in their assessment. Moreover the study offers a hight level of transparency and traceability from the methodological point of view. The data are given in Table 6.

Table 6: Residue potentials in 2020 and 2050 (own calculations, database /8/ and /13/)

residue potential in EJ/yr	2020			2050		
	dry residues (solid fuels)	wet residues (biogas)	total	dry residues (solid fuels)	wet residues (biogas)	total
OECD Europe	6.4 [b]	0.5[d]	7.0	7.0 [e]	0.5 [d]	7.5
OECD North America	11.3 [b]	0.5 [d]	11.8	17.0 [e]	0.6 [d]	17.6
OECD Pacific	2.3 [b]	0.2 [d]	2.5	6.0 [e]	0.2 [d]	6.2
Transition Economies	4.8 [b]	0.3 [d]	5.1	5.0 [e]	0.3 [d]	5.3
China	5.6[c]	1.4 [d]	7.0	6.3 [f]	1.4 [d]	7.7
India	3.6[c]	1.3 [d]	4.9	6.3 [f]	1.5 [d]	7.8
Rest of Asia	9.3 [b]	1.2 [d]	10.5	6.4 [e]	1.6 [d]	8.0
Latin America	5.6 [b]	0.5 [d]	6.1	12.0 [e]	0.6 [d]	12.6
Africa [a]	1.9 [b]	1.1 [d]	3.0	12.3 [e]	1.5 [d]	13.8
Middle East [a]	0.4 [b]	0.2 [d]	0.6	0.7 [e]	0.4 [d]	1.1
World	51.2	7.4	58.6	79.0	8.6	87.6

a: In both studies the original division is "Sub-Saharan Africa" and "Middle East and North Africa", the division in "Africa" and "Middle East" is calculated on the basis of population.

b: original data of the category "residues" in /13/ plus the values of "forest residues" in /8/ minus 10%

c: "residues" of /13/ plus forest residues which are calculated by the following method: On the basis of FAO data the development of forest area is estimated. With the data "forest residues" of /8/ for "East Asia" and "Southeast Asia" data for China and India are calculated.

d: potential of wet residues is assumed by the estimated factor of 1 PJ per 1 mn people

e: original data of /8/

f: /8/ gives potentials for East Asia (included China) and South and Southeast Asia (included India). Following these data, the potentials for China and India are calculated on the basis of population data. 70% of the potential (9 EJ) are in India, 63% of the potential (10 EJ) are in China.

4 Potentials of energy crops for Greenpeace’ “Energy [R]evolution 2008”

During energy recovery of biomass, renewable fuels from vegetable materials are directly converted into usable heat and electrical energy or into other energy sources like transport fuel or methane. Besides the utilisation of biomass from residues, the production of energy crops in agricultural production systems is of high significance. On the one hand energy crops give the possibility to generate a new type of income for farmers, on the other hand risks of competitions between the production of food and bioenergy have to be avoided by all stakeholders.

In the calculations, the technical potentials of energy crops are calculated assuming that the demand for food takes priority. The agricultural trade within the scope of existing exports is not considered as biomass potential for energy production. Furthermore, the demand for food, which will increase in future, must be satisfied on the basis of domestic resources. The technical potential calculated in this study would, in fact, only be used when prevailed future the general conditions meet this requirement. The decision of whether the accumulated additional agricultural raw materials will be used for bioenergy production at home, for exports or refined products of higher added value in turn depends on the economic and legal general conditions prevailing in each case.

In the following chapters, the assumptions, methodology and results of the calculations of world wide energy crop potentials are described. The timeframe taken into account are the years 2010, 2015, 2020 and 2050.

4.1 Land availability

Agricultural land as arable land and/or grassland is necessary for the production of energy crops. An assumption of the following calculations is to ensure the production of food and to avoid negative competitions between food and energy crops. Therefore, only agricultural land that is not necessary for food production is used for energy crop production, so only idle agricultural areas are taken into account for calculation of energy crop potentials. In a first step, in different scenarios, the demand of arable land and grassland for food production (chapter 4.1.1) is calculated for each listed country. The surplus of agricultural land can be used for energy crops. More information about the methodology is given in chapter 4.1.4. In a next step, different crops were assumed to calculate the primary energy crop potential (chapter 4.2).

Albania
Algeria
Angola
Argentina
Australia
Austria
Azerbaijan
Bangladesh
Belarus
Belgium Luxembourg
Benin
Bolivia
Bosnia Herzegovina
Botswana
Brazil
Bulgaria
Burkina Faso
Burundi
Cambodia
Cameroon
Canada
Cen. Afr. Republic
Chad
Chile
China
Colombia
Costa Rica
Cuba
Cyprus
Czech Republic
D. Rep. of the Congo
Denmark
Dominican Republic
Ecuador
Egypt
El Salvador
Eritrea
Estonia
Ethiopia
Finland
France
Gabon
Georgian Republic
Germany
Ghana
Greece
Guatemala
Guinea
Guyana
Haiti
Honduras
Hungary
India
Indonesia
Iran
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kazakhstan
Kenya
Kirghizia
Kroatia
Laos
Latvia
Libya
Lithuania
Madagascar
Malawi
Malaysia
Mali
Malta
Marocco
Mauritania
Mauritius
Mexico
Mongolia
Mozambique
Myanmar
Namibia
Nepal
New Zealand
Nicaragua
Niger
Nigeria
North Korea
Norway
Pakistan
Paraguay
Peru
Philippines
Poland
Portugal
Rep. of the Congo
Romania
Russia
Rwanda
Saudi Arabia
Senegal
Serbia Montenegro
Slovakia
Slovenia
South Africa
South Korea
Spain
Sri Lanka
Sudan
Suriname
Sweden
Switzerland
Syria
Tadzhikistan
Tanzania
Thailand
the Fiji Islands
the Netherlands
Togo
Tunisia
Turkey
Turkmenistan
Uganda
Ukraine
U. Arab Emirates
United Kingdom
Uruguay
USA
Usbekistan
Venezuela
Vietnam
Yemen
Zimbabwe

4.1.1 Scenarios of agricultural production

Calculating agricultural land potentials for energy crops for the next decades, the question about future development of agricultural framework conditions and practices and therewith the corresponding demand of agricultural land must be posed. In order to represent possible developments for the demand as well as the expansion of agricultural land during the investigated time frame, the following five scenarios for agricultural production are defined.

BAU scenario

The legal and economic general conditions existing at present time also apply for the future. Forest clearing, change of grazing land and loss of valuable agricultural areas for industry and traffic purposes continue to take place. There is no re-introduction of intensity-suppressing measures, the existing measures remain in place.

Basic scenario

Forest clearing is no longer taking place. In countries having political programs for land set-aside, these measures are discontinued with the effect that 80% of the fallow areas demarcated for this land will be used for agricultural production in the usual cultivation mix. For all other countries is assumed that under the changed economic general conditions following the shortage of agricultural raw materials, the demarcated fallow areas will be used. For this process is assumed that basically 30% in 2010, 50% in 2015, 60% in 2020 and 75% in 2050 of the available fallow areas will be used for the production of agricultural raw materials.

Sub scenario 1 (additional to the Basic scenario)

Compared with the basic Greenpeace scenario, it is assumed that in all countries the area productivity increases more slowly than hitherto. Underneath this lies the assumption that the trend towards lower growth rates, identifiable since 1990, persists worldwide and the scope of ecological husbandry, up to now small in terms of area will be expand disproportionately. On the other hand, it is assumed that cultivation methods are more strongly oriented towards sustainability and sparse use of yield-increasing agents. This has the consequence that the yield level compared with the base will be reduced by 10% in 2010, by 20% in 2015 and by 30% up to 2020. This yield decrease will not be used for each country, but it depends on the yield level of each country. E.g. Russia has already a high percentage of ecological agriculture

and low yields, therefore an additional yield decrease of 30 % is not expedient.
Additionally, no change of grassland and pasture takes place.

Sub scenario 2 (additional to the Basic scenario)
In this scenario it is assumed that in countries having a level of food consumption significantly above the recommendations of the World Health Organisation a change in consumption habits will be made. For the calculations is assumed that all countries consuming more that 850 grain units per capita per year will reduce per-capita consumption by 30% maximum. This applies to countries such as the USA, Canada, Australia and most EU Countries. Countries below the per-capita consumption of 850 grain units/year do not restrict the per-capita consumption. Countries having a moderate consumption level (between 850 and 1215 grain units) reduce the per-capita consumption by less than 30%, to the level of 850 grain units/per capita.

Sub scenario 3
In this scenario is assumed that a reduction in area productivity and also a change in consumption habits in accordance with the recommendation of the World Health Organisation take place throughout the world.

Following these five scenarios, the demand of agricultural land is calculated country specific by using the following methods.

4.1.2 Main drivers for the future food and feedstock demand

The land availability for energy crop production depends on the overall amount of available agricultural land as well as the demand of land for the food and fodder production. There are various drivers that influence the actual and future food and feedstock demand. Climate zone, soil quality or local conditions are factors that influence these drivers. But the main factors are universally valid in a global context. In the following an overview of the main influencing factors is given.

Influencing factors:

1. Development of the global population
2. Per-Capita consumption of food (global per-capita consumption of food changes slowly but increasingly; production of animal products needs more acreage than production of plant products (at least by factor 6))
3. Increase of harvests by increase of specific yields by breeding successes
4. Increase of yields by improving the state of the art (real situation in agriculture; i.e. assimilation of production systems particularly in Africa and Asia)
5. Climate change influences both, the availability of acreage and the development of the yields
6. Loss of agricultural acreage by soil degradation (erosion, salinisation) and additional need of areas for non-agricultural purposes (infrastructure, restrictions of use etc.)
7. Competing needs for nature conservation
8. Acreage for flood protection
9. Extensification towards environment protection
10. Use as raw material in industry
11. Use for attractive non subsidized exports

The main factors are the development of the global population, the future per-capita consumption - both driven by the development of the world wide economic growth - and the development of the specific yields for food, fodder and biomass production. An important but difficult predictable factor will be the climate change and the influence on agriculture. The main drivers and connections between the different levels are shown in Figure 7. It shows the different interrelationships between the levels in the system of biomass supply. The parameters will be quantified in a model in order to estimate present and future potentials for biomass available for energy. This will be explained in the following chapter.

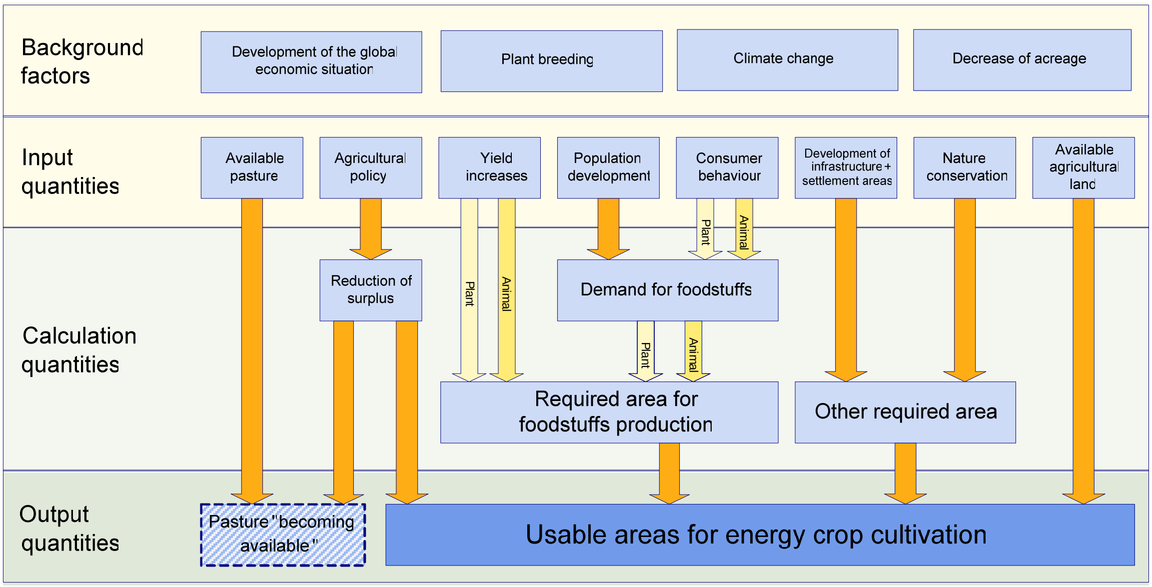


Figure 7: Interrelationships and drivers for energy crop potential /1/, adapted

4.1.3 Additional factors with influence of land availability

In the following section potentially available agricultural areas and the associated supply of agricultural bio-mass for 133 selected countries of importance for world-wide nourishment for the period 2000 – 2050 is quantified. The calculation of agricultural area takes the following factors into consideration:

- Fallow areas (disused areas): It is assumed that fallow land is partly available for energy crop cultivation.
- Reduction of surplus production of market regulation products provides additional areas for energy crop cultivation [1]
- Changes in food consumption due to the demographic development and changes in per capita consumption. Higher consumption decreases and lower consumption increases the available potentials for bio-energy sources.
- Expected redesignation of previously agricultural land for residential building, traffic and other purposes. This redesignation of land reduces the potential for bio-energy sources

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[1] It is assumed for simplicity that the domestic production of these surplus products could be used up to the limit for self-sufficiency in food and above this for exports or for bioenergy.

- Increases in the yield and performance of crop and animal production. These increases make potentials from agricultural land and grassland available for bio-energy sources.

A differentiation is made between arable land and grassland. Producible quantities of regenerative raw materials are derived, based on this area potential. Quantification of potential is based on the data from FAO, consistently collected for all countries.

4.1.4 Method

Since further increases in yield will come about in the future, the area usage productivity will thereby be increased, with the result that smaller areas will be required to ensure food production at constant food consumption. This released area can thus be used for energy crop production. The magnitude of the increase in yield is in each case determined as a linear trend differentiated for the countries being studied according to the main products produced, and aggregated to give a weighted yield progress coefficient. For arable areas yield data are available for most countries for cereals, oilseed rape, sugar plants, starch-containing root crops (turnips, potatoes) and also for some field fodder crops. No information is available for changes in yield on grassland. With the exception of a few countries in which grassland is very intensively cultivated and is laid out on good soils under good climatic conditions (e.g. New Zealand), this is probably not available. This assumption is based on the fact that the extensive grassland areas of the world are characterised by dryness and seasonal vegetation and in part also by poor soil qualities. The weighted average yield progress was calculated in earlier studies by weighting the changes in yield specific to the type of crop with the proportional area of the total agricultural useful area. This leads to an underestimate of the average change in yield in those countries in which comprehensive extensive grasslands exist which certainly occupy a high proportion of the agricultural useful area but where only small proportions are involved in the total production. Since the average total change in yield appears in the balancing as a parameter of the total change in supply, the area release potential of the countries being studied is found to be too low by this method.

Thus, the proportion of the total demand for food which is provided by grassland is initially determined for the present calculations. Primarily milk and beef are produced on grassland. The proportion of milk and beef in the total food consumption is determined in grain units and forms the weighting factor for the yield progress component of grassland. The average yield progress rate of grassland and arable land will be determined by weighting the yield progress set to zero on grassland with the proportion of the food demand for milk and beef in the total demand. The yield progress for arable land crops is initially weighted specific to the type of crop with the proportional area of arable land. This weighted yield variation parameter for arable land will be weighted with the proportion of food obtained from the total consumption minus the fraction of milk and beef. This methodical procedure has the result that as a result of setting the yield progress to zero, in future only exactly the same amount as previously can be produced on grassland. On arable land the production quantities vary according to the changes in yield. If more beef and milk products are required in one country to ensure the food supply, these must be produced on arable areas (fodder silage, hay). These areas can then be converted from arable to grassland.

4.1.5 Used data base

The development of the variables essentially determining the potential in the individual countries is shown, i.e. population, per capita consumption, self-sufficiency portion. The self-sufficiency portion was calculated from the self-sufficiency portion of the most important foods, weighted by its proportion of the entire food consumption in grain units. Theses variables are valid for all scenarios. The development of agriculturally utilized area and area yield are scenario specific and is explained afterwards.

Assumptions for all scenarios

Food consumption is primarily influenced by the development of a country's population (Table 1). While in Germany and the EU 27 population figures are stagnant to the largest extent, population development in the transformation countries in the rest of Europe (Ukraine and Russia) is on the decline. On the other hand high population growth figures are anticipated for Africa, Asia, America and Australia. The change in consumption of foodstuff is derived together with the per capita consumption.

Table 7: Developing of population and per capita income, own calculations

country	population					per capita income
	Ø 2002 - 2005 (thousand)	rate of change in %				US $/year Ø 2002 - 2005
		2003 - 2010	2010 - 2015	2015 - 2020	2020 - 2050	
EU-27	484,638	0.34	-0.10	-0.35	-6.50	22,305
Europe others	306,973	-0.54	-0.78	-1.29	-12.37	4,505
Europe	791,611	0.00	-0.37	-0.71	-8.78	15,403
North America	325,553	6.89	4.54	4.29	17.98	38,336
Central America	169,921	10.16	5.98	5.14	15.95	4,980
South America	362,096	9.17	5.55	4.79	16.21	2,966
America	857,570	8.50	5.25	4.67	16.83	16,950
Australia	19,731	6.15	3.83	3.47	13.59	25,260
Oceania	5,935	5.19	3.03	2.64	5.15	13,484
Asia	3,677,249	8.23	5.07	4.22	11.50	2,535
Africa	794,128	15.73	9.95	9.07	47.23	795
sum of 133 countries	6,146,224	8.17	5.02	4.26	14.21	6,005

Per capita consumption (Table 8:) shows a differing development in the countries under observation, and will grow above average, especially in Asia (China and India). A somewhat lower increase in per capita consumption, but still above average, is expected for Middle- and South-America. Further growth in population as well as an increasing per capita consumption at the higher levels is expected for North America until 2010 (primarily because of the high consumption of energy in the production of beef). A small increase in per capita consumption is predicted for the average of EU member countries. On the other hand a stagnating per capita consumption is expected for Australia and a rising per capita consumption is expected for transforming countries like Russia and the Ukraine. However, - contrary to Russia – a growth in population of almost 14 % is expected for Australia for the period 2003 to 2020 and from 2020 to 2050.

Table 8: Per-Capita-Consumption and self-sufficiency

country	per capita consumtion					self-sufficiency
	Ø 2002 - 2005 (grain unit)	rate of change in %				Ø 2002 - 2005
		2003 - 2010	2010 - 2015	2015 - 2020	2020 - 2050	
EU-27	1,186	3.17	0.63	0.42	3.79	1.0112
Europe	1,051	2.29	1.26	1.13	7.59	0.9710
North America	1,667	4.64	0.00	0.00	0.00	1.0760
Central America	738	6.32	3.46	3.46	20.77	0.8525
South America	924	3.21	1.98	1.98	11.89	1.1603
America	1,169	4.37	1.52	1.52	9.14	1.0673
Australia	1,344	-0.78	-0.55	-0.55	-3.33	1.6357
Oceania	969	-3.62	0.59	0.59	3.56	2.9162
Asia	495	9.13	5.21	5.21	31.28	0.9593
Africa	399	2.58	1.92	1.92	11.55	0.8154
sum of 133 countries	652	6.69	3.74	3.73	22.46	0.9613

Australia has a rate of self-sufficiency regarding foodstuffs of more than 160%, South America only has got 116%, despite its huge agricultural potential. The EU-27[2], Asia and North America are within a range of balanced self-sufficiency, while East Europe (Russia) on the other hand is still in a range of deficiency with 80% of self-sufficiency.

The **agriculturally utilised area** is estimated based on the so-called "agricultural area" of the FAO statistics of 1991 – 2002. Agriculturally utilised area is decreasing in industrial countries like Australia, North America, Europe and the EU, while in threshold countries like in South America, Africa and Asia an increase could be observed due to increased utilisation of previously un-utilised agriculturally usable areas, and to a certain extent of rain forest areas, and this trend is expected to continue in the coming years at least until 2020. It has not been taken into consideration that the global change in climate can lead to a gain in areas (Northern Europe) or to a loss of areas (Southern Sahara). These effects will, however, not yet be able to be confirmed by 2020, but probably later.

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[2] Within the EU, Great Britain shows a traditionally low degree of self-sufficiency. Germany is close to being self-sufficient.

Table 9: Agricultural area and arable land

country	Ø 2002 - 2005 (thousand ha)	
	agricultural area	arable land
EU-27	193,566	111,203
Europe others	321,794	191,863
Europe	515,360	303,066
North America	483,137	221,089
Central America	138,814	35,295
South America	552,957	106,108
America	1,174,908	362,491
Australia	442,940	48,296
Oceania	17,800	1,800
Asia	1,587,284	471,114
Africa	1,027,978	183,583
sum of 133 countries	4,766,269	1,370,349

The assumptions regarding **future development of yield** are of cardinal importance for the result of the estimation of potential. Linear regression coefficients were calculated for the period 1994 - 2002[3] for the relevant cultivars (grain, oil crops, root crops, sugar cane and sugar beet, starchy root crops and agricultural feed crops [Silage maize and similar] for purposes of estimation. For strongly deviating trends within time series, change rates were oriented on plausibility criteria.

Only very fragmentary data is available for area yield of grasslands and their development[4]. In order not to over-estimate the potential of energy crops, it was assumed for all countries, that no yield increases were to be expected for grasslands for the period until 2050[5].

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[3] The growth rate per year is established from the regression coefficients with reference to the average yield level of the past three years. In Germany, for instance, it is 1.29% for grain. The average improvement rate per year, weighted with the area proportions of all cultures, is 0.97%; this results in a growth of 6.35% for the period 2003 – 2010, based on 2003. Based on this increase in yield, the improvement rate for the decade 2010 – 2020 with constant absolute increase in yield per year is 9.07%, based on 2010.

[4] For example, the yield of permanent grasslands in Germany rose from 73.7 dt dry hay mass/ha in 1992 to 82.5 dt dry hay mass/ha in 2001. The rate of change of yield for Germany therewith was only 1% per year, compared to about 1.5% for agricultural market crops.

[5] Arguments for both more optimistic and more pessimistic assumption (decreasing absolute yield gain) can be tabled. In view of higher yield increase rates in case of the bio-energy option by virtue of a stronger focus on plant cultivation for higher energy yields in future, area-specific cultivation and better management, the selected approach seems to be rather pessimistic.

In those countries dominating world trade with agricultural products, like for instance North and South America and the EU-27, and here especially their large agricultural area states France, Germany and Poland, yields are characterized by sustained significant increases (Table 10).

Table 10: Development of yields

country	grain area Ø 2002 - 2005 (thou. ha)	yield t/ha Ø 2002 - 2005	rate of change in % 2003 - 2010	2010 - 2015	2015 - 2020	2020 - 2050
EU-27	60,065	4.8	7.86	5.61	5.61	33.68
Europe	133,337	1.32	13.22	9.41	9.41	56.64
North America	73,038	5.45	9.71	6.93	6.93	41.60
Central America	12,942	2.76	6.86	4.90	4.90	29.42
South America	35,930	3.27	15.28	10.91	10.91	65.48
America	121,910	4.52	11.06	7.90	7.90	47.40
Australia	19,299	1.73	2.05	1.47	1.47	8.80
Oceania	134	6.88	12.01	8.58	8.58	51.46
Asia	291,214	3.36	9.50	6.79	6.79	40.73
Africa	92,133	1.37	8.24	5.89	5.89	35.31
sum of 133 countries	658,028	3.25	10.24	7.30	7.30	43.87

Noteworthy increases in yield were achieved in the past, even in the most densely populated countries of the world, like China and India. And further increases in yield can be expected. In East Europe (Russia and the Ukraine) yield increases were initially negative or only slightly positive directly after the political turnaround. During the past years they achieved average values, however, still at a low yield level.

For areas with specific and apparently increasing drought, like Australia, yield increases were negative. They are quite frequently ascribed to the results of climatic change in this respect. Changes in climate will not only result in increased limitation of growth in yield as a result of temperature increases and rainfall deficits in arid areas, but also in growth impulses due to higher CO_2 concentrations and increased temperatures in other areas. However, these effects appear to be limited and insignificant until 2020.

Potential of land availability in the historical data base 2002 to 2005

The method for the estimation of area potential for bio-mass for generating energy, was used to calculate results for all countries presented. The following trends for individual countries emerge:

Table 11: Potential of agricultural land for energy crops in 2002 to 2005

country	available land for energy crops Ø 2002 - 2005 in thousand ha				
		surplus area from			
	fallow land	crop production	milk production	beef production	sum
EU-27	14,145	9,390	4,919	2,140	30,595
Europe others	88,975	5,141	1,837	351	96,336
Europe	103,121	14,531	6,756	2,491	126,932
North America	93,373	31,182	-400	373	126,123
Central America	15,279	1,241	-4,148	-2,322	17,468
South America	19,100	16,102	5,734	25,904	71,140
America	127,753	49,985	7,604	29,296	214,732
Australia	24,909	12,268	65,658	89,925	192,760
Oceania	3,219	138	8,197	1,628	13,182
Asia	47,595	13,832	41	675	62,188
Africa	43,337	352	270	65	45,451
sum of 133 countries	349,933	91,105	88,527	124,081	655,244

In **Europe (EU27)**, at least 30 million ha of land will be available in 2002-2005 for bio-energy sources. The proportion of land made available accounted for grassland is almost zero, because an increase of yields on grassland was not assumed. The rest of Europe is mainly dominated by Russia and the Ukraine. Russia disposes of a huge agriculturally usable area of 216 million ha. About 1.5 ha of agriculturally utilised area is available per capita. The level of productivity was exceptionally low for 2002 – 2005. During the first years of transformation it declined, but has shown strong growth since a few years. Russia therefore disposes of significant area potential to increase the production of foodstuffs. These are mainly situated in fallow areas, which are currently not being utilised. It must be assumed that the extremely low level of production will increase significantly more than during the time period on which the regression analysis is based, due to the renovation of agricultural technology, which started years ago. In the medium term Russian agriculture will profit significantly from the climatic change.

In the Ukraine the same trends have shown up during the transformation process as for Russia. The Ukraine is a country with an agricultural surplus. Contrary to Russia, it has not yet been possible to convert increases in productivity into a positive development of yield through modernisation of agriculture. Growing area and production potential can in future, however, result in comparatively similar orders of magnitude as in Russia. Decreasing per capita consumption trends and yield change rates will not continue. The estimation leads to growing area potential for bio-energy sources in the order of ca. 20 million ha.

Australia is one of the countries with the highest grain export surplus. With more than 440 million ha of agriculturally utilized area, more than 20ha of agricultural area per capita is available. However, the trend in this respect has been strongly regressive in the past years.[6]. If this trend continues, it is expected that the significant area potential available in 2003 for bio-energy (almost 193 million ha), compared to 137 million ha in 2020 is markedly regressive, because a strong growth in population coincides with a reduction in agriculturally utilised area and yield.

In **North America** only 1.4 ha of agriculturally usable land per capita is available. Noteworthy successes in a further increase in yield per ha have been achieved and will still be achieved in future. A significant expansion of yield-effective cultivation of maize and a consistent utilization of genetically modified cultivars is expected to play a major role here. With an area potential of 126 million ha (extending beyond domestic supply for the population), North America disposes over large area and production potential, based on high average yields. Area potential also results from a significant scope of fallow areas and extensive irrigation and dual-crop areas.

South America currently is one of the big agricultural exporters of the world, and at the same time Brazil is one of the largest exporters of ethanol world-wide. The agriculturally utilised area has been expanded significantly during the past ten years, and at the same time average yield could be increased, comparably to the scope of increases achieved in the EU-27 and North America. Available area potential for bio-energy of about 71 million ha as a base line, will be decreased.

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[6] Since yields have also been slightly regressive, structural changes could also be ascribed to influences of climatic change besides numerous economic factors.

Asia can currently still provide enough food for itself, however only about 0.4 ha agriculturally used area is available per capita. And this number is decreasing rapidly. On the other hand it was possible to increase yield, even more than in highly developed industrial countries, and it is expected that this will be possible until 2020 and 2050. An evaluation of developments shows that only about 60 million ha are available for bio-energy cultivation. Domestically produced dairy products and beef are short in supply and are being imported.

The calculations of the historical data between 2002 and 2005 indicate ca. 655 million ha area potential for non-food uses, about 14% of the agriculturally utilised area. Of this around 350 million ha was accounted for by fallow land, that is, agriculturally non-utilised but usable areas. Another 300 million ha area was used in countries having an agricultural surplus as export/import surplus for regenerative raw materials or for supplying the world market, partly at subsidized prices. In addition, there were countries with import/export deficits so that on balance worldwide, not 655 but only 527 million ha area potential was available for non-food purposes. This area consists of 405 million ha, potential of arable area and 150 million ha potential of grassland areas.

The absolute quantity of available areas seems enormous. The impression is put into perspective however if this is related to the total available area where this only accounts for 10-14% of this. The current shortage of food has shown that this potential can rapidly be used up by expected demand for food in populous countries.

4.1.6 Results

BAU scenario

In the BAU scenario ("business as usual"), there is a considerable potential for agricultural raw materials for use outside the food supply area. In this case, it is assumed that the available fallow areas will be 100% utilised by 2010: this was hitherto not the case for almost 360 million ha worldwide because of overfilled agricultural markets and less efficient conversion methods for bio-energy.

Table 12: Potential of agricultural land for energy crops in the BAU scenario

country	available land for energy crops in thousand ha and % of agricultural area							
	2010	%	2015	%	2020	%	2050	%
EU-27	26,427	13.7	27,788	14.4	29,418	15.2	38,462	19.9
Europe others	114,298	35.5	123,887	38.5	133,711	41.6	178,194	55.4
Europe	140,725	27.3	151,676	29.4	163,129	31.7	216,656	42.0
North America	96,968	20.1	90,913	18.8	85,804	17.8	65,571	13.6
Central America	249	0.2	-7,962	-5.7	-14,487	-10.4	-31,112	-22.4
South America	65,857	11.9	68,001	12.3	73,770	13.3	145,858	26.4
America	163,073	13.9	150,952	12.8	145,088	12.3	180,317	15.3
Australia	169,046	38.2	153,887	34.7	139,666	31.5	72,115	16.7
Oceania	13,426	75.4	13,429	75.4	13,440	75.5	13,570	76.2
Asia	-187,116	-11.8	-331,204	-20.9	-453,411	-28.6	-1,007,654	-63.5
Africa	-107,543	-10.5	-193,681	-18.8	-264,540	-25.7	-700,785	-68.2
sum of 133 countries	191,611	4.02	-54,941	-1.15	-256,629	-5.38	-1,225,783	-25.72

In the BAU scenario at the beginning of this decade extensive agriculturally utilised areas were available which were not required for food production. These non-required areas were used in a few countries for regenerative raw materials but predominantly turned over to fallow land due to politically prescribed obligatory set-aside or lack of economic viability with the agricultural prices prevailing at that time.

The available non-food potentials for the years 2010, 2015, 2020 and 2050 are shrinking so rapidly with time due to growing population and increasing per-capita consumption worldwide that by 2015, and in particular 2050, almost no further resources will be available for bio-energy and other non-food uses; this is unless higher increases in yield are developed and implemented on the limited available area than was assumed for the calculations. If the additionally required foodstuffs for 2010 are to be produced domestically, which is an assumption of the estimation method, then an area potential of 55 million ha will be short in 2015 and 257 million ha in 2020, in 2050 even more than 1,200 million ha.

Nevertheless, there are countries and continents which have considerable potential for agricultural raw materials and, over and above the domestic supply of the population with food can either convert these into bio-energy carriers or export them as agricultural raw materials or food goods. Since, at the same time the food supply is becoming increasingly scarce in some regions of the Earth, world market prices and agricultural trade will develop so as to ensure the basic supply of food in areas of the Earth receiving aid; although this will be at comparatively higher prices and with an increase in poverty and hunger. However, this scenario need not necessarily occur worldwide. A prerequisite for this is that efforts are made worldwide to break the current trends in food demand and food supply.

Basic scenario

The basic scenario differs from the BAU scenario by renouncing the conversion of forest areas. The forest area of the countries being studied is almost 5 billion ha. It is therefore slightly greater than the agriculturally utilised area. Whereas globally the agriculturally utilised area has slightly increased, the forest area has decreased by approximately the same order of magnitude. In Central America, the forest area has decreased rapidly in all countries except Cuba. In South America, particularly in Brazil which possesses almost 20% of the forest areas of the Earth, in the last 15 year almost 50 million ha of forest have been deforested. In Asia the forest area increased slightly overall with a rapid decrease in the countries of Indonesia, Malaysia, Myanmar and Cambodia.

As the figures in the following table show, forest clearing is taking place to a greater extent particularly in Brazil and Indonesia.

Table 13: Forest clearing from 1990 to 2005 in selected countries

country	forest area			
	1990 (1000 ha)	2005 (1000 ha)	rate of change 1000 ha	rate of change %
Brazil	520,027	477,698	-42,329	-8.14
Indonisia	116,567	88,495	-28,072	-24.08
Nigiria	26,951	16,584	-10,367	-38.47
Zimbabwe	27,671	17,540	-10,131	-36.61
Sudan	76,381	67,546	-8,835	-11.57
Myanmar	49,438	43,056	-6,382	-12.91
Mexico	89,721	84,146	-5,575	-6.21
Mongolia	17,756	12,640	-5,116	-28.81
Madagascar	34,840	29,892	-4,948	-14.20
Venezuela	59,552	55,082	-4,470	-7.51
Bolivia	65,268	61,213	-4,055	-6.21
Cameroon	39,303	36,003	-3,300	-8.40
South Africa	24,647	21,807	-2,840	-11.52
Ecuador	15,018	12,302	-2,716	-18.08
Cambodia	13,281	10,717	-2,564	-19.31
Honduras	7,656	5,358	-2,298	-30.02
Ethiopia	59,764	57,650	-2,114	-3.54
Chad	23,179	21,073	-2,106	-9.09
Philippines	12,804	10,773	-2,031	-15.86
North Korea	8,201	6,187	-2,014	-24.56

The reduction in forest areas in the range of less than 0.1% per year has certainly had an effect on the area potentials for non-food use. However, this effect has been over-compensated by the increase in agriculturally utilised areas. The results of this scenario show a substantial reduction in the area potentials for energy crop production compared with the BAU scenario which, in the year 2015, can lead to significant disturbances in the equilibrium between food supply and food demand. This can be attributed to the assumption that the fallow areas in the USA and in the EU will only be re-used up to 80% and all the other countries will only use 30% of the hitherto available areas which have been laid fallow, in 2010, only 60% in 2015 and only 75% in 2020 and 2050. As a consequence, it can be assumed that either the provision of supply will be changed by a significant increase in productivity or the demand for food will be changed by increasing prices and other circumstances. In 2020 there will be a considerable deficit in the agriculturally utilised areas for food production which comes about in small part by renouncing rainforest clearing and other clearing of forest areas.

In relation to the total available forest areas which are significantly greater than the agriculturally utilised area of the Earth, the proportion of forest clearing does not carry very much weight. However, this change in land usage is ascribed very great importance particularly with a view to climate change goals and ultimately the forest clearing in the countries principally making use of this account for a considerable fraction of the land area available in these countries. If the potentials for non-food use are considered, these are only slightly reduced by renouncing forest clearing.

In addition, these area differences are countered by the lost forest areas which play a more important role for climate protection than the newly acquired land areas.

Table 14: Potential of agricultural land for energy crops in the Basic scenario

country	available land for energy crops in thousand ha and % of agricultural area							
	2010	%	2015	%	2020	%	2050	%
EU-27	23,571	12.2	22,198	11.5	21,202	11.0	28,882	14.9
Europe others	51,526	16.0	29,536	9.2	23,288	7.2	76,477	23.8
Europe	75,097	14.6	51,735	10.0	44,490	8.6	105,359	20.4
North America	65,353	13.5	36,379	7.5	12,962	2.7	-15,523	-3.2
Central America	-14,422	-10.4	-31,159	-22.4	-43,675	-31.5	-76,974	-55.5
South America	28,262	5.1	7,477	1.4	-5,598	-1.0	-22,351	-4.0
America	79,193	6.7	12,698	1.1	-36,311	-3.1	-114,847	-9.8
Australia	151,610	34.2	126,591	28.6	106,305	24.0	33,682	7.8
Oceania	11,171	62.8	9,987	56.1	9,345	52.5	9,539	53.6
Asia	-238,612	-15.0	-412,495	-26.0	-556,152	-35.0	-1,181,896	-74.5
Africa	-156,753	-15.2	-271,501	-26.4	-365,481	-35.6	-885,991	-86.2
sum of 133 countries	-78,294	-1.6	-482,986	-10.1	-797,804	-16.7	-2,034,154	-42.7

Sub scenario 1 ("ecological sustainability")

Under this scenario, it is assumed that ecological goals in land cultivation and landscape utilisation are pursued more strongly throughout the world. In this case, change of pasture is renounced, the use of yield-increasing agricultural chemical aids is successively reduced and ecological cultivation is massively expanded. The reference for this scenario is the Greenpeace basic scenario. Compared the basic scenario the level of yield was reduced worldwide up to 2010 by 10%, up to 2015 by 20% and up to 2020 by 30%.

In addition to renouncing forest clearing, in the basic scenario there is no change of pasture land. In the following table the countries are shown which have implemented changing pasture land in the past to a greater extent. On renouncing change of pasture land, again the potentials for non-food production change only slightly. However, the climate change contribution is considerable.

Table 15: Development of grasland in selected countries

country	agricultural grassland areas			
	Ø 2002 - 2005	change rate per year in %	development 1990 to 2005	
			(1000 ha)	%
Australia	394,310	-0.50	-29,485	-7.48
Austria	1,864	-0.52	-147	-7.87
Belgium Luxembourg	596	-0.50	-45	-7.48
Croatia	1,512	-0.55	-125	-8.28
Cyprus	4	-1.03	-1	-15.44
France	10,014	-0.91	-1,361	-13.59
Germany	4,945	-0.74	-546	-11.04
Greece	4,600	-1.26	-866	-18.83
Hungary	1,061	-0.90	-143	-13.46
India	10,575	-0.73	-1,155	-10.93
Indonesia	11,194	-0.72	-1,217	-10.87
Ireland	3,122	-1.56	-731	-23.41
Israel	127	-1.19	-23	-17.80
Jamaica	229	-0.67	-23	-9.99
Japan	411	-1.24	-76	-18.59
Jordan	742	-0.53	-59	-8.01
Latvia	618	-0.59	-55	-8.90
Myanmar	314	-1.31	-62	-19.62
Peru	16,900	-0.58	-1,459	-8.63
Poland	3,396	-1.44	-733	-21.60
Rwanda	485	-3.38	-246	-50.65
Serbia Montenegro	1,846	-1.62	-449	-24.33
Slovakia	658	-0.63	-62	-9.45
Slovenia	302	-0.52	-24	-7.83
South Korea	57	-1.65	-14	-24.68
Sweden	505	-1.25	-95	-18.74
Switzerland	1,092	-0.51	-83	-7.58
the Netherlands	987	-0.77	-114	-11.51

The reference for this scenario is the Greenpeace basic scenario. The results show that as early as in 2010, there would be deficit for securing the food supply. With 72 million ha of agriculturally utilised area, however, there is a shortfall of only 1.5% to meet the food requirement. However, no more areas would be available for producing bio-energy carriers. In the case of arable areas, with 158 million ha there would be a larger deficit with a surplus of 86 million ha pasture area still existing. If the proportion of ecological cultivation and the simultaneous reduction in yield-increasing expenditure of agro-chemical aids is expanded up till 2015 to such an extent that the harvest yields account for 20% less compared with the base, there will be a shortfall of ca. 1% of the available agriculturally utilised area to meet the food requirement. With further increasing extensification and expansion of ecological cultivation, in the year 2020 there will be a shortfall of ca. 20% of the agriculturally utilised area and there would be no more potential at all for bio-energy carriers. In this context it should be noted that under the assumed general conditions food would be extremely scarce. This would have the result that either the pre-defined extensification would not progress so rapidly or disproportionately rapidly increasing food prices need to be reckoned on, which in turn would provoke a change in demand towards vegetarian food. This is because under this scenario the prices for refined products would increase significantly more strongly than those for vegetarian food.

Table 16: Potential of agricultural land for energy crops in the Sub 1 scenario

country	available land for energy crops in thousand ha and % of agricultural area							
	2010	%	2015	%	2020	%	2050	%
EU-27	20,243	10.5	15,988	8.3	11,636	6.0	2,311	1.2
Europe others	49,336	15.3	23,912	7.4	12,358	3.8	43,465	13.5
Europe	69,579	13.5	39,900	7.7	23,993	4.7	45,776	8.9
North America	62,593	13.0	30,017	6.2	1,337	0.3	-53,413	-11.1
Central America	-15,040	-10.8	-32,838	-23.7	-47,089	-33.9	-90,281	-65.0
South America	23,244	4.2	-3,919	-0.7	-26,306	-4.8	-91,864	-16.6
America	70,798	6.0	-6,740	-0.6	-72,058	-6.1	-235,558	-20.0
Australia	137,652	31.1	102,550	23.2	72,023	16.3	-61,414	-14.3
Oceania	11,143	62.6	9,903	55.6	9,164	51.5	8,906	50.0
Asia	-233,195	-14.7	-411,222	-25.9	-568,564	-35.8	-1,285,051	-81.0
Africa	-169,381	-16.5	-308,986	-30.1	-447,500	-43.5	-1,107,734	-107.8
sum of 133 countries	-113,403	-2.4	-574,595	-12.1	-982,941	-20.6	-2,635,075	-55.3

Sub scenario 2 ("change in eating habit")

With regard to the postulated relationship between extensification of production and changing eating habit towards vegetarian food ratios, in this scenario the influence of changed modes of behaviour is investigated in the area of food demand. Recommendations of the World Health Organisation for healthier eating only relate to those countries or population strata in countries having food deficiencies having extremely high per-capita food consumption. The feeding recommendations relate to the reduction in total energy consumption as well as restrictions in the consumption of free sugars and unsaturated fatty acids. For reasons of simplicity it was assumed for this scenario that the total energy consumption of the overfed population is reduced by a maximum of 30% and does not fall below a minimum of 850 grain units per capita per year. This means that for more than 70% of countries, in particular many African and Asian countries. The per capita consumption is not changed at all.

Table 17: Potential of agricultural land for energy crops in the Sub 2 scenario

country	available land for energy crops in thousand ha and % of agricultural area							
	2010	%	2015	%	2020	%	2050	%
EU-27	73,250	37.8	71,657	37.0	70,454	36.4	78,649	40.6
Europe others	68,626	21.3	49,037	15.2	44,996	14.0	116,983	36.4
Europe	141,876	27.5	120,693	23.4	115,450	22.4	195,633	38.0
North America	190,787	39.5	157,107	32.5	129,162	26.7	78,732	16.3
Central America	-855	-0.6	-12,995	-9.4	-21,083	-15.2	-28,021	-20.2
South America	97,750	17.7	77,940	14.1	65,732	11.9	59,998	10.9
America	287,682	24.5	222,052	18.9	173,811	14.8	110,709	9.4
Australia	226,297	51.1	199,458	45.0	177,362	40.0	94,022	21.8
Oceania	11,850	66.6	10,633	59.7	9,960	56.0	10,010	56.2
Asia	-238,085	-15.0	-410,351	-25.9	-550,548	-34.7	-955,218	-60.2
Africa	-156,753	-15.2	-271,501	-26.4	-365,481	-35.6	-884,204	-86.0
sum of 133 countries	272,866	5.7	-129,016	-2.7	-439,445	-9.2	-1,429,048	-30.0

The results show that the change of eating habit in the over-supplied countries will keep the food deficit in check even in the Greenpeace basic scenario. However, the supply deficits of the previously described scenarios cannot be completely compensated. In 2020 there will be a shortfall of ca. 9% area potentials and ca. 30% in 2050. These deficits primarily arise in Central America, Asia and Africa whilst the other regions of the world could use appreciable areas for bio-energy.

Sub scenario 3 ("ecological sustainability" and "change in eating habit")

As expected, again a fairly large deficit in area potential for bio-energy will be obtained assuming a combination of reduced eating level and use of agricultural chemical aids. By 2050 area potentials for non-food uses will decrease all the more significantly, the more the use of fallow land and the use of yield-increasing aids is renounced. The agricultural raw materials markets will naturally tend to compensate for supply and demand. Higher agricultural prices will increase the demand (compared with the calculations) and bring about a reduction in overeating on the demand side. Countries having a large agricultural surplus will retain area potentials for bio-energy. Whether they use them for this or for food exports depends on the future economic and political general conditions.

Table 18: Potential of agricultural land for energy crops in the Sub 3 scenario

country	available land for energy crops in thousand ha and % of agricultural area							
	2010	%	2015	%	2020	%	2050	%
EU-27	69,922	36.1	65,785	34.0	61,720	31.9	55,293	28.6
Europe others	66,285	20.6	43,441	13.5	34,451	10.7	85,869	26.7
Europe	136,206	26.4	109,227	21.2	96,171	18.7	141,161	27.4
North America	188,028	38.9	151,686	31.4	119,813	24.8	49,394	10.2
Central America	-1,472	-1.1	-14,574	-10.5	-24,200	-17.4	-39,801	-28.7
South America	92,732	16.8	67,249	12.2	46,795	8.5	-2,767	-0.5
America	279,287	23.8	204,362	17.4	142,408	12.1	6,826	0.6
Australia	212,339	47.9	175,505	39.6	143,298	32.4	-123	0.0
Oceania	11,822	66.4	10,556	59.3	9,795	55.0	9,433	53.0
Asia	-232,668	-14.7	-409,075	-25.8	-563,151	-35.5	-1,059,666	-66.8
Africa	-169,381	-16.5	-308,986	-30.1	-447,500	-43.5	-1,105,946	-107.6
sum of 133 countries	237,606	5.0	-218,412	-4.6	-618,978	-13.0	-2,008,316	-42.1

Summary of the scenario results

The projection of the area potentials in the BAU scenario for 2010, 2015, 2020 and 2050 clearly reveal that the area potentials for non-food uses are significantly reduced. By 2010 these will have melted away to about 5%, by 2015 to 1%, by 2020 to –3% and by 2050 to –26% of the agriculturally utilised area. That is to say, in 2020 assuming the future trend, it will no longer be possible to meet the food demand. However, there is only a 3% shortfall. By changing the demand behaviour, changing the production structure in favour of greater-yield crops and more intensive utilisation of yield-increasing potentials, this deficit can easily be eliminated. Since the shift of supply and demand will be accompanied by price increases in agricultural raw materials, corresponding effects will be exerted on agricultural supply and food demand, so that the global market will remain in equilibrium. However, equalisation between the continents and their countries will only come about if the EU, the other European countries, North America and South America use their agricultural surplus not for non-food uses, but make them available for export to the deficit countries of Asia and Africa. The differentiation of the area potentials according to grassland and arable land shows that in the period up to 2005 primarily arable areas were available in surplus. In 2020 grassland will still be available as area potential for non-food uses whereas arable areas will disproportionately enter into a deficit. In the BAU scenario either pasture will continue to be redevoted to arable land and to a greater extent or some of the food production which has hitherto come from arable land will be shifted to grassland. This is possible by reducing the cultivation of arable fodder crops in favour of grain, oil-producing plants etc. and greater production of silage and hay as well as utilising grassland as pasture.

For the interpretation of the prognosis results, it fundamentally holds that these should merely be considered as predicted values if the trends and assumed developments occur. If some countries having high area potentials for non-food use enforce the production of bio-energy carriers from a national viewpoint in order to meet supply goals, for example, North America, the equilibrium of supply and demand in the food sector can be appreciably disturbed.

4.2 Energy potentials

Based on the calculated needs and surpluses of agricltural area the country specific energy crop potentials are estimated in the following. The methodology and results are described in the following chapters.

4.2.1 Methodology

Sustainable energy crop production takes only place on the surplus area of arable land and grassland. As described in the previous chapter the needs and surpluses of agricultural area are estimated for all 133 countries. These areas are balanced between the countries of one group. Country groups are the EU-27, the other european countries, North America, Central America, South America, Oceania, Asia and Africa. A balance takes only place between these groups, because a world wide balance seems not to be realistic. In consequence of this balance process, the area surplus of one group can reduce maximum to zero. If a need of agricultural area exists in spite of the balance process, the energy crop potential is zero in the following calculations.

The surpluses of agricultural area are classified as arable land and grassland. On grassland hay and grass silage are produced, on arable land fodder silage and SRC are cultivated. The share of each energy crop culture in the considered years is listed in Table 19. This mixture of cultures is used for all scenarios. Based on Greenpeace' sustainable criteria for energy crop production which evaluate the production of energy crops for 1st generation biofuels on new agricultural areas unfavourable, no energy crops for the production of starch or oil were taken into account. Therefore green fodder silage and gras silage for biogas production, wood from short rotation coppice (SRC) and hay from grasslands for the production of heat, electricity and synthetic fuels (BtL, ethanol from lignocelluloses) are assumed. The country specific yield development like for the calculation of land availability in chapter 4.1 are taken into consideration.

Table 19: Assumed energy crops in 2010, 2015, 2020 and 2050

		2010	2015	2020	2050
arable land	green fodder silage	97 %	85 %	67 %	33 %
	short rotation coppice	3 %	15 %	33 %	67 %
grasland	gras silage	100 %	40 %	25 %	25 %
	hay	0 %	60 %	75 %	75 %

Production areas of SRC are assumed relatively high, since an increasing demand for energy crops for the solid fuel sector will be noted in future. From the technical point of view, wood presents itself as being of advantage for all combustion processes. Therefore a further result of the increasing demand for wood will be the establishment of short rotation coppices. These can very well incorporated into agricultural production systems, and they offer advantages in view of their extensively oriented form of cultivation compared to annual agricultural cultures.

In principle a distinct expansion of energy crop cultivation in tropical and sub-tropical regions must be expected. Based on climatic conditions, high yields at favourable production costs can be presented.

4.2.2 Results

The energy crop potential is calculated with the mass yield of energy crops and the corresponding energy content. The assumed mean energy content for biogas (less silage leakage) is 3,560 MJ/t, for wood 15,400 MJ/t and for hay 14,000 MJ/t. The calculated energy crop potentials are given in the following tables for the groups of countries. The country group potentials are listed in the annex.

Table 20: Energy crop potential in the BAU scenario (PJ for primary energy substitution)

BAU scenario	2010		2015			2020			2050		
PE substitution PJ per year	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
EU-27	2,530	130	2,609	748	11	2,466	1,886	0	2,586	6,565	0
Europe others	5,350	274	5,184	1,571	362	4,921	4,007	440	4,921	12,429	756
North America	10,750	469	9,901	2,423	0	8,220	5,548	0	5,359	13,663	0
Central America	0	28	0	0	0	0	0	0	0	0	0
South America	1,576	446	1,650	2,850	0	1,901	7,988	0	3,074	43,863	0
Australia	4,436	178	1,451	804	2,401	1,510	1,556	1,660	351	0	1,083
Oceania	1,079	16	509	98	588	453	252	614	432	831	567
Asia	0	0	0	0	0	0	0	0	0	0	0
Africa	0	0	0	0	0	0	0	0	0	0	0
Total	25,721	1,543	21,305	8,494	3,362	19,471	21,237	2,714	16,722	77,351	2,406

Table 21: Energy crop potential in the Basic scenario (PJ for primary energy substitution)

Basic scenario	2010		2015			2020			2050		
PE substitution PJ per year	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
EU-27	2,236	116	2,076	603	11	1,799	1,393	0	2,034	5,165	0
Europe others	1,939	85	512	96	321	158	0	487	1,500	3,121	756
North America	7,501	334	4,730	1,177	0	2,482	1,643	0	0	0	0
Central America	0	0	0	0	0	0	0	0	0	0	0
South America	1,010	143	449	343	0	0	0	0	0	0	0
Australia	3,354	77	1,159	0	1,191	487	0	1,501	351	0	1,083
Oceania	840	1	245	2	588	199	2	614	184	0	567
Asia	0	0	0	0	0	0	0	0	0	0	0
Africa	0	0	0	0	0	0	0	0	0	0	0
Total	16,881	756	9,172	2,221	2,112	5,125	3,038	2,601	4,069	8,286	2,406

Table 22: Energy crop potential in the Sub scenario 1 ("ecological sustainability")

Sub scenario 1	2010		2015			2020			2050		
PE substitution PJ per year	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
EU-27	2,026	112	1,639	482	0	1,163	909	0	784	3,125	0
Europe others	1,838	80	253	19	308	71	3	210	353	325	715
North America	7,317	324	4,188	1,033	0	1,605	991	0	0	0	0
Central America	0	0	0	0	0	0	0	0	0	0	0
South America	848	115	0	0	0	0	0	0	0	0	0
Australia	2,521	0	939	0	965	330	0	1,017	0	0	0
Oceania	827	1	222	2	531	171	3	529	184	0	567
Asia	0	0	0	0	0	0	0	0	0	0	0
Africa	0	0	0	0	0	0	0	0	0	0	0
Total	15,377	632	7,240	1,536	1,804	3,340	1,905	1,755	1,321	3,450	1,283

Table 23: Energy crop potential in the Sub scenario 2 ("change in eating habit")

Sub scenario 2 PE substitution PJ per year	2010		2015			2020			2050		
	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
EU-27	7,843	375	7,080	1,929	19	5,768	4,379	0	4,471	12,408	0
Europe others	3,472	171	1,445	367	349	812	508	537	2,500	5,492	975
North America	20,194	934	16,376	4,291	0	11,741	8,363	0	6,249	16,321	0
Central America	0	0	0	0	0	0	0	0	0	0	0
South America	2,991	761	2,585	3,747	0	2,246	7,170	0	2,548	23,256	0
Australia	8,089	521	5,297	2,288	1,200	3,172	4,217	1,660	758	2,998	1,083
Oceania	1,017	12	238	0	571	187	2	575	200	54	567
Asia	0	0	0	0	0	0	0	0	0	0	0
Africa	0	0	0	0	0	0	0	0	0	0	0
Total	43,606	2,774	33,022	12,622	2,140	23,926	24,640	2,773	16,726	60,528	2,625

Table 24: Energy crop potential in the Sub scenario 3 ("ecological sustainability" and "change in eating habit")

Sub scenario 3 PE substitution PJ per year	2010		2015			2020			2050		
	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
EU-27	7,409	362	6,555	1,798	0	5,244	3,964	0	3,741	10,812	0
Europe others	2,733	130	1,179	284	342	573	343	411	1,441	2,823	935
North America	20,092	921	15,765	4,071	0	11,049	7,859	0	4,894	12,676	0
Central America	0	0	0	0	0	0	0	0	0	0	0
South America	2,744	670	2,226	2,839	0	1,885	5,440	0	0	0	0
Australia	7,122	430	3,811	1,465	1,200	1,670	1,813	1,660	0	0	0
Oceania	901	4	236	2	566	183	3	565	184	0	567
Asia	0	0	0	0	0	0	0	0	0	0	0
Africa	0	0	0	0	0	0	0	0	0	0	0
Total	41,000	2,517	29,772	10,459	2,108	20,604	19,422	2,636	10,260	26,311	1,502

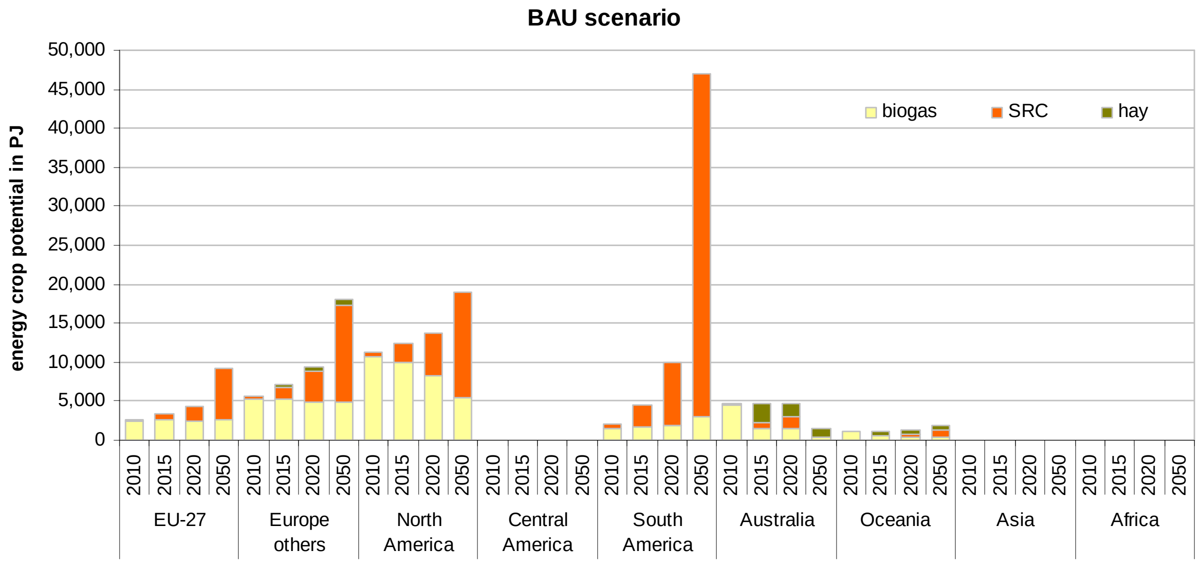

Figure 8: Energy crop potential in the BAU scenario (PJ for primary energy substitution)

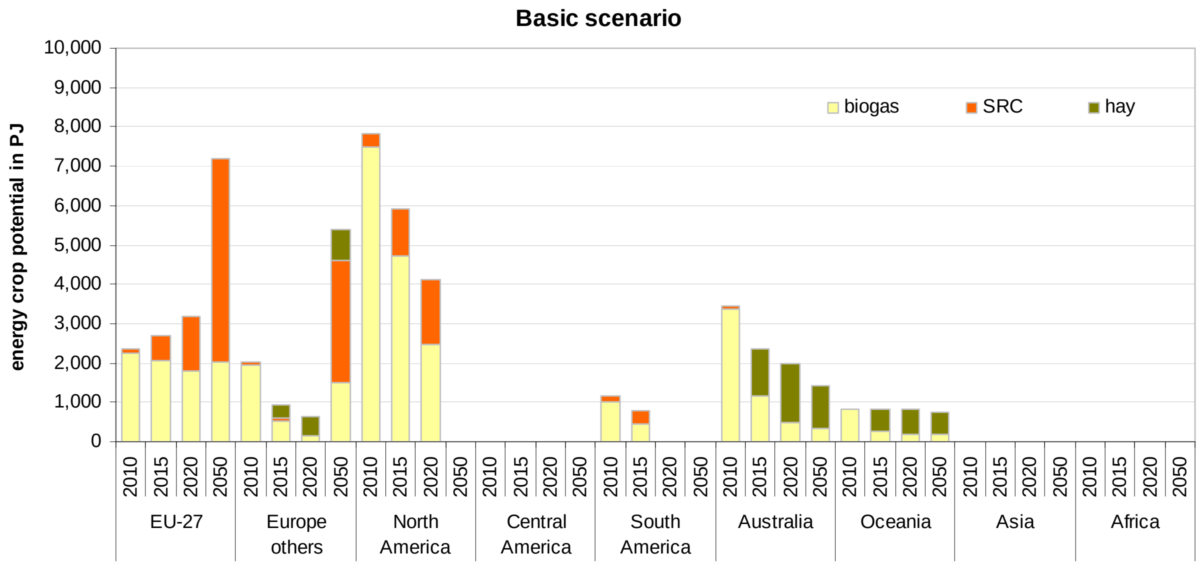

Figure 9: Energy crop potential in the Basic scenario (PJ for primary energy substitution)

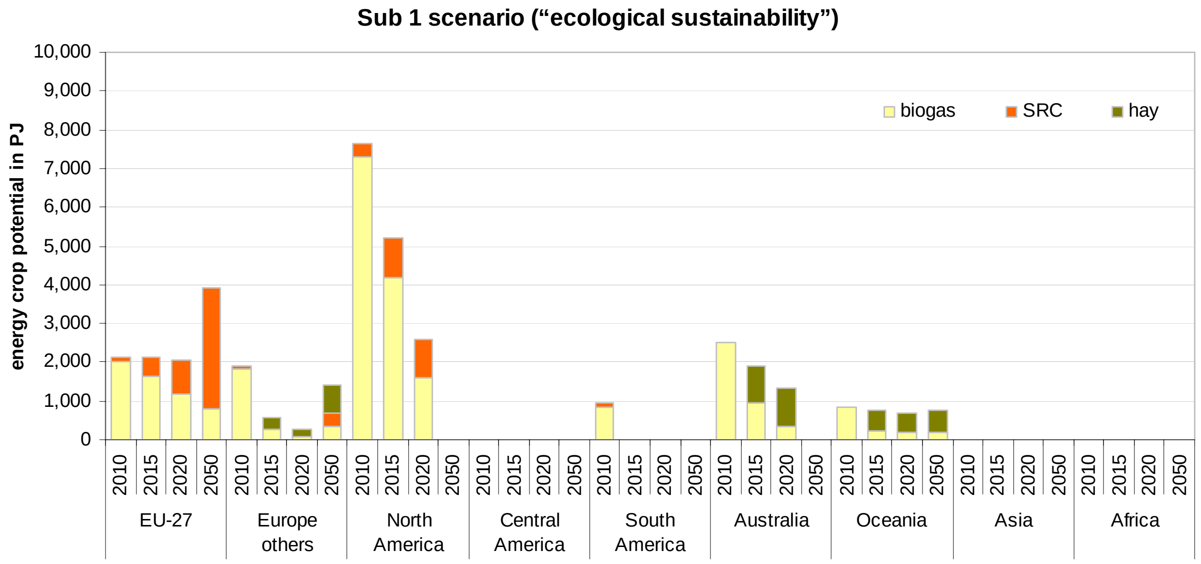

Figure 10: Energy crop potential in the Sub 1 scenario (PJ for primary energy substitution)

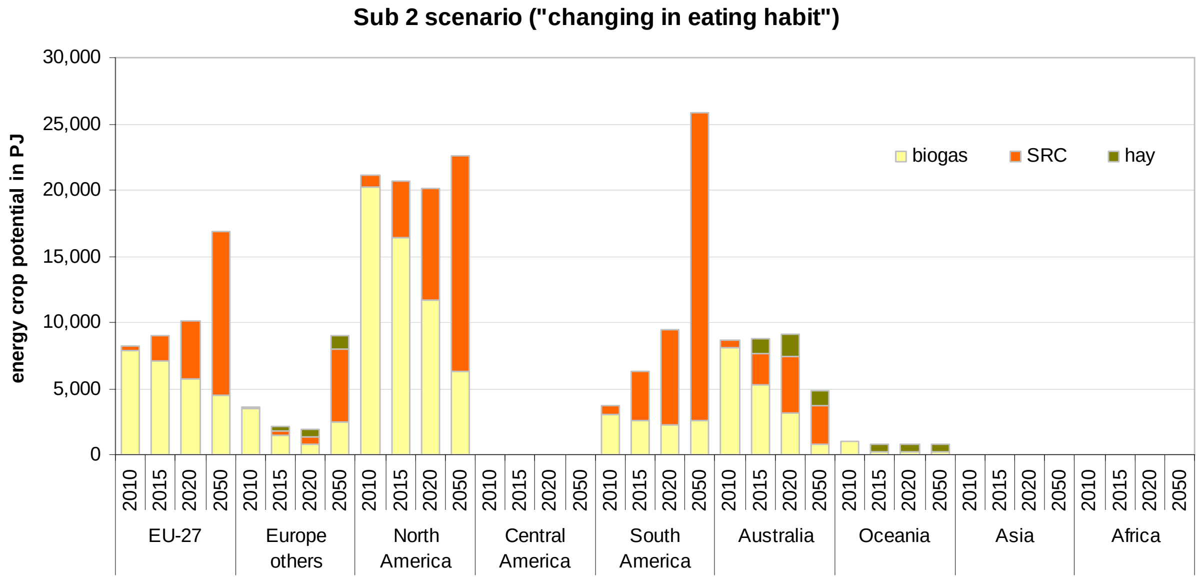

Figure 11: Energy crop potential in the Sub 2 scenario (PJ for primary energy substitution)

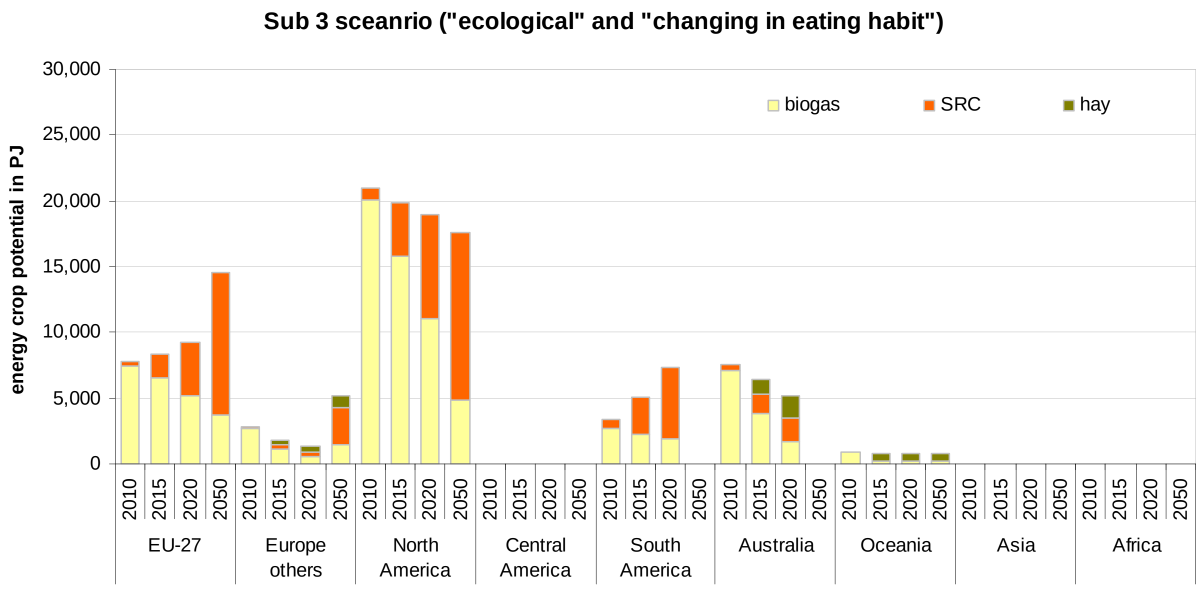

Figure 12: Energy crop potential in the Sub 3 scenario (PJ for primary energy substitution)

In comparison to the BAU scenario, potentials decrease clearly in the Basic and Sub 1 scenario, whereas the lowest potentials exist in the Sub 1 scenario. Here, the considerable higher demand of agricultural area appears by an ecological orientated agriculture with less fertilizer and less pesticides. The effects of an ecological orientated agriculture are lower specific yields and therefore a higher demand of area. In comparison with the Sub 2 scenario, considerable high energy crop potentials can be released by changing the nourishment to WHO level. This has an effect of less meat consumption and therefore a strong reduction of area demand for fodder production. Apart from South America in 2050, a nourishment of WHO level effects higher potentials than in the BAU scenario. Also in the Sub 3 scenario considerable potentials can be realized, in most cases even higher than in the BAU scenario. The most important country for the differences between the scenarios in 2050 is Brazil. In the BAU scenario big agricultural areas are released by deforestation. Whereas in the Basic and Sub 1 scenario this deforestation does not occur anymore. Therefore no agricultural area for energy crops is available. In contrast high potentials are available in the Sub 2 scenario as a consequence of the reduced meat consumption of the Brazilian.

Because of high population and low quantity of agricultural area no area surpluses for energy crop production are available in Central America, Asia and Africa. However, the EU, North America and Australia have relatively stable potentials.

To achieve a comparative overview beyond the worldwide and country specific energy crop potentials, a translation in MJ per inhabitant takes place. These results are visualised in worldwide maps. Exemplary maps for the Basic and Sub 3 scenario for the years 2020 and 2050 are given in the following. These two scenarios are of particular importance, since the Basic scenario shall be the "minimum solution" for the future agriculture. The Sub 3 scenario demonstrates the development of an ecological orientated agriculture. But such a changing in agriculture is only realistic, when the behaviour in nourishment is changing. Otherwise the higher demand of agricultural area can not be compensated.

Maps of all scenarios are listed in the annex.

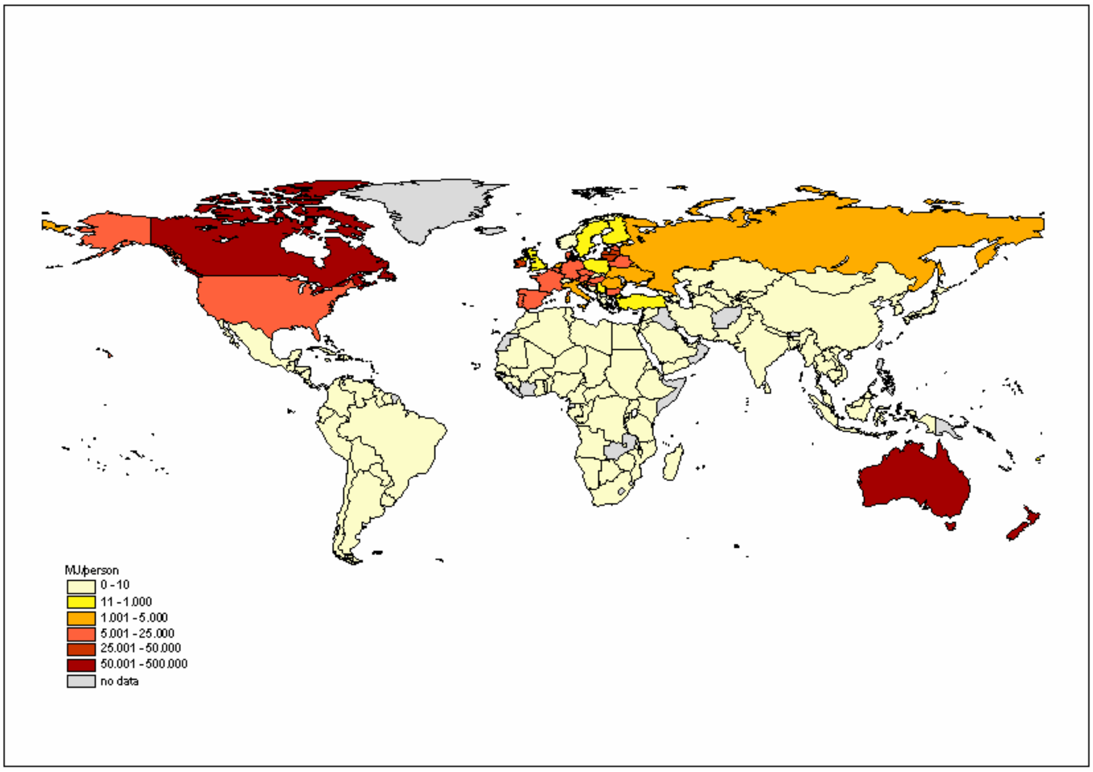

Figure 13: Energy crop potential of the Basic scenario 2020

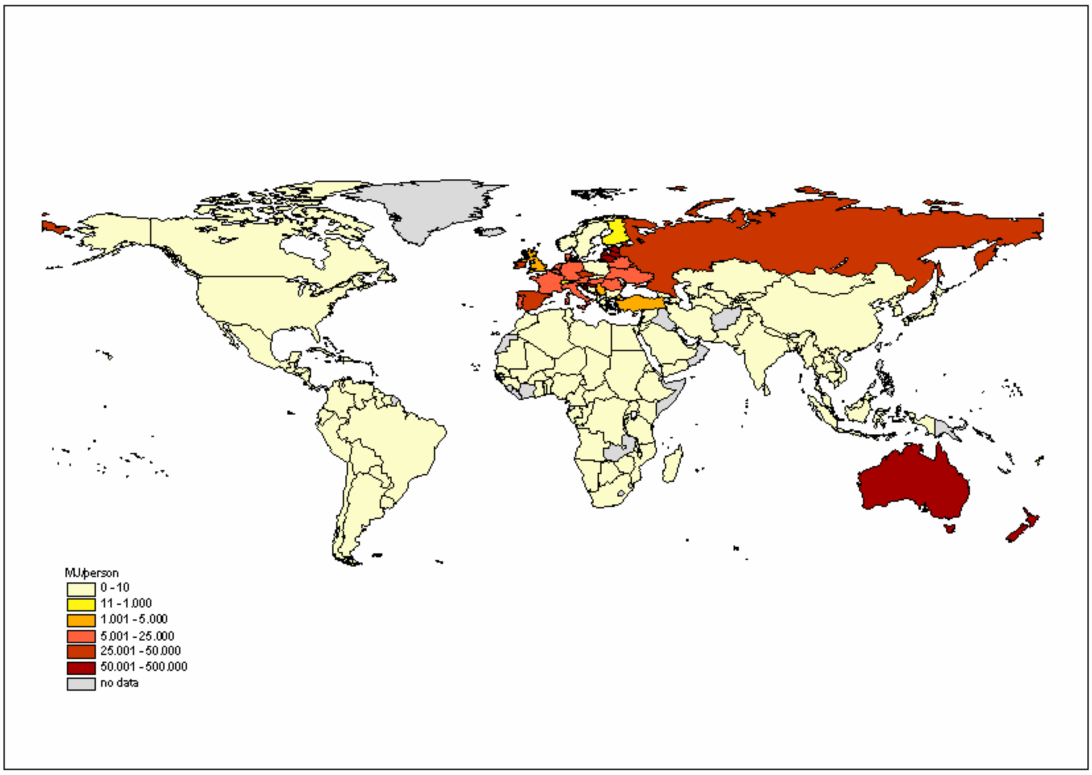

Figure 14: Energy crop potential of the Basic scenario 2050

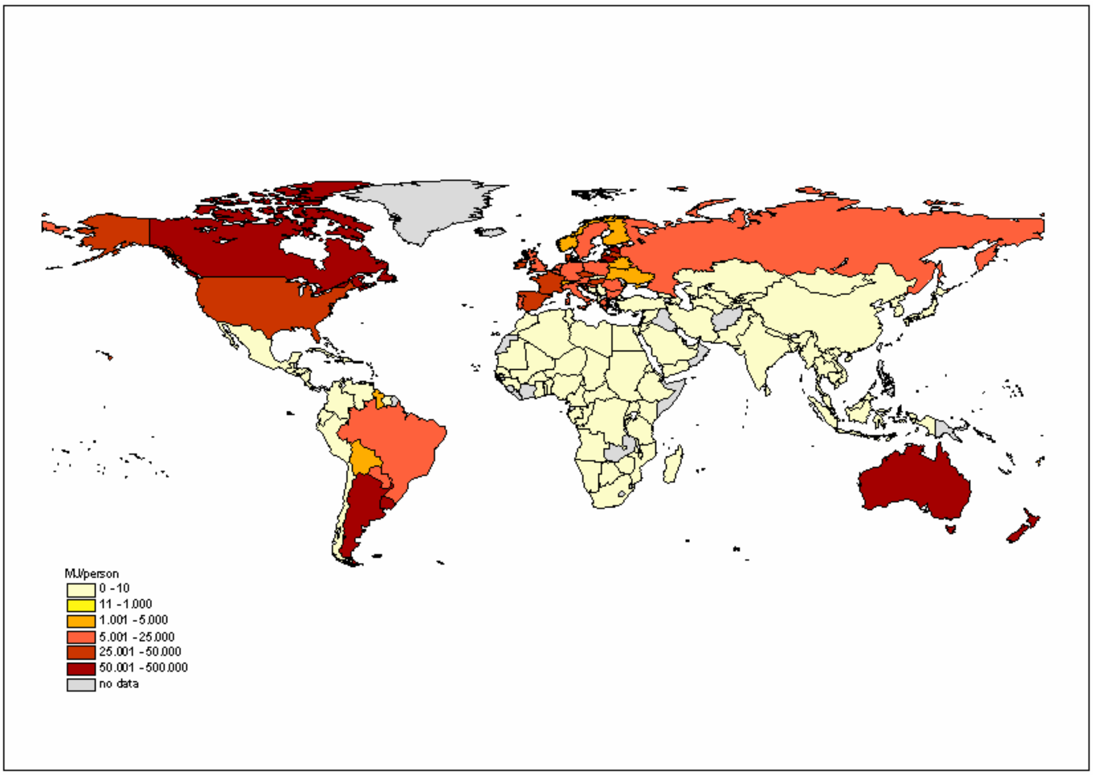

Figure 15: Energy crop potential of the Sub 3 scenario 2020

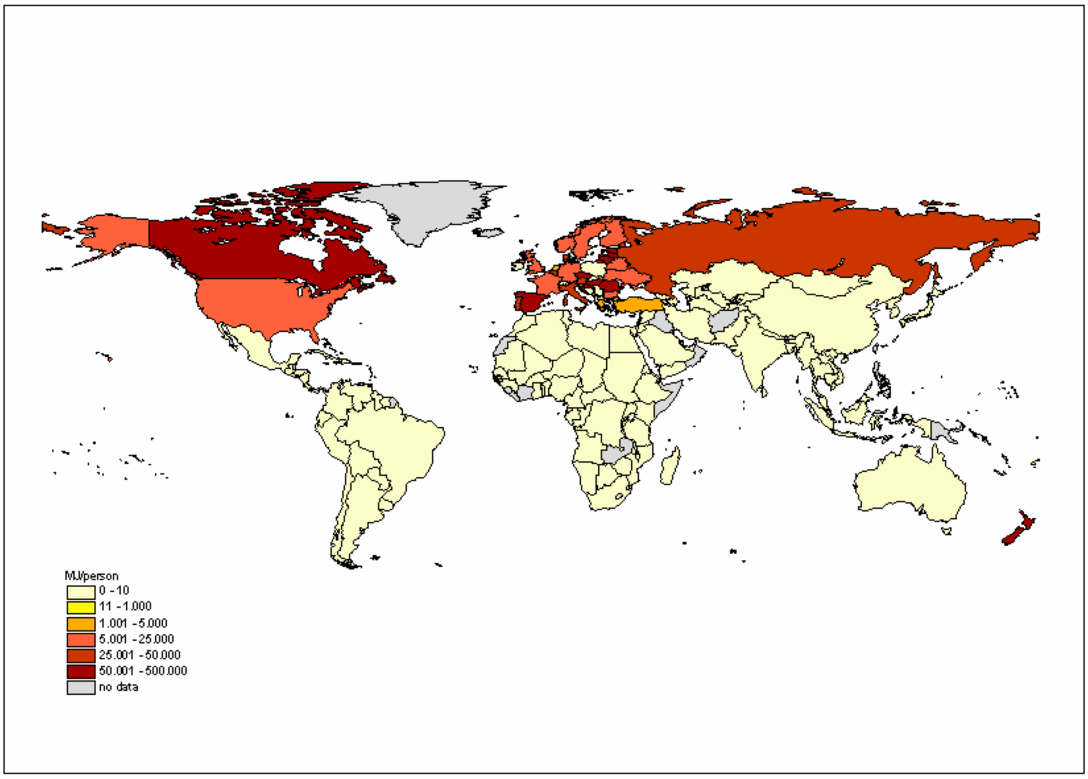

Figure 16: Energy crop potential of the Sub 3 scenario 2050

5 Remote sensing in biomass potential research

In order to supplement the current used methodologies of the potential-survey and to generate data with high topicality, research activities exist in the field of remote sensing and biomass potential-survey in the recent past. Aim of this methodology is the surface-specific investigation of the crop cultures, whereby the current biomass potentials can be calculated. In the following chapter the “state of the art” of remote sensing with the focus on biomass detecting for potential analysis is described.

5.1 Introduction

Biomass is defined as mass of all organic matter per unit area at a particular time and is given in the units *g/m²* or *kg/ha* /25/. Biomass is a renewable energy source that can be used as fuel in solid, liquid and gaseous form or to provide heat or electricity /26/. The term biomass refers to all non-fossil organic material that has an intrinsic chemical energy content. This includes trees and plants, forestry, crops, organic wastes, and wastes from agriculture, agro-industry and municipalities. The term ‘biomass potential’ includes wood, plants, and animal wastes /27/.

In order to calculate biomass potentials, it is necessary to determine the above-ground biomass (AGB). This can be achieved with a high degree of accuracy with some approaches. Direct volume measurements (volume, weight etc.) is one method of AGB estimation. This may be achieved through destructive or non-destructive sampling. Another method of AGB estimation is the calculatation of biomass with the help of models using data received from measurements, statistics or remote sensing /25/.

Traditional techniques based on field measurements provide the most accurate method of AGB estimation. However, in some cases this method is not feasible due to the remoteness of a location, time consumption and the labour intensive processing. Therefore, in recent years remote sensing techniques have been increasingly implemented for AGB estimation as an alternative to conventional methodologies /28/. Some of these approaches will be discussed in this report.

Accurate biomass estimation is dependent on the quality of the vegetation parameter data that deciphered from satellite-based images. In order to understand these techniques, a brief introduction into remote sensing (RS) is provided.

5.2 Principles of Remote Sensing

5.2.1 Overview

In remote sensing (RS), the real world is captured and reflected in data. The goal of RS data is to create an attribute table describing the real world as accurately as possible. Broadly, RS is defined as the collection of information about an object without being in physical contact with the object. The term remote sensing is restricted to methods that employ *electromagnetic energy* as the means of detecting and measuring target characteristics. Figure 17 shows the simplified workflow for RS data extraction.

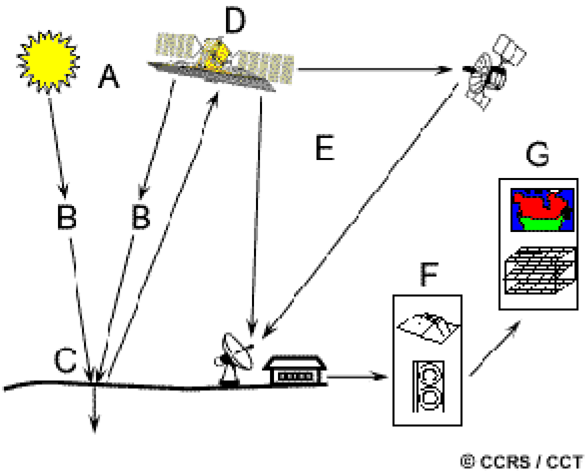

Figure 17: workflow of RS data extraction /48/

The first requirement of RS is to illuminate a target with an energy source. This is done in two manners, passively (passive sensors that use the backscattered radiation of the sun) or actively (active sensors that have an own energy source). All electromagnetic radiation has fundamental properties and behaves in predictable ways according to the basics of wave theory.

The electromagnetic spectrum ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). The electromagnetic spectrum, as shown in the left half of Figure 18, comprises a number of *atmospheric windows* that allow multispectral detection of reflected light and emitted thermal energy from space (white bars in the right half of Figure 18). It is within these atmospheric windows, that specifically the red, near-infrared and thermal regions, are of highest interest for RS techniques.

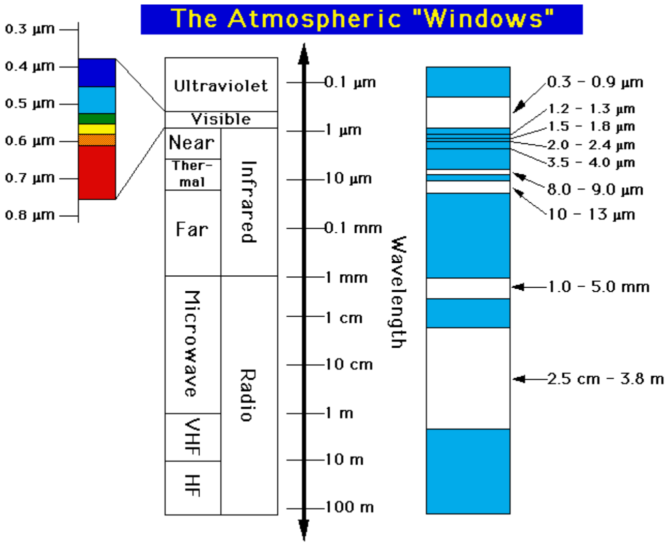

Figure 18: Atmospheric windows /49/

When electromagnetic energy impinges on a target different interactions can be measured. Possible interactions are:

- scattering
- reflection
- absorption
- refraction
- transmission
- emission.

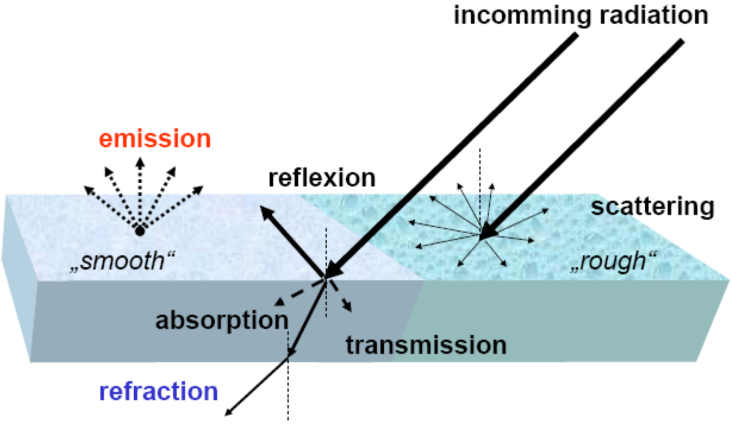

Figure 19: Target interactions /49/ (changed)

These interactions are specific for every target and can be measured by RS techniques. Specifically, the information carrier in RS is the signature of the specific electromagnetic radiation that is detected by the sensor. The information extraction is done by analysing these signatures. Overall, five different signatures can be distinguished:

- ***spectral*** (information about pigment- and water status, cell structure)
- ***angular*** (information about plant architecture, canopy structure)
- ***textural*** (information about pattern of similar frequency inside a structure)
- ***polarisation*** (information are not sufficient explored, to low experience)
- ***temporal*** (information about change of signatures between two or more observations).

Vegetation analyses of multi- and hyperspectral images are normally carried out by analyzing the spectral signature of objects. Spatial and temporal characteristics of an object are used to underpin the received results, but the two additional known signature types, angular and polarization, are in optical RS still in research.

The *multispectral approach* is based on the different reflectance behaviour of unvegetated and vegetated surfaces. Unvegetated surfaces like soils, bare rocks, etc., show a nearly linear and slow increase in reflectance from the blue to the short wave infrared (SWIR) region. In the contrary, vegetation’s reflectance is characterized by typical absorption features in the blue and red region as well as by a steep increase, the so-called "red edge" towards the NIR (see Figure 20).

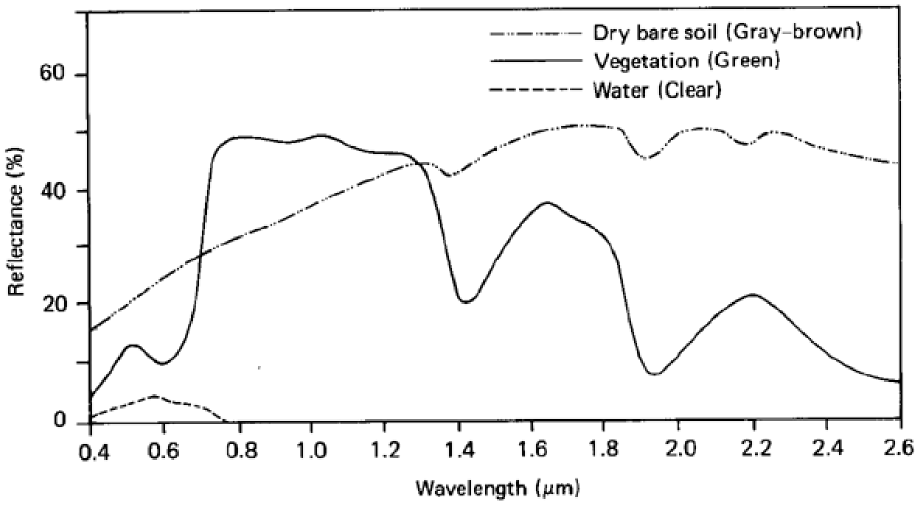

Figure 20: Spectral signature of water, vegetation and soil /50/

5.2.2 Active and passive sensors

In general, active and passive systems can be distinguished. Passive systems use only the naturally present electromagnetic radiation such as solar or thermal radiation, while active systems generate radiation artificially and use the back-scattered signal for remote sensing. Sensors can be situated in space or on aerial platforms and are defined by characteristic bands, the spectral regions, where they can absorb incoming radiation /31/. The most important spectral regions for RS purposes are 0.4 µm – 14 µm in the optical range and 2 mm – 0.8 m in the microwave range /29/.

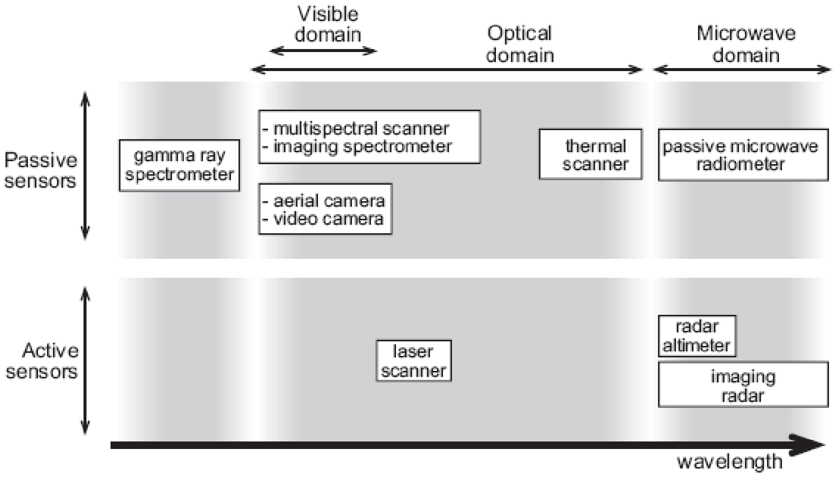

Figure 21: Overview of active and passive sensors /47/

Passive sensors

Multispectral and hyperspectral scanner - measure the reflected sunlight in the visible and infrared spectrum. This is done simultaneously for several wavelength bands (intervals of EM spectrum). Every wavelength band is then saved as a grey value picture. When bands are assigned to visible colours (blue, green, red) and combined, colour or false colour images can be created.

Thermal scanner - measures thermal data in the range of 8 – 14 µm. The wavelengths in this range are directly related to the temperature of an object (thermal IR). Mostly used for meteorology systems.

Microwave radiometer - records the emitted long wavelength EM energy (1 cm to 1 m). This is the brightness temperature and is used to measure the blackbody radiation.

Active sensors

RaDAR (Radio Detection And Ranging) - operates in the 1cm to 100 cm wavelength range (microwaves). The sensor sends out an active signal (pulse) and the object emits the echoes. Calculations of the range between sensor and target are possible in this way. This system works at day and night and can penetrate clouds. RaDAR is not susceptible to atmospherically affects. An additional advantage of RaDAR is the use of the polarization signature for analysis.

LiDAR (Light Detection And Ranging) - operates in the 1.5 micrometer region. The sensor emits laser light in visible or NIR wavelengths as a series of pulses (1000 per second) to the surface. The measured parameters are the travel-time for the round-trip and the returned intensity. This system can also operate at day and night. Furthermore, laser light penetrates certain targets, making tree heights and canopy condition assessment possible.

SoNAR (Sound Navigation And Ranging) - sound waves are the information carriers in SoNAR technology. SoNAR is used to map sea floor topography. This system is also functions day and night.

5.2.3 Available satellites

Remote sensing satellites are normally configured to operate several sensor systems, and the various sensor types are constructed to detect different objects, e.g. RaDAR systems, optical sensors or thermal sensors. The size of the region that can be observed and the resolution of the image are determined by the optic in use, which also controls the repeat cycle, i.e. the time needed to record every place on earth one time (see Table 25).

Satellites can be distinguished by the resolution of the recorded images. Fine resolution data have a resolution less than 5 m, i.e. one pixel shows 5x5 m of the earth’s surface. Common spaceborne examples are *IKONOS* or *QuickBird* images. Medium spatial resolution ranges between 10 and 100 m. They are typically provided by the *Landsat 7* satellite and used most frequently for research problems. Coarse spatial resolution is usually more than 100 m and is often used on national, continental or global scales because no detailed picture of the landscape exists. These data are still very limited because of the commonly occuring mixed pixels and the significant differences between field measurements and pixel size in the image.

Table 25: Most common commercial satellites /31/

Satellite	Resolution	Repeat Cycle
Landsat 7 Enhanced Thematic Mapper Plus (ETM+)	15 m	16 days
SPOT-5	10 m	26 days
IKONOS-2	0,82 m	14 days
Quickbird	0,82 m	20 days
OrbView-3	1 m	16 days

Disadvantages of high-resolution images are that they are large (amount of data) and a long time is needed to process the data. Furthermore, high costs for image purchase have to be considered which often times renders them cost ineffective for mapping large areas /28/. The differences in resolution are illustrated in **Fehler! Verweisquelle konnte nicht gefunden werden.**, there the problem of mixed pixel as well as that the image use needs to be weighed against the spatial resolution requirement can be seen.

Figure 22: Satellite images of the same spot in an urban area with a resolution ranging from 0.6 m (Quickbird), 2.5 m (IKONOS) up to 15 m (Landsat 7) /33/

Figure 23 shows an overview of the NASA satellites available for environmental research. Furthermore, the ESA has four additional environmental research satellites, *Envisat*, *ERS*, *MetOp* and *Proba*. In addition, there are four other important research satellites that are not controlled by NASA or ESA, and these are *QuickBird*, *OrbView*, *Ikonos* and *Spot*.

Figure 23: Overview about the NASA satellites for environmental research /51/

The following section briefly discuses the most important satellites for environmental research.

Envisat – launched in 2002; the largest Earth Observation spacecraft ever built; carries 10 optical and radar instruments that provide continuous observation of the Earth's land, atmosphere, oceans and ice caps; operated by ESA. /53/

ERS (European Remote Sensing) – launched in 1991; was ESA's first Earth Observation satellite; carries radar instruments that measure ocean surface temperature and winds. /53/

MetOp (Meteorological Operational) – launched in 2006; Europe's first polar-orbiting satellite; it monitors the climate and has improved weather forecasting; operated by ESA. /53/

Proba (Project for On-Board Autonomy) – launched in 2001; one of the most advanced small satellites ever flown in space; main load is the image spectrometer CHRIS with multiple view angles possibilities; operated by ESA. /53/

Aqua (originally called EOS PM-1) **–** launched in 2002; carries six state-of-the-art instruments that observe the Earth's oceans, atmosphere, land, ice and snow covers, and vegetation; it provides high measurement accuracy, spatial detail and temporal frequency and is operated by NASA. /52/

Earth Observing-1 NMP (New Millennium Program Earth Observing-1) **–** launched in 2000; carries a hyperspectral instrument that is the first of its kind to provide images of land-surfaces in more than 220 spectral colors; operated by NASA. /52/

Landsat 7 **–** launched in 1999; carries the Enhanced Thematic Mapper Plus (ETM+) that provides well-calibrated, multispectral, moderate resolution, substantially cloud-free, Sun-lit digital images of the Earth's continental and coastal areas with global coverage on a seasonal basis; operated by NASA. /52/

NOAA-N (NOAA Polar Operational Environmental Satellites N Series) **–** launched in 2005; collects information about Earth's atmosphere and environment; helps to improve weather prediction and climate research across the globe; operated by NASA. /52/

SPOT-5 (Systeme Pour l'Observation de la Terre) **–** launched in 2002; carries different multispectral sensors for environmental research; images are widely available; operated by Spot Image Group. /54/

Ikonos-2 **–** launched in 1999; has a spatial resolution of 3.28 m in the multispectral mode; images are widely available; operated by GeoEye Inc.. /55/

QuickBird **–** launched in 2001; has a spatial resolution of 2.44 m in the multispectral mode; images are widely available; operated by DigitalGlobe. /56/

OrbView-3 **–** launched in 2003; has a spatial resolution of 4 m in the multispectral mode; used for agriculture and forestry research; images available from 2007 with degraded quality; operated by Orbital Image Corporation (now: GeoEye Inc.). /55/

5.3 State-of-the-art of satellite-based biomass potential estimation

A significant amount of biomass estimation research has been conducted in the last few years, especially relative to forests (see selected projects in Table 26). Forest biomass is one of the most important parameters for accurate global carbon stock and potential biomass modelling, but yet it is also one of the most poorly understood parameters. However, satellite approaches for biomass estimation are still in an experimental stage and its accuracy is uncertain. Nevertheless, several methodologies have provided promising results for AGB estimation and biomass monitoring.

Table 26: Selected projects of biomass estimation using remote sensing

Institution	Research objectives
Center for Remote Sensing on Land Applications (ZFL), Bonn University	land use classification
FAO	forest monitoring
	land use classification
Friedrich-Schiller University Jena, Institute for Geoinformatics	biomass determination with LIDAR-sensor and the model Carbon-3D
NASA's Goddard Space Flight Center	LIDAR and Radar measurements of forest biomass and comparison of these methodologies
German Aerospace Center (DLR)	determination of forest biomass with Pol-InSAR technologies
	modelling of NPP and NEP with the model BETHY-DLR
Indian Institute of Remote sensing	determination of forest biomass with Landsat TM data
Center for the Study of Institutions, Population, and Environmental Change (CIPEC), Indiana/USA	land use classification, forest monitoring, monitoring of changes in natural resources

In general, there is a difference between the direct and indirect RS approaches of biomass estimation. The direct approach calculates information about biomass directly from the satellite signal using long-wavelengths. This has significant potential for forest biomass mapping as displayed in /34/ and /35/.

Indirect methods use models that correlate known variables and biophysical parameters, for example tree height, with the amount of biomass in a specific area /36/. Coniferous forests have been especially interesting for study purposes because of their simple stand structure and tree species composition. Tropical forests with their complex stand structure and enormous variety of species on the other hand are difficult for AGB estimation /28/.

5.3.1 Spectral classification of land use

The specific reflection of objects is essential for distinguishing objects in RS images. Green plants, for example, have a higher reflection especially in the region of visible green light wavelengths (~ 0.5 µm). This is explained with the specific reflection behaviour of green leaves and is related to vitality and water supply within the plants. This aspect is very helpful for image interpretation and recognition of potential vegetation damage. This aspect also helps in that hyper- and multispectral images are used to create classification maps.

The classification of land use for relatively homogenous vegetation determination, such as forest or grassland, can be done with data such as *Landsat Thematic Mapper* images. Afterwards these classes are attributed to average biomass densities and so the total biomass of the area can be calculated. The classification of vegetation types must be based on parameters that can be easily observed from RS data, such as crown cover and major species. Furthermore, to obtain reliable results it is necessary to collect field data for ground truthing purposes in order to validate the calculated values /36/ and to calibrate the parameters.

Figure 24 shows a map with a typical land use classification of *Landsat ETM+ images*. A characteristic problem of this type of image (medium resolution of 30 m) is that it is impossible to obtain more detailed information about land use. In addition, there are numerous classification errors associated with this resolution, as is seen as with red areas in Figure 24. These red areas are classified as streets, but in reality some of the red areas are residential or sealed plains.

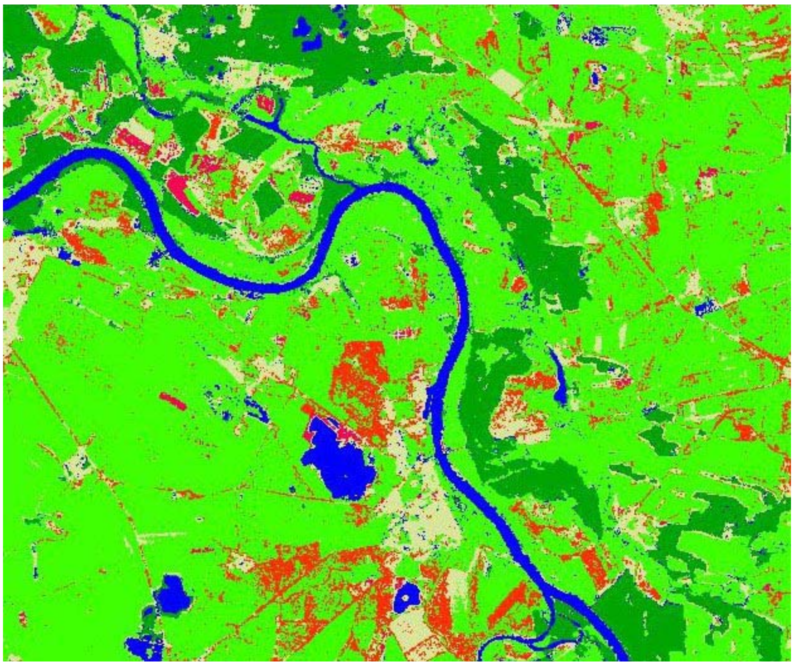

Figure 24: Land use classification (red=streets; green=agricultural land; beige=residentialarea; blue=water), spatial resolution=30m /38/

For the assessment of biomass potentials, it is crucial to obtain detailed information about the current land use. Multi-temporal analysis with time series of satellite or airborne images is one method of obtaining this information. This method also allows for phonological difference observation and interpretation. However, this kind of image interpretation is usually labour and cost intensive. The Center for Remote Sensing on Land Applications (ZFL) of the Bonn University is currently researching the possibility of an automated classification for high-resolution satellite images using specialized software. The best results are obtained by combining multiple sensors and time sections. Regardless, it is still difficult to obtain a differentiated distinction of cultivation types. If any land use information is available, the semi-automated processing may be applied, but until now a fully automated classification is not possible /37/.

The amount of vegetation biomass is directly correlated with the vegetation productivity, and therefore of the net carbon exchange between atmosphere and photosynthesis active plant tissues. Considering this, estimations of absorbed light with satellite-based algorithms and observations of vegetation structure in terms of age and types lead to estimations of the net primary production.

As a result, some approaches exist (Table 27) that convert optical satellite observations into estimations of net primary production using the correlation between light absorption and net carbon uptake by vegetation. It is important to note that the accuracy of this approach is limited because the effects of temperature and soil moisture. These effects influence the correlation and derivation of biomass from these parameters. However, applications that use satellite images ensure spatial and temporal details, and are more accurate than the aforementioned method. /39/.

The value of canopy reflectance can be *causally* related to the leaf area index. Based on this it is possible to use remote sensing canopy reflectance models for estimating foliage, woody biomass and productive potential /41/.

Table 27: Selected projects of other approaches to estimate biomass

Institution	**Research Objectives**
Friedrich-Schiller University Jena, Institute for Geoinformatics	determination of biomass using NDVI
Indian Institute of Remote sensing	forest biomass estimation with leaf area index (LAI)
German Aerospace Center (DLR)	modelling of NPP and NEP with the model BETHY-DLR

Vegetation vitality can also be observed using the *Normalized Difference Vegetation Index* (NDVI). Healthy canopies of green vegetation have a distinct interaction with certain portions of the electromagnetic spectrum. There are absorption peaks in the red and blue areas of the visible spectrum, while the green area of the visible light spectrum is reflected by chlorophyll, thus leading to the characteristic green appearance of most leaves. At the same time, the near-infrared region of the spectrum is strongly reflected by the internal structure of the leaves. NDVI is expressed as the difference between the near infrared and red bands normalized by the sum of those bands. Again, ground-based inventory data are necessary to correlate the seasonally integrated measures of satellite-observed vegetation greenness /39/. Figure 25 shows the NDVI value of vital green vegetation (left) and dying vegetation (right) where the higher the value (up to 1.0) the healthier the vegetation.

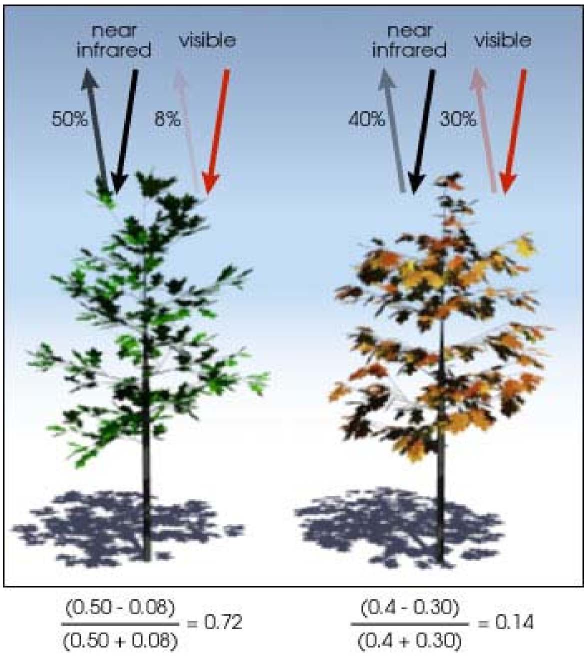

Figure 25: NDVI of vital and dying green vegetation /47/

The NDVI value increases with the amount of present vegetation, but saturates at a certain amount e.g. at dense forests. Moreover, the NDVI is affected by soil background in the vegetation signal. Due to this, different alterations of the NDVI with a correction factor are normally used. Every day, three successive *NOAA-17* satellite scenes are used to derive a synthesis product in stereographic projection for Europe and North Africa. Weekly and monthly thematic synthesis products are derived from this daily operational product, at each step becoming successively free of clouds.

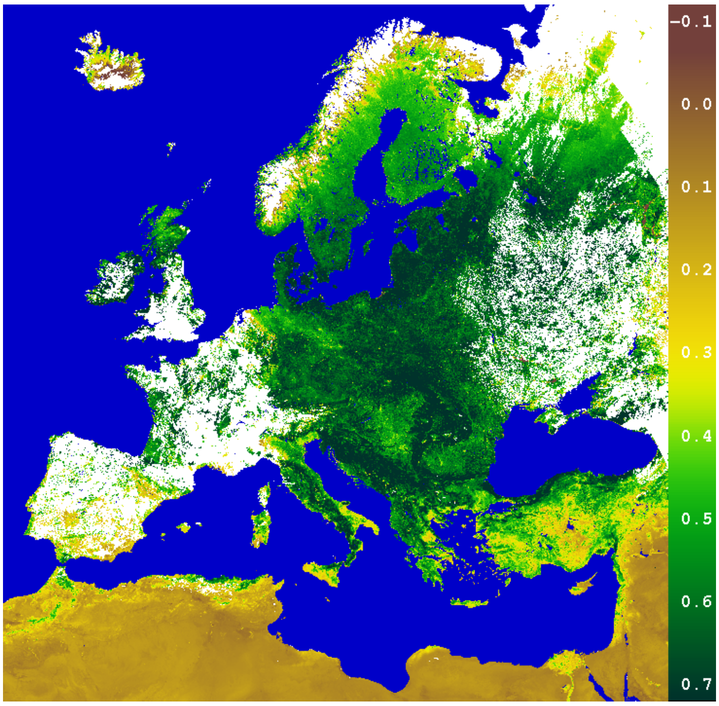

Figure 26: NDVI overview map of Europe (1-week composite, 26.05.2008 to 01.06.2008) /44/

Figure 26 shows a map of Europe depicted by NDVI. Brown colours signify low values of NDVI and consequently little vegetation. In this case, the brown areas may be desert. Green colours, on the other hand, signify high values of NDVI. The green areas signify higher amounts of vegetation, such as forests.

An indirect measurement of biomass using NDVI is reported by /42/. A statistically significant relation between biomass and seasonal greenness totals was generated because NDVI increases with higher amounts of biomass and varies with latitude, showing the largest values in temperate latitudes. Possible errors can be atmospheric effects, calibration errors in satellite data and the use of relatively simple models that were used to convert greenness data to biomass values. The differences for forest area estimations between RS and inventory approaches are not easily reconcilable because of definition issues /42/.

In Figure 27 biomass data derived from the NDVI of different countries are plotted. In this chart the total woody biomass compared to cumulative growing season NDVI is shown. The correlations of these parameters are easily recognized in this chart. The anomalies 1 and 2 represent high biomass of old growth forests in some Pacific North-Western States in the

United States (situations where the satellite NDVI saturates). The data shown in Figure 27 were transformed and used to estimate a statistically significant relation between biomass and seasonal greenness totals (without the anomalies). The correlation coefficient has been calculated ($r^2 = 0.43$) and this result indicates that biomass increases with NDVI. Nevertheless, there needs be a stronger correlation in order to have a high confidence in the amount of biomass that results from these calculations. /42/. Furthermore, only green vegetation is detected by NDVI so corn or dried vegetation would not be detected /39/.

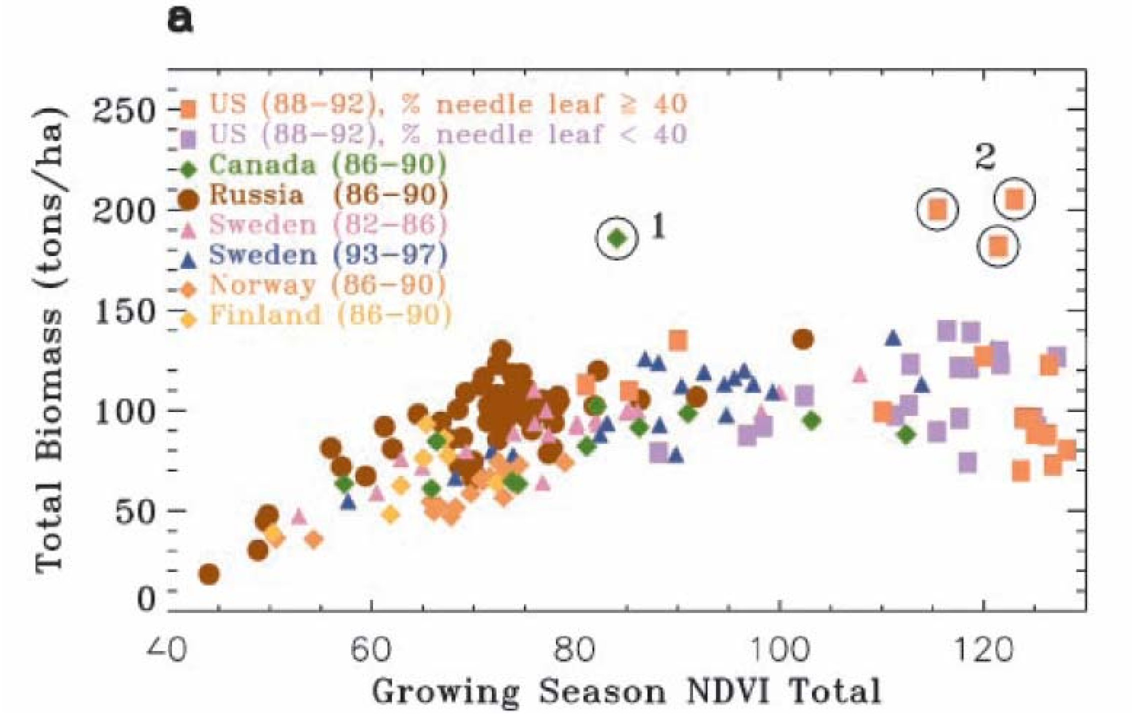

Figure 27: Plot of total woody biomass versus cumulative growing season NDVI /42/

The DLR works with time series of NDVI, land surface temperature and sea surface temperature to model NPP and NEP with *BETHY-DLR* (*Biosphere Energy Transfer Hydrology Model*). Inputs for this model are weather data such as radiation, temperature and precipitation, as well as information about land cover, soil types and *leave area index* (LAI). As result, net primary production (NPP) and net ecosystem productivity (NEP) can be modelled. Furthermore, maps of the annual biomass potential of a special region can be generated by the fusion of NPP with statistical data and allocation parameter /43/.

5.3.2 RaDAR approach

Microwaves are commonly utilized in RS. In the case of forestry, radar images can be used to obtain information about forest canopy, biomass and different forest types. Radar images also allow the differentiation of land cover types, such as urban areas, agricultural fields, water bodies, etc. For agricultural crop identification, radar images that employ the use of different polarization (mainly airborne) are quite effective. It is crucial for agricultural applications to acquire data at a certain point in time (season) to obtain the necessary parameters. This is possible because radar can operate independently of weather or daylight conditions.

The typical used wavelength regions for RaDAR approaches are:

X-Band:	2.4 – 4.5 cm
C-Band:	4.5 – 7.5 cm
L-Band:	15 – 30 cm
P-Band:	60 – 300 cm.

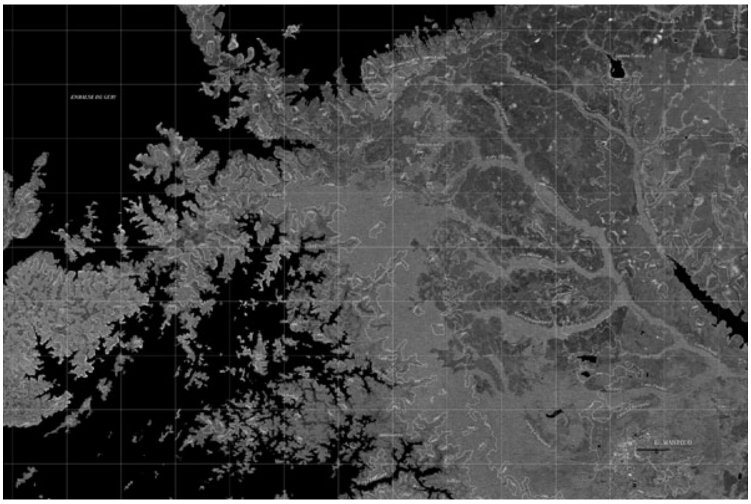

Figure 28: X-band Radar Map of the area El Manteco in Venezuela /32/

Figure 28 shows a characteristic radar image that was taken in the X-band, making it possible to detect geological and surface structures. Longer wavelength radiation infiltrates deeper into the ground. This fact can be used for some special RS techniques. SAR (Synthetic Aperture Radar) is a special sensor technique that makes it possible to record radar images on satellites An important enhancement of this radar technique is InSAR (Interferometric Synthetic

Aperture Radar). This technique is used to model heights of different objects on earth's surface, such as trees /31/.

Another methodology that utilizes radar is Polarimetric radar (PolSAR). This technique exploits the fact that different materials depolarize the electromagnetic radiation in a different way. As a result, objects can be distinguished and their spatial structure can be recognized. Hence, they can be mapped in 3D and their volume can be determined.

SAR, as explained above, is a specific airborne or spaceborne radar technology. The lowest frequency that can be used for SAR technology is P-band (60 – 300 cm). It is especially sensitive to forest biomass up to a saturation level of 100 to 150 t/ha and therefore this technology is used especially for forest monitoring /36/.

With SAR-technologies, biomass can be modelled using vegetation height information with regression analyses application of allometric height-biomass. This technique also requires additional data, such as stem diameter and volume /39/. One example for measuring vegetation heights is Polarimetric Interferometry L-Band SAR (Pol-InSAR). The German Aerospace Center (DLR) has developed a radar sensor with this technology and is currently on the Japanese Satellite *ALOS* (Advanced Land Observing Satellite) which was launched in 2006. With this methodology it is possible to model tree height and calculate biomass indirectly /35/. A significant problem of this methodology is that the data saturates at a certain density of biomass e.g. in tropical forests /28/.

5.3.3 LiDAR approach

LiDAR Sensing is another methodology that determines biomass indirectly. This is an active sensor that uses an artificial laser beam which irradiates the earth. When the rays meet the ground, they are backscattered and subsequently sensed by the detector. This technology also uses differences in reflectivity in very fine spectral bands /29/.

There are two major advantages of laser ranging compared to microwave radar: 1) high energy pulses can be generated in short intervals and 2) highly directional light rays can be emitted by using small apertures. The latter is possible because of the short wavelength of lasers (10,000 to 1,000,000 times shorter than microwave). The result has a much higher ranging accuracy. For example, the study area total ABG for study /39/ could be predicted from airborne LiDAR that has derived metrics with r² values up to 0.96 on biomass levels of 1300t/ha. This approach far exceeds the capabilities of radar technologies.

Large-footprint LiDAR appears to have the potential for tropical and temperate forest biomass estimation and a range of vegetation parameters, such as:

- vegetation height
- vertical distribution of intercepted surfaces
- sub-canopy topography
- biomass
- crown volume
- stem diameter
- basal area
- forest age

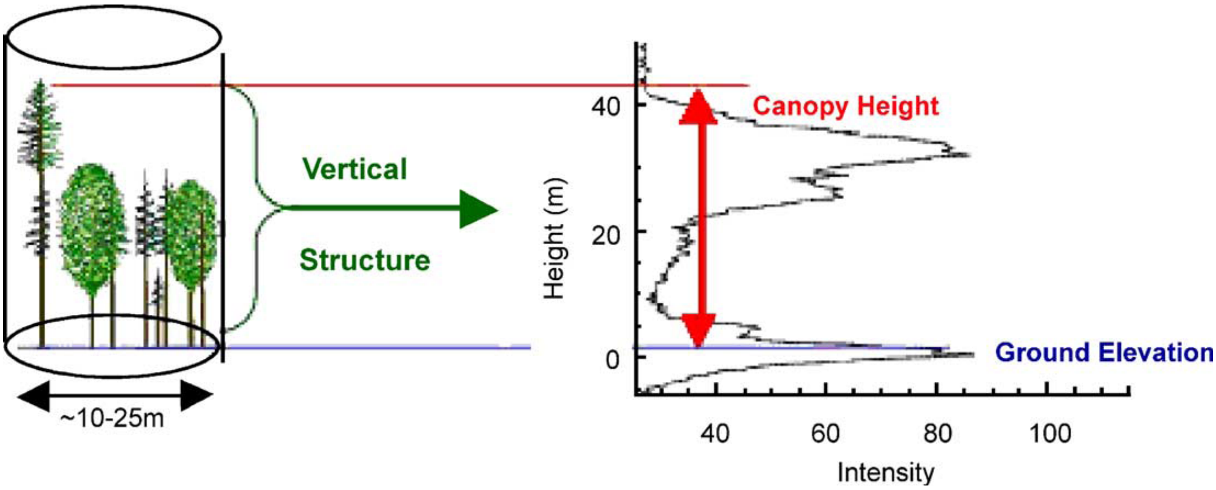

Figure 29: Retrieval of vertical forest structure by LiDAR remote sensing /39/

Since it is critical to precisely identify the top of the canopy and ground reference level for accurate parameter assessment, LiDAR remote sensing is a breakthrough technology for the determination of important forest structure features. Direct information of vegetation height, vertical structure and the sub-canopy topography can be obtained from the waveform information (see Figure 29). It is essential to achieve an accurate retrieval of vertical forest parameter since these are the measurements by which other biophysical characteristics are modelled. AGB is commonly modelled using the height information by performing regression analyses or applying allometric height–biomass relations.

/39/ reports the findings from the model Carbon-3D which attempted to map height profiles and reflectance to retrieve biomass. Carbon-3D works with a simultaneous operation of a LiDAR with a multi-angle imager, which provides BRDF information (Bidirectional Reflectance Distribution Function). The result is a combined information in fine-scale structure of the canopy and direct determination of biophysical properties, such as vegetation height, vertical structure of intercepted surfaces and sub-canopy topography of surface targets. The extrapolation of point measurements can be done to obtain complete spatial coverage. Again, it is imperative to collect ground truth data for calibration and verification purposes /39/.

When compared to SAR-technologies, LiDAR has proved to be the most effective sensor to provide biomass potential estimates. Generally, LiDAR clearly defines the top of the canopy and the ground. This produces a direct physical measurement, canopy height, which is highly correlated with biomass. Although SAR-sensors are capable of making the same or similar measurements, there may be inaccuracies in the magnitude of several meters which can cause significant errors in the estimations for biomass /40/.

5.3.4 Combined approaches

In the recent years there has been significant research that investigated the implementation of the combined methodologies for biomass estimation. These approaches use the advantages of different methods that can produce a more accurate estimation of the AGB. One of the auspicious approaches is the combination of RaDAR and LiDAR technology for determining the vertical and horizontal structure of forests and estimation of the AGB.

The DESDynI mission /45/ attempted to provide previously unavailable information about terrestrial ecosystems worldwide. In particular, the DESDynI mission will enable much improved estimates of terrestrial carbon sources and sinks by providing the data required for two information types: (1) the distribution of aboveground woody carbon stocks over the world’s forests, and (2) the distribution of terrestrial carbon sinks and sources resulting from forest disturbance and recovery.

The mission consists of utilizing orbital platform(s) with two active remote sensing sensors: (1) an imaging Synthetic Aperture Radar, SAR, operating at L-band frequency (1.25 GHZ, 26 cm wavelength) in fully polarimetric and interferometric (INSAR) capability, and (2) a multi-beam LiDAR operating at 1064 nanometer. The sensors provide complementary information on the forest structure and biomass. The polarimetric InSAR measurements provide all-time imaging capability to measure forest height and biomass and to quantify the area and intensity of vegetation disturbance and the rate of recovery. The multi-beam LiDAR sensor is capable of sampling the vegetation height and vertical structure with high vertical and horizontal resolution and precision. Synergism of these active sensors to achieve the required science measurements and accuracy is an important element of the DESDynl mission concept.

Another auspicious approach is the integration of LiDAR with hyperspectral imagery for AGB estimation, which is implemented in the research of /46/. Improvements of 8-9% across all forest conditions were seen in the coefficients of determination for measurements of AGBM, BA, and QMSD through the use of integrated data. Estimates of error dropped by 5-8% for the same measures. Moreover, this synergetic use of hyperspectral and waveform LiDAR data enable the creation of maps for predicting species abundance patterns. This provides a level of detail on the spatial dynamics and variability seen in forest structure not readily accessed through typical, ground-based approaches to forest sampling.

5.4 Software, costs and image provider

There are several software providers and RS images in Germany. Some of them are listed in Table 28, all of which provide software for visualization and processing of air- and spaceborne images. Furthermore, some offer special features such as classification tools and the possibility to process LiDAR and SAR data.

According to an NOAA sponsored research by Global Marketing Insights, Inc., the most commonly used software among Asian academic groups involved in remote sensing are as follows: ESRI 30%, ERDAS 25%, ITT ENVI 17%, MapInfo 17%, and ERMapper 11%. Among Western Academic respondents as follows: ESRI 39%, ERDAS 27%, ITT ENVI 17%, MapInfo 9%, and AutoDesk 7%.

Table 28: Selected provider of software for processing of remote sensing images

Provider	Software	Features
CGI-Systems www.cgisystems.de	Geomatica	visualize, analyse and process satellite images and geographical information in general
	EarthView	visualize and use SAR data, can be used for SAR-Interferometry
	Geomatica LidarEngine	visualize, analyse and process LIDAR-data
Geosystems www.geosystems.de	ERDAS Imagine	supervised and unsupervised classification
Terrasolid www.terrasolid.fi	Terrascan	visualize and use LIDAR-data
ITT www.itt.com	ENVI	supervised and unsupervised classification

Table 29 shows a selection of satellite images and aerial photographs providers. Additionally, the provider Infoterra offers Land Cover Services i.e. they provide land cover information. This information has an accuracy of more than 80% and is updated every 2 to 5 years.

Table 29: Selected provider of air- and spaceborne images

Provider	Kind of images	Spatial resolution
Geocontent www.geocontent.de	optical Landsat images	15 m
	aerial photographs	-
Infoterra www.infoterra.de	radar images	up to 1 m
Rapideye www.mdafederal.com	optical and radar images	up to 0.6 m

Costs for images could only be determined for images provided by Geocontent. They offer optical *Landsat* images with a spatial resolution of 15 m with the size of 1° x 1° for 125 USD. Prizes for high resolution (up to 0.6 m) data e.g. of the satellite *QuickBird* from the provider Rapideye are available for at least 22 USD per km².

Overall, it is difficult to provide costs estimations for image data. Costs comparisons for image data can only be compared when calculated for a specific project with specific data requirements. Existing data from the archive are cheaper than data that have to be speacially ordered. Another reason for caution, pricing for different image data qualitiy (processing level) exist. The costs of vertical aerial photographs depend on the size of the area, the photo scale, the type of film and processing used and the availability of aerial reconnaissance companies. Under European conditions the costs of the aerial photography ranges from 5 Euro/km² to 20 Euro/km² /47/. The cost of optical satellite data varies from free (public domain) to 45 Euro/km² /47/. Usually, the images either have a fixed size, or a minimum order applies.

Low resolution data (*NOAA AVHRR*) can be downloaded for free from the Internet. Here the *EOS Data Gateway Center* of the NASA provides these images with spatial resolution of 250, 500, or 1000 m per pixel. Medium resolution data (*Landsat*, *SPOT*, *IRS*) cost in the range of 0.01 Euro/km² to 0.70 Euro/km² /47/. High resolution satellite data (*Ikonos*, *SPIN-2*) cost between 15 Euro/km² and 45 Euro/km² /47/. For *Ikonos* derived information products prices can go up to 150 Euro/km².

5.5 Discussion

With RS, it is possible to take images of all regions of the world in regular intervals. The first dates back to the 1960s when the first satellites were launched. One advantage of remotely sensed data is that they are available in digital format, which enables rapid processing. Furthermore, they allow a synoptic view and the repeat cycle for data collection is low depending on the chosen satellite.

With some technologies presented above, e.g. SAR, it is also possible to quantify forest biomass in t/ha. Deciduous and coniferous forests can be distinguished with a high degree of accuracy what can be helpful to calculate biomass potentials. For reliable results, the use of high-resolution data is required, and it is important to note that this type of data requires a large amount of storage capacity and processing time. Moreover, high resolution may not be a cost effective option for large areas because these image types are cost intensive /28/.

Medium or coarse spatial resolution data sets need less storage capacity and processing. Due to mixed pixel appearance with this type of data, accurate AGB estimation is difficult. Additionally, spectral and radiometric resolution (e.g. value saturation) is limited. Data fusion of optical and radar data may provide a potential solution for this resolution problem; however, there is a lack of research in this area and more research is necessary for reliable results.

Qualitative and quantitative errors can also arise in rugged and mountainous areas because of topographic factors such as slope, which can affect vegetation reflectance. In addition, many different factors, especially clouds, can adulterate the reflected radiation signal (see Figure 30). These errors can be minimized by advanced methods for radiometric and geometric image correction as well as adjustment of the readout parameters from ground truthing.

RS biomass measuring methodology is limited due to the weak or medium correlation of measured variables with biomass and as a result, selecting the proper variables is difficult. In addition, accuracy is a significant problem because of possible discrepancies between field measurements and estimation results /28/. Biomass calculations for areas with heterogeneous vegetation are still not accurate, because currently measurements cannot handle complex stand structure. Thus, the accurate estimation of biomass of heterogeneous forests is more dependent on field measurements. Conversely, satellite images provide information about infrastructure, cities etc. as well as information about vegetation and biomass. By comparing various satellite images from multiple years, it is possible to observe trends in vegetation development.

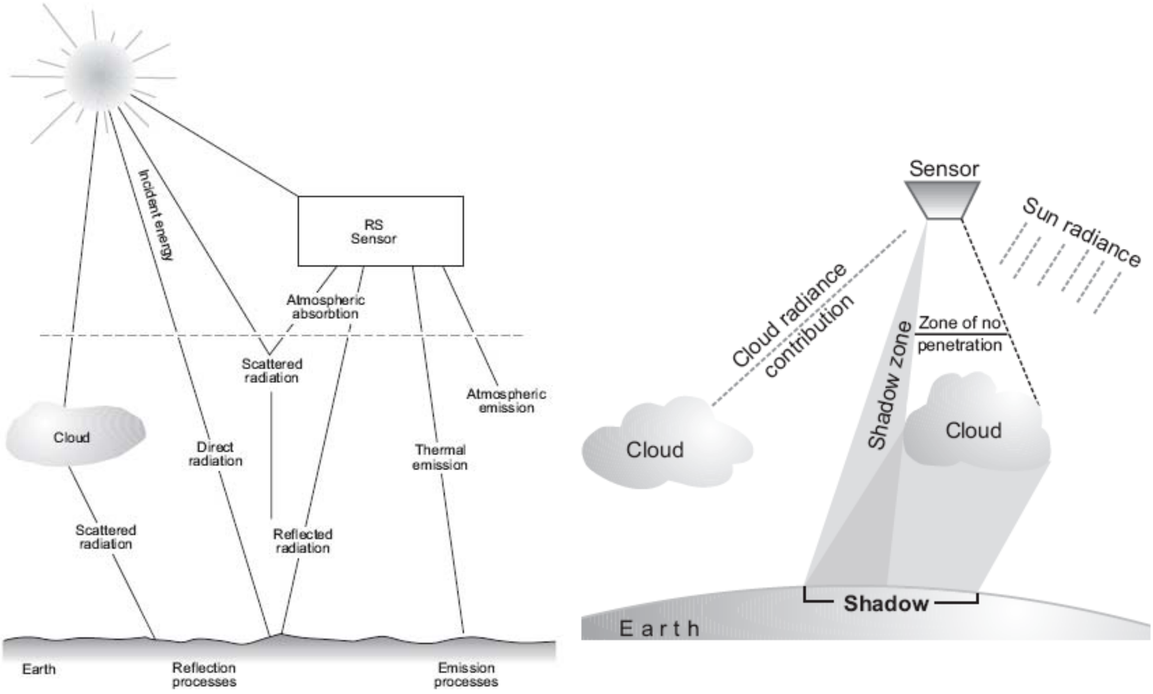

Figure 30: Topographic and other factors that can affect the amount of reflected radiation /47/

There is a large body of vegetation studies that have emphasized leaf biochemistry and structure, and canopy structure. Biophysical models for leaf constituents are currently available as are soil-vegetation models. Estimates of plant material and structure and biophysical parameters include: carbon balance, yield/volume, nitrogen, cellulose, chlorophyll, etc. The leaf area index and vegetation indices have been extended to the hyperspectral domain and remain important physical parameters for characterizing vegetation. Vegetation indices methods have been successfully field tested and as a result they have been proven to be accurate for biomass estimation of forestland.

5.6 Conclusion and outlook

As illustrated in this report, several institutions and universities are currently conducting research in order to improve the feasibility of measuring biomass with RS. In contrast, the possibility of potential biomass estimation is not adequately discussed in current research due to the problems of exact differentiation of land types on a global scale and the extreme costs for a medium resolution global research. Furthermore, it is difficult to provide qualitative statements for biomass values in special areas. There only quantitative information can be given, which is not sufficient for the assessment of biomass potentials.

Almost all approaches presented in this report are still in the experimental stage. Therefore, they do not have a high degree of accuracy nor can they be validated. Furthermore, these methodologies are work intensive, since they implement complex models or need ground truth data calibration. Exacerbating the situation, collecting required field data in remote regions can render project inapplicable or too cost and time intense. Currently, there is not a simplified methodology available, especially for extremely large geographical areas, In the near future, there is potential for semi-automated classification but this process will still require a specialist for processing and appropriate satellite images are still too expansive.

Currently, it is possible to attain the following results using RS for the purpose of biomass potential calculation on a global scale:

- information about the amount of green vegetation biomass using the NDVI
- NDVI comparisons over the time can help to estimate crop yields, landscape changes, land use changes, and climate changes
- the classification of agricultural crop type
- coniferous and deciduous forest differentiation
- vegetation health and damage determination
- sharp land use map (on lot scale) creation

It is not possible to predict future developments in biomass estimation due to the rapidly evolving field and technologies. However, the trends are as follows:

- development of sensor types that have not been previously used in space. For example, no P-band radar has been used in space. P-band has a longer wavelength (30 cm to 100 cm) than the radar systems used before and penetrates deeper into the soil, which means it may offer an unprecedented view on the subsurface
- higher spatial resolution (1-meter detail), higher spectral resolution (more than 100 bands), higher temporal resolution (global coverage within 3 days), and higher radiometric resolution (simultaneous observation of dark and bright targets)
- new systems may offer multi-frequency, multipolarization and multiple look angles (Radarsat-2/SAR, ALOS/PALSAR). Many of the current satellite have improved pointing capabilities, which allows faster revisits, meaning the same area can be observed twice within a couple of days rather than a couple of weeks
- one of the bottlenecks in RS has always been the capacity of the downlink channel. Basically, the amount of image data that could be sent to the ground was limited by the microwave channels that were used. The use of modern laser optical communication channels may give rise to an unprecedented flow of data to the Earth
- stiff competition on the RS market has caused a significant drop in price. Also, the quality of free data sources has improved considerably. When beginning a project, it is advisable to first check for free and low-cost data sources before spending large amounts of money on commercial data
- the trend in airborne INSAR is towards multi-frequency and multi-polarization systems. The advantages of a long-wave-band (L or P) are that they can penetrate canopies and will probably result in a ground surface height map in dense forest. The use of combinations of short wavebands (X or C) with long wavebands enables bio mass estimation. The use of longer wavelengths with better coherence behaviour, such as L-or P-band, offers the possibility of an analysis of long-term processes, even in vegetated areas.

One project that has significant potential, is the *Earth Explorer Missions* of the ESA Living Planet Program. The seventh mission bears the name *BIOMASS* and carriers special equipment for biomass estimation in global scale. Unfortunately, this mission is planed for the year 2014/15. Another already launched project is the *ALOS* satellite which carries a new Pol-

InSAR instrument has the capability for global biomass estimation. The testing and calibration of this sensor is still in process.

In conclusion, it can be said that one of the major applications of RS in environmental resource management and decision making is the detection and quantitative assessment of green vegetation. The advantage of using remotely sensed data for above-ground biomass estimation are:

- data can be repeatedly collected over the same area,
- format of the data facilitates fast processing of large quantities, and
- correlation between vegetation structure and some spectral reflectance values may be strong.
- RS makes it possible to collect data on dangerous or inaccessible areas.

6 Conclusions and recommendations

An increasing use of bioenergy builds the basis to achieve a more environmental sound energy supply system, but also depends on the available resources and their development. The availability of biomass resources is driven by different factors, which do not only affect the global food situation but also the conservation of natural forests and other biospheres. So, the assessment of future biomass potentials is the starting point for the discussion about the integration of bioenergy into a renewable energy system.

Against this background the goal of this study is to summarize and to analyse the current state of knowledge about global biomass potentials and the relevant drivers (e.g. population development and food consumption), and to estimate future biomass potentials with a focus on agricultural energy crops. In the last part of the study an overview of the state of the art in remote sensing for biomass potential measurements is given. The results of the investigation is summarised in the following:

1. A lot of different studies are available for the estimation of global biomass potentials till 2050 (and even 2100). The studies come to very different results especially for the biomass potentials from energy crops. This is caused by different estimations and modelling parameters for the further development, while the current situations is comparable well described by agricultural data.

2. Potential estimations for bioenergy from energy crops can be performed according to different approaches. Theoretical and technical potentials either don’t take into consideration utilisation concurrence with the sectors of foodstuffs and feed production, nature conservation and other area demands, or only take insufficient consideration thereof. Prognoses of economical potential assume that usable price prognoses for agricultural raw materials, energy sources and prognosis models are available, which simultaneously correctly display utilisation concurrence and willingness to invest in conversion plants. Generally this is only possible for individual countries with complex models, but not for large economic areas, like for instance the EU 15 or EU 27. Therefore, in the example on hand a largely simplified approach is selected, which establishes the so-called exploitable area potentials with rigorous assumptions, which are comprehensible for political

decision makers, based on available statistics, using simple regression calculations and plausibility considerations. Special attention is given to the relationship between area demands for the production of foodstuffs (including feed production), dwelling, industry and nature conservation. According to the assignment, many countries are considered and calculated.

3. To figure out the uncertainties of available agricultural area scenarios for the development of energy crop potentials are considered:

- In the **BAU scenario** the agricultural practices existing at the present time also apply for the future.
- In the **Basic scenario** forest clearing is no longer taking place. Depending on the economic general conditions fallow areas will be used.
- In the **Sub scenario 1** (additional to the Basic scenario) the area productivity increases more slowly than hitherto. Cultivation methods are more strongly oriented towards sustainability and sparse use of yield-increasing agents with the consequence that the yield level will be reduced. No change of grassland and pasture takes place.
- In the **Sub scenario 2** (additional to the Basic scenario)_it is assumed that in countries having a level of food consumption significantly above the recommendations of the World Health Organisation. USA, Canada, Australia and most EU Countries will reduce per-capita consumption by 30% maximum. Countries having a moderate consumption level reduce the per-capita consumption by less than 30%.
- In the **Sub scenario 3** the aggregation of the Sub scenario 1 and Sub scenario 2 takes place.

All scenarios show relevant energy crop potentials in the industrialized regions EU, North America, South America and Australia. Certain world regions (i.e. Africa, Asia) will not have any energy crop potential under the elaborated assumptions. For the calculation of biomass potentials those world regions were neglected, but it has to be pointed out, that the food provision in those regions might be one of the challenges for the next decades.

Beside this, the global biomass potential from energy crops is estimated in a range from 6.0 EJ in the Sub 1 scenario ("ecological and sustainable") till 97 EJ in the BAU scenario ("business as usual") in 2050.

4. Referring to biomass potentials from residues many studies stress that there are substantial data gaps concerned with particularly the recoverable amounts of residues and the required residue quantities for material use. Also there is country specific data for certain countries, which differ dramatically from the global studies. So, the data base for residues is comparable bad, while the driver and the development effects are significant lower than for energy crops. Based on the analysis of transparent and complete studies and some additional own calculation, for residues a global potential of 59 EJ in 2020 and 88 EJ in 2050 is estimated.

5. The total global biomass potential differs in 2020 in a range of 67 EJ (Sub scenario 1) till 110 EJ (Sub scenario 2) and in 2050 in a range of 94 EJ (Sub scenario 1) till 168 EJ (Sub scenario 2). Those numbers are more conservative calculations and may have an estimated uncertainty, especially for in 2050, of a factor of two. Reasons for this uncertainty are
    - the non observance of effects from climate change
    - changes of the worldwide political and economical situation in a unpredictable dimension
    - a higher yield increase as assumed in consequence of
        - a disproportionate change in agricultural techniques
        - the fast development and wide use of GMO cultures

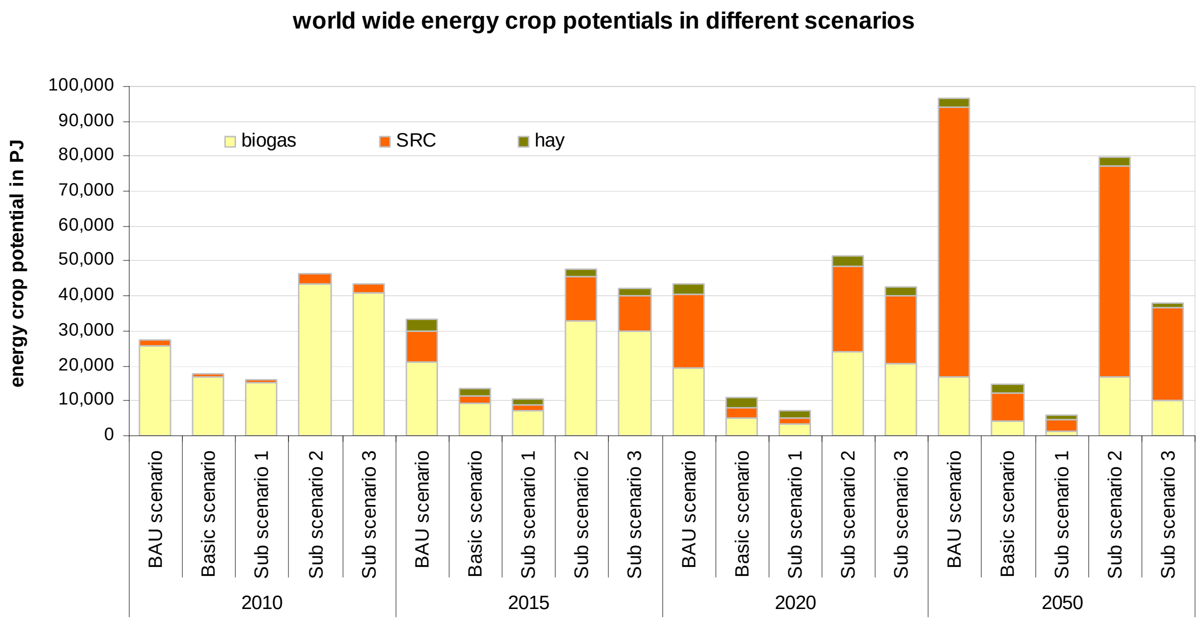

Table 30: World wide energy crop potentials

6. In conclusion it must be emphasized again, that this study does not constitute a prognosis of energy crop production and utilisation for the next decade, but merely allows estimation based on a continuation of observed trends and the resulting exploitable area potential for foodstuff imports or energy crops. Especially by additional improvement in the agricultural field, the biomass potential from energy crops can increase strongly. Those significant compensation options are to be expected both in industrialised and in developing countries for continued higher agricultural prices. Such price-induced measures could, for instance, be:

- Change of land utilisation in line with future price developments, mainly towards higher yield cultivars and a waiver of fallow ground
- Higher import of milk and meat from countries with comparative cost advantages and a surplus of grasslands
- Increase of general area productivity (cropping index, irrigation, breeding, substitution of cultivars, etc.)
- Change in eating habit.

So, additional action in the agricultural field is necessary to integrate the bioenergy production into a sustainable agricultural system.

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Annex 1: Energy crop potentials of all investigated countries

BAU scenario	2010		2015			2020			2050		
PE potential PJ per year	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
OECD Europe											
Germany	446	18	478	116	2	449	302	0	436	1,094	0
France	614	34	548	177	1	440	400	0	326	1,199	0
United Kingdom	0	0	0	0	0	13	12	0	67	254	0
Italy	110	5	124	30	0	122	84	0	150	418	0
Spain	616	16	781	114	0	810	322	0	1,010	1,404	0
Ploland	65	3	1	0	1	10	9	0	0	0	0
the Netherlands	49	2	46	10	1	39	26	0	27	78	0
Greece	0	0	0	0	0	0	0	0	0	0	0
Belgium Luxembourg	50	1	62	10	0	64	30	0	91	148	0
Czech Republic	162	8	162	45	1	143	110	0	124	354	0
Portugal	56	1	74	8	0	78	24	0	106	112	0
Hungary	88	7	77	37	0	60	81	0	35	190	0
Sweden	0	2	0	9	0	0	17	0	0	15	0
Austria	34	2	33	12	0	30	32	0	30	132	0
Slovakia	1	0	0	0	0	0	0	0	0	0	0
Denmark	53	3	51	17	0	43	40	0	28	109	0
Finland	0	1	0	3	0	0	5	0	0	2	0
Ireland	29	12	2	66	3	0	153	0	0	218	0
Norway	0	0	0	0	0	0	0	0	0	0	0
Switzerland	0	0	0	0	0	0	0	0	0	0	1
Turkey	337	8	18	0	28	2	0	7	61	0	187
	2,711	**123**	**2,457**	**655**	**38**	**2,305**	**1,645**	**7**	**2,491**	**5,726**	**187**
OECD North America											
USA	6,503	310	5,553	1,485	0	4,277	3,150	0	1,784	4,804	0
Canada	4,247	159	4,348	938	0	3,942	2,399	0	3,574	8,859	0
Mexico	0	0	0	0	0	0	0	0	0	0	0
	10,750	**469**	**9,901**	**2,423**	**0**	**8,220**	**5,548**	**0**	**5,359**	**13,663**	**0**
OECD Pacific											
Australia	4,436	178	1,451	804	2,401	1,510	1,556	1,660	351	0	1,083
Japan	0	0	0	0	0	0	0	0	0	0	0
South Korea	0	0	0	0	0	0	0	0	0	0	0
New Zealand	1,079	15	509	93	588	453	241	614	432	801	567
	5,515	**194**	**1,960**	**897**	**2,989**	**1,963**	**1,798**	**2,274**	**784**	**801**	**1,650**
Transition Economies											
Russia	4,099	207	4,402	1,247	211	4,283	3,227	270	4,342	10,045	336
Usbekistan	0	0	0	0	0	0	0	0	0	0	0
Ukraine	676	48	583	266	75	492	649	95	387	2,000	110
Kazakstan	0	0	0	0	0	0	0	0	0	0	0
Azerbaijan	0	0	0	0	0	0	0	0	0	0	0
Tadzhikistan	0	0	0	0	0	0	0	0	0	0	0
Kirghizia	0	0	0	0	0	0	0	0	0	0	0
Georgian Republic	0	0	0	0	0	0	0	0	0	0	0
Turkmenistan	0	0	0	0	0	0	0	0	0	0	0
Serbia Montenegro	29	3	24	14	3	18	28	6	8	0	24
Belarus	135	4	93	22	36	73	53	45	52	139	47
Kroatia	41	2	44	16	9	43	44	16	71	245	51
Bosnia Herzegovina	18	1	10	3	0	5	4	0	0	0	0
Albania	15	1	9	2	0	3	2	0	0	0	0
Romania	29	4	30	23	0	30	64	0	48	420	0
Bulgaria	44	5	41	24	0	33	52	0	0	0	0
Lithuania	34	3	39	22	1	41	60	0	40	180	0
Latvia	37	3	43	18	0	43	48	0	47	165	0
Slovenia	4	0	4	1	0	3	2	0	1	1	0
Estonia	9	1	13	5	0	15	15	0	21	72	0
Cyprus	0	0	0	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0	0	0
	5,169	**281**	**5,336**	**1,664**	**335**	**5,082**	**4,248**	**433**	**5,016**	**13,268**	**568**

BAU scenario	2010		2015			2020			2050		
PE potential PJ per year	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
China	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
India	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Rest of Asia											
Bangladesh	0	0	0	0	0	0	0	0	0	0	0
Nepal	0	0	0	0	0	0	0	0	0	0	0
Pakistan	0	0	0	0	0	0	0	0	0	0	0
Sri Lanka	0	0	0	0	0	0	0	0	0	0	0
North Korea	0	0	0	0	0	0	0	0	0	0	0
Mongolia	0	0	0	0	0	0	0	0	0	0	0
Indonesia	0	0	0	0	0	0	0	0	0	0	0
Cambodia	0	0	0	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0	0	0	0
Laos	0	0	0	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0	0	0	0
Vietnam	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Latin America											
Guatemala	0	0	0	0	0	0	0	0	0	0	0
Cuba	0	11	0	0	0	0	0	0	0	0	0
Dominican Republic	0	0	0	0	0	0	0	0	0	0	0
Haiti	0	0	0	0	0	0	0	0	0	0	0
Honduras	0	0	0	0	0	0	0	0	0	0	0
El Salvador	0	0	0	0	0	0	0	0	0	0	0
Nicaragua	0	15	0	0	0	0	0	0	0	0	0
Costa Rica	0	1	0	0	0	0	0	0	0	0	0
Jamaica	0	0	0	0	0	0	0	0	0	0	0
Brazil	0	326	0	1,858	0	0	4,864	0	0	27,317	0
Colombia	0	0	0	0	0	0	0	0	0	0	0
Argentina	1,396	105	1,644	826	0	1,874	2,554	0	3,018	14,185	0
Peru	0	0	0	0	0	0	0	0	0	0	0
Venezuela	0	0	0	0	0	0	0	0	0	0	0
Chile	0	0	0	0	0	0	0	0	0	0	0
Ecuador	0	0	0	0	0	0	0	0	0	0	0
Bolivia	0	0	1	0	0	4	10	0	20	213	0
Paraguay	19	1	6	1	0	23	17	0	35	134	0
Uruguay	161	14	0	164	0	0	541	0	0	2,003	0
Guyana	0	0	0	1	0	0	3	0	0	12	0
Suriname	0	0	0	0	0	0	0	0	0	0	0
	1,576	**475**	**1,650**	**2,850**	**0**	**1,901**	**7,988**	**0**	**3,074**	**43,863**	**0**

BAU scenario	2010		2015			2020			2050		
PE potential PJ per year	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
Sub-Saharan Africa											
Nigeria	0	0	0	0	0	0	0	0	0	0	0
Ethiopia	0	0	0	0	0	0	0	0	0	0	0
Dem. Rep. of the Congc	0	0	0	0	0	0	0	0	0	0	0
South Africa	0	0	0	0	0	0	0	0	0	0	0
Tanzania	0	0	0	0	0	0	0	0	0	0	0
Kenya	0	0	0	0	0	0	0	0	0	0	0
Uganda	0	0	0	0	0	0	0	0	0	0	0
Ghana	0	0	0	0	0	0	0	0	0	0	0
Mosambique	0	0	0	0	0	0	0	0	0	0	0
Madagascar	0	0	0	0	0	0	0	0	0	0	0
Cameroon	0	0	0	0	0	0	0	0	0	0	0
Angola	0	0	0	0	0	0	0	0	0	0	0
Mali	0	0	0	0	0	0	0	0	0	0	0
Burkina Faso	0	0	0	0	0	0	0	0	0	0	0
Zimbabwe	0	0	0	0	0	0	0	0	0	0	0
Malawi	0	0	0	0	0	0	0	0	0	0	0
Niger	0	0	0	0	0	0	0	0	0	0	0
Senegal	0	0	0	0	0	0	0	0	0	0	0
Chad	0	0	0	0	0	0	0	0	0	0	0
Guinea	0	0	0	0	0	0	0	0	0	0	0
Rwanda	0	0	0	0	0	0	0	0	0	0	0
Burundi	0	0	0	0	0	0	0	0	0	0	0
Benin	0	0	0	0	0	0	0	0	0	0	0
Togo	0	0	0	0	0	0	0	0	0	0	0
Eritrea	0	0	0	0	0	0	0	0	0	0	0
Central African Republi	0	0	0	0	0	0	0	0	0	0	0
Republic of the Congo	0	0	0	0	0	0	0	0	0	0	0
Mauretania	0	0	0	0	0	0	0	0	0	0	0
Namibia	0	0	0	0	0	0	0	0	0	0	0
Botswana	0	0	0	0	0	0	0	0	0	0	0
Gabon	0	0	0	0	0	0	0	0	0	0	0
Egypt	0	0	0	0	0	0	0	0	0	0	0
Algeria	0	0	0	0	0	0	0	0	0	0	0
Libya	0	0	0	0	0	0	0	0	0	0	0
Marocco	0	0	0	0	0	0	0	0	0	0	0
Sudan	0	0	0	0	0	0	0	0	0	0	0
Tunisia	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Middle East											
Iran	0	0	0	0	0	0	0	0	0	0	0
Saudi Arabia	0	0	0	0	0	0	0	0	0	0	0
United Arab Emirates	0	0	0	0	0	0	0	0	0	0	0
Yemen	0	0	0	0	0	0	0	0	0	0	0
Israel	0	0	0	0	0	0	0	0	0	0	0
Jordan	0	0	0	0	0	0	0	0	0	0	0
Syria	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
world	**25,721**	**1,543**	**21,305**	**8,494**	**3,362**	**19,471**	**21,237**	**2,714**	**16,722**	**77,351**	**2,406**

Basic scenario	2010		2015			2020			2050		
PE potential PJ per year	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
OECD Europe											
Germany	420	17	419	102	2	373	251	0	369	925	0
France	584	32	481	155	1	358	326	0	268	986	0
United Kingdom	0	0	0	0	0	10	9	0	59	224	0
Italy	79	3	65	16	0	51	35	0	95	266	0
Spain	507	13	564	82	0	537	213	0	768	1,068	0
Ploland	31	1	1	0	1	10	9	0	0	0	0
the Netherlands	49	2	43	10	1	36	24	0	25	71	0
Greece	0	0	0	0	0	0	0	0	0	0	0
Belgium Luxembourg	48	1	57	10	0	57	26	0	81	131	0
Czech Republic	144	7	125	34	1	98	75	0	90	259	0
Portugal	44	1	49	5	0	47	14	0	78	83	0
Hungary	80	7	62	29	0	43	57	0	24	134	0
Sweden	0	2	0	5	0	0	5	0	0	0	0
Austria	32	2	29	11	0	24	26	0	26	114	0
Slovakia	1	0	0	0	0	0	0	0	0	0	0
Denmark	52	3	49	16	0	40	37	0	25	98	0
Finland	0	1	0	1	0	0	0	0	0	2	0
Ireland	29	11	2	56	3	0	117	0	0	135	0
Norway	0	0	0	0	0	0	0	0	0	0	0
Switzerland	0	0	0	0	0	0	0	0	0	0	1
Turkey	4	0	0	0	0	17	0	54	61	0	187
	2,103	**103**	**1,945**	**533**	**10**	**1,702**	**1,225**	**54**	**1,970**	**4,494**	**187**
OECD North America											
USA	5,131	245	3,033	811	0	1,036	763	0	0	0	0
Canada	2,370	89	1,697	366	0	1,447	880	0	0	0	0
Mexico	0	0	0	0	0	0	0	0	0	0	0
	7,501	**334**	**4,730**	**1,177**	**0**	**2,482**	**1,643**	**0**	**0**	**0**	**0**
OECD Pacific											
Australia	3,354	77	1,159	0	1,191	487	0	1,501	351	0	1,083
Japan	0	0	0	0	0	0	0	0	0	0	0
South Korea	0	0	0	0	0	0	0	0	0	0	0
New Zealand	840	0	245	0	588	199	0	614	184	0	567
	4,194	**77**	**1,405**	**0**	**1,779**	**686**	**0**	**2,115**	**535**	**0**	**1,650**
Transition Economies											
Russia	1,501	64	410	80	211	88	0	270	1,309	2,846	336
Usbekistan	0	0	0	0	0	0	0	0	0	0	0
Ukraine	313	17	48	0	75	31	0	95	57	120	110
Kazakstan	0	0	0	0	0	0	0	0	0	0	0
Azerbaijan	0	0	0	0	0	0	0	0	0	0	0
Tadzhikistan	0	0	0	0	0	0	0	0	0	0	0
Kirghizia	0	0	0	0	0	0	0	0	0	0	0
Georgian Republic	0	0	0	0	0	0	0	0	0	0	0
Turkmenistan	0	0	0	0	0	0	0	0	0	0	0
Serbia Montenegro	25	3	16	9	3	2	0	6	8	0	24
Belarus	69	1	16	0	24	15	0	45	15	0	47
Kroatia	28	1	22	7	9	5	0	16	51	155	51
Bosnia Herzegovina	0	0	0	0	0	0	0	0	0	0	0
Albania	0	0	0	0	0	0	0	0	0	0	0
Romania	24	3	21	16	0	18	40	0	37	329	0
Bulgaria	38	4	31	18	0	20	32	0	0	0	0
Lithuania	32	3	34	19	1	34	50	0	34	156	0
Latvia	31	2	30	12	0	27	30	0	34	120	0
Slovenia	4	0	4	1	0	3	2	0	1	1	0
Estonia	8	1	11	5	0	13	14	0	19	65	0
Cyprus	0	0	0	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0	0	0
	2,072	**98**	**643**	**166**	**322**	**256**	**167**	**433**	**1,564**	**3,792**	**568**

Basic scenario	2010		2015			2020			2050		
PE potential PJ per year	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
China	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
India	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Rest of Asia											
Bangladesh	0	0	0	0	0	0	0	0	0	0	0
Nepal	0	0	0	0	0	0	0	0	0	0	0
Pakistan	0	0	0	0	0	0	0	0	0	0	0
Sri Lanka	0	0	0	0	0	0	0	0	0	0	0
North Korea	0	0	0	0	0	0	0	0	0	0	0
Mongolia	0	0	0	0	0	0	0	0	0	0	0
Indonesia	0	0	0	0	0	0	0	0	0	0	0
Cambodia	0	0	0	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0	0	0	0
Laos	0	0	0	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0	0	0	0
Vietnam	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Latin America											
Guatemala	0	0	0	0	0	0	0	0	0	0	0
Cuba	0	0	0	0	0	0	0	0	0	0	0
Dominican Republic	0	0	0	0	0	0	0	0	0	0	0
Haiti	0	0	0	0	0	0	0	0	0	0	0
Honduras	0	0	0	0	0	0	0	0	0	0	0
El Salvador	0	0	0	0	0	0	0	0	0	0	0
Nicaragua	0	0	0	0	0	0	0	0	0	0	0
Costa Rica	0	0	0	0	0	0	0	0	0	0	0
Jamaica	0	0	0	0	0	0	0	0	0	0	0
Brazil	0	85	0	70	0	0	0	0	0	0	0
Colombia	0	0	0	0	0	0	0	0	0	0	0
Argentina	836	54	443	222	0	0	0	0	0	0	0
Peru	0	0	0	0	0	0	0	0	0	0	0
Venezuela	0	0	0	0	0	0	0	0	0	0	0
Chile	0	0	0	0	0	0	0	0	0	0	0
Ecuador	0	0	0	0	0	0	0	0	0	0	0
Bolivia	1	0	1	0	0	0	0	0	0	0	0
Paraguay	12	0	6	1	0	0	0	0	0	0	0
Uruguay	161	4	0	48	0	0	0	0	0	0	0
Guyana	0	0	0	0	0	0	0	0	0	0	0
Suriname	0	0	0	0	0	0	0	0	0	0	0
	1,010	**143**	**449**	**343**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Basic scenario PE potential PJ per year	2010		2015			2020			2050		
	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
Sub-Saharan Africa											
Nigeria	0	0	0	0	0	0	0	0	0	0	0
Ethiopia	0	0	0	0	0	0	0	0	0	0	0
Dem. Rep. of the Congc	0	0	0	0	0	0	0	0	0	0	0
South Africa	0	0	0	0	0	0	0	0	0	0	0
Tanzania	0	0	0	0	0	0	0	0	0	0	0
Kenya	0	0	0	0	0	0	0	0	0	0	0
Uganda	0	0	0	0	0	0	0	0	0	0	0
Ghana	0	0	0	0	0	0	0	0	0	0	0
Mosambique	0	0	0	0	0	0	0	0	0	0	0
Madagascar	0	0	0	0	0	0	0	0	0	0	0
Cameroon	0	0	0	0	0	0	0	0	0	0	0
Angola	0	0	0	0	0	0	0	0	0	0	0
Mali	0	0	0	0	0	0	0	0	0	0	0
Burkina Faso	0	0	0	0	0	0	0	0	0	0	0
Zimbabwe	0	0	0	0	0	0	0	0	0	0	0
Malawi	0	0	0	0	0	0	0	0	0	0	0
Niger	0	0	0	0	0	0	0	0	0	0	0
Senegal	0	0	0	0	0	0	0	0	0	0	0
Chad	0	0	0	0	0	0	0	0	0	0	0
Guinea	0	0	0	0	0	0	0	0	0	0	0
Rwanda	0	0	0	0	0	0	0	0	0	0	0
Burundi	0	0	0	0	0	0	0	0	0	0	0
Benin	0	0	0	0	0	0	0	0	0	0	0
Togo	0	0	0	0	0	0	0	0	0	0	0
Eritrea	0	0	0	0	0	0	0	0	0	0	0
Central African Republi	0	0	0	0	0	0	0	0	0	0	0
Republic of the Congo	0	0	0	0	0	0	0	0	0	0	0
Mauretania	0	0	0	0	0	0	0	0	0	0	0
Namibia	0	0	0	0	0	0	0	0	0	0	0
Botswana	0	0	0	0	0	0	0	0	0	0	0
Gabon	0	0	0	0	0	0	0	0	0	0	0
Egypt	0	0	0	0	0	0	0	0	0	0	0
Algeria	0	0	0	0	0	0	0	0	0	0	0
Libya	0	0	0	0	0	0	0	0	0	0	0
Marocco	0	0	0	0	0	0	0	0	0	0	0
Sudan	0	0	0	0	0	0	0	0	0	0	0
Tunisia	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Middle East											
Iran	0	0	0	0	0	0	0	0	0	0	0
Saudi Arabia	0	0	0	0	0	0	0	0	0	0	0
United Arab Emirates	0	0	0	0	0	0	0	0	0	0	0
Yemen	0	0	0	0	0	0	0	0	0	0	0
Israel	0	0	0	0	0	0	0	0	0	0	0
Jordan	0	0	0	0	0	0	0	0	0	0	0
Syria	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
world	**16,881**	**756**	**9,172**	**2,221**	**2,112**	**5,125**	**3,038**	**2,601**	**4,069**	**8,286**	**2,406**

Sub scenario 1	2010		2015			2020			2050		
PE potential PJ per year	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
OECD Europe											
Germany	397	17	340	83	0	254	171	0	53	132	0
France	498	28	334	108	0	186	169	0	2	6	0
United Kingdom	0	0	0	0	0	0	0	0	0	0	0
Italy	63	3	37	9	0	17	12	0	8	22	0
Spain	460	12	437	64	0	335	133	0	90	125	0
Ploland	32	2	25	8	0	30	27	0	0	0	0
the Netherlands	46	2	35	8	0	24	16	0	1	2	0
Greece	0	0	0	0	0	0	0	0	0	0	0
Belgium Luxembourg	45	1	46	8	0	39	18	0	46	74	0
Czech Republic	150	7	118	33	0	84	64	0	146	418	0
Portugal	39	1	37	4	0	28	9	0	9	10	0
Hungary	73	6	48	23	0	28	38	0	78	426	0
Sweden	0	1	0	3	0	0	0	0	0	0	0
Austria	28	2	21	8	0	15	16	0	16	68	0
Slovakia	1	0	1	0	0	0	0	0	0	0	0
Denmark	52	3	44	14	0	31	29	0	7	27	0
Finland	0	1	0	1	0	0	0	0	0	12	0
Ireland	0	12	0	46	0	0	80	0	0	0	0
Norway	0	0	0	0	0	0	0	0	0	0	0
Switzerland	0	0	0	0	0	0	0	0	0	0	0
Turkey	0	0	0	0	0	0	0	0	60	0	185
	1,884	**98**	**1,522**	**419**	**0**	**1,072**	**781**	**0**	**514**	**1,322**	**185**
OECD North America											
USA	4,889	233	2,504	670	0	107	79	0	0	0	0
Canada	2,428	91	1,684	363	0	1,499	912	0	0	0	0
Mexico	0	0	0	0	0	0	0	0	0	0	0
	7,317	**324**	**4,188**	**1,033**	**0**	**1,605**	**991**	**0**	**0**	**0**	**0**
OECD Pacific											
Australia	2,521	0	939	0	965	330	0	1,017	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0	0
South Korea	0	0	0	0	0	0	0	0	0	0	0
New Zealand	827	0	222	0	531	171	0	529	184	0	567
	3,348	**0**	**1,161**	**0**	**1,496**	**501**	**0**	**1,545**	**184**	**0**	**567**
Transition Economies											
Russia	1,421	60	173	11	210	47	0	145	211	245	333
Usbekistan	0	0	0	0	0	0	0	0	0	0	0
Ukraine	309	16	44	0	68	12	0	37	35	0	109
Kazakstan	0	0	0	0	0	0	0	0	0	0	0
Azerbaijan	0	0	0	0	0	0	0	0	0	0	0
Tadzhikistan	0	0	0	0	0	0	0	0	0	0	0
Kirghizia	0	0	0	0	0	0	0	0	0	0	0
Georgian Republic	0	0	0	0	0	0	0	0	0	0	0
Turkmenistan	0	0	0	0	0	0	0	0	0	0	0
Serbia Montenegro	16	2	5	3	0	0	0	0	0	0	0
Belarus	68	0	15	0	23	5	0	15	15	0	46
Kroatia	25	1	17	5	7	7	3	14	31	80	42
Bosnia Herzegovina	0	0	0	0	0	0	0	0	0	0	0
Albania	0	0	0	0	0	0	0	0	0	0	0
Romania	21	3	15	11	0	10	22	0	100	878	0
Bulgaria	37	4	24	14	0	10	17	0	0	0	0
Lithuania	38	4	38	21	0	35	51	0	118	532	0
Latvia	34	3	29	12	0	24	26	0	75	265	0
Slovenia	3	0	1	0	0	0	0	0	0	0	0
Estonia	10	1	11	5	0	11	12	0	38	127	0
Cyprus	0	0	0	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0	0	0
	1,980	**94**	**370**	**82**	**308**	**162**	**131**	**210**	**623**	**2,128**	**530**

Sub scenario 1 PE potential PJ per year	2010		2015			2020			2050		
	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
China	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
India	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Rest of Asia											
Bangladesh	0	0	0	0	0	0	0	0	0	0	0
Nepal	0	0	0	0	0	0	0	0	0	0	0
Pakistan	0	0	0	0	0	0	0	0	0	0	0
Sri Lanka	0	0	0	0	0	0	0	0	0	0	0
North Korea	0	0	0	0	0	0	0	0	0	0	0
Mongolia	0	0	0	0	0	0	0	0	0	0	0
Indonesia	0	0	0	0	0	0	0	0	0	0	0
Cambodia	0	0	0	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0	0	0	0
Laos	0	0	0	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0	0	0	0
Vietnam	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Latin America											
Guatemala	0	0	0	0	0	0	0	0	0	0	0
Cuba	0	0	0	0	0	0	0	0	0	0	0
Dominican Republic	0	0	0	0	0	0	0	0	0	0	0
Haiti	0	0	0	0	0	0	0	0	0	0	0
Honduras	0	0	0	0	0	0	0	0	0	0	0
El Salvador	0	0	0	0	0	0	0	0	0	0	0
Nicaragua	0	0	0	0	0	0	0	0	0	0	0
Costa Rica	0	0	0	0	0	0	0	0	0	0	0
Jamaica	0	0	0	0	0	0	0	0	0	0	0
Brazil	0	65	0	0	0	0	0	0	0	0	0
Colombia	0	0	0	0	0	0	0	0	0	0	0
Argentina	712	47	0	0	0	0	0	0	0	0	0
Peru	0	0	0	0	0	0	0	0	0	0	0
Venezuela	0	0	0	0	0	0	0	0	0	0	0
Chile	0	0	0	0	0	0	0	0	0	0	0
Ecuador	0	0	0	0	0	0	0	0	0	0	0
Bolivia	0	0	0	0	0	0	0	0	0	0	0
Paraguay	0	0	0	0	0	0	0	0	0	0	0
Uruguay	136	4	0	0	0	0	0	0	0	0	0
Guyana	0	0	0	0	0	0	0	0	0	0	0
Suriname	0	0	0	0	0	0	0	0	0	0	0
	848	**115**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Sub scenario 1 PE potential PJ per year	2010		2015			2020			2050		
	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
Sub-Saharan Africa											
Nigeria	0	0	0	0	0	0	0	0	0	0	0
Ethiopia	0	0	0	0	0	0	0	0	0	0	0
Dem. Rep. of the Congc	0	0	0	0	0	0	0	0	0	0	0
South Africa	0	0	0	0	0	0	0	0	0	0	0
Tanzania	0	0	0	0	0	0	0	0	0	0	0
Kenya	0	0	0	0	0	0	0	0	0	0	0
Uganda	0	0	0	0	0	0	0	0	0	0	0
Ghana	0	0	0	0	0	0	0	0	0	0	0
Mosambique	0	0	0	0	0	0	0	0	0	0	0
Madagascar	0	0	0	0	0	0	0	0	0	0	0
Cameroon	0	0	0	0	0	0	0	0	0	0	0
Angola	0	0	0	0	0	0	0	0	0	0	0
Mali	0	0	0	0	0	0	0	0	0	0	0
Burkina Faso	0	0	0	0	0	0	0	0	0	0	0
Zimbabwe	0	0	0	0	0	0	0	0	0	0	0
Malawi	0	0	0	0	0	0	0	0	0	0	0
Niger	0	0	0	0	0	0	0	0	0	0	0
Senegal	0	0	0	0	0	0	0	0	0	0	0
Chad	0	0	0	0	0	0	0	0	0	0	0
Guinea	0	0	0	0	0	0	0	0	0	0	0
Rwanda	0	0	0	0	0	0	0	0	0	0	0
Burundi	0	0	0	0	0	0	0	0	0	0	0
Benin	0	0	0	0	0	0	0	0	0	0	0
Togo	0	0	0	0	0	0	0	0	0	0	0
Eritrea	0	0	0	0	0	0	0	0	0	0	0
Central African Republi	0	0	0	0	0	0	0	0	0	0	0
Republic of the Congo	0	0	0	0	0	0	0	0	0	0	0
Mauretania	0	0	0	0	0	0	0	0	0	0	0
Namibia	0	0	0	0	0	0	0	0	0	0	0
Botswana	0	0	0	0	0	0	0	0	0	0	0
Gabon	0	0	0	0	0	0	0	0	0	0	0
Egypt	0	0	0	0	0	0	0	0	0	0	0
Algeria	0	0	0	0	0	0	0	0	0	0	0
Libya	0	0	0	0	0	0	0	0	0	0	0
Marocco	0	0	0	0	0	0	0	0	0	0	0
Sudan	0	0	0	0	0	0	0	0	0	0	0
Tunisia	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Middle East											
Iran	0	0	0	0	0	0	0	0	0	0	0
Saudi Arabia	0	0	0	0	0	0	0	0	0	0	0
United Arab Emirates	0	0	0	0	0	0	0	0	0	0	0
Yemen	0	0	0	0	0	0	0	0	0	0	0
Israel	0	0	0	0	0	0	0	0	0	0	0
Jordan	0	0	0	0	0	0	0	0	0	0	0
Syria	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
world	**15,377**	**632**	**7,240**	**1,536**	**1,804**	**3,340**	**1,905**	**1,755**	**1,321**	**3,450**	**1,283**

Sub scenario 2	2010		2015			2020			2050		
PE potential PJ per year	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
OECD Europe											
Germany	1,059	45	989	240	4	839	564	0	658	1,649	0
France	1,415	79	1,248	403	2	963	877	0	589	2,168	0
United Kingdom	672	37	641	206	0	495	451	0	300	1,141	0
Italy	774	33	704	172	0	545	375	0	377	1,051	0
Spain	1,733	46	1,640	239	0	1,409	559	0	1,391	1,934	0
Ploland	380	20	217	68	2	161	144	0	14	51	0
the Netherlands	99	4	84	19	1	72	48	0	44	129	0
Greece	402	9	344	47	0	257	100	0	128	215	0
Belgium Luxembourg	118	4	125	21	0	110	51	0	122	197	0
Czech Republic	247	12	220	61	1	186	142	0	179	514	0
Portugal	227	5	221	25	0	173	52	0	163	172	0
Hungary	158	13	141	67	0	108	145	0	72	394	0
Sweden	0	8	0	38	0	0	76	0	0	136	0
Austria	122	8	107	40	1	88	94	0	58	253	0
Slovakia	6	0	0	0	0	0	0	0	0	0	0
Denmark	103	6	95	31	0	77	71	0	48	185	0
Finland	0	3	0	14	0	0	26	0	0	27	0
Ireland	29	15	4	66	5	0	153	0	0	203	0
Norway	23	1	19	4	0	14	8	0	11	27	0
Switzerland	41	3	28	11	0	16	19	0	0	0	1
Turkey	4	0	0	0	0	17	0	54	61	0	188
	7,612	**349**	**6,827**	**1,771**	**17**	**5,531**	**3,955**	**54**	**4,215**	**10,446**	**188**
OECD North America											
USA	17,286	825	14,668	3,923	0	9,532	7,019	0	3,895	10,488	0
Canada	2,908	109	1,708	368	0	2,209	1,344	0	2,353	5,833	0
Mexico	0	0	0	0	0	0	0	0	0	0	0
	20,194	**934**	**16,376**	**4,291**	**0**	**11,741**	**8,363**	**0**	**6,249**	**16,321**	**0**
OECD Pacific											
Australia	8,089	521	5,297	2,288	1,200	3,172	4,217	1,660	758	2,998	1,083
Japan	0	0	0	0	0	0	0	0	0	0	0
South Korea	0	0	0	0	0	0	0	0	0	0	0
New Zealand	1,017	11	238	0	571	187	0	575	200	51	567
	9,105	**533**	**5,535**	**2,288**	**1,771**	**3,358**	**4,217**	**2,235**	**958**	**3,049**	**1,650**
Transition Economies											
Russia	2,914	142	1,281	331	231	688	449	321	2,234	4,887	537
Usbekistan	0	0	0	0	0	0	0	0	0	0	0
Ukraine	341	19	49	0	75	31	0	96	103	355	126
Kazakstan	0	0	0	0	0	0	0	0	0	0	0
Azerbaijan	0	0	0	0	0	0	0	0	0	0	0
Tadzhikistan	0	0	0	0	0	0	0	0	0	0	0
Kirghizia	0	0	0	0	0	0	0	0	0	0	0
Georgian Republic	0	0	0	0	0	0	0	0	0	0	0
Turkmenistan	0	0	0	0	0	0	0	0	0	0	0
Serbia Montenegro	27	3	21	12	3	10	14	6	8	0	24
Belarus	93	2	21	0	32	15	0	45	15	0	47
Kroatia	29	2	26	8	9	21	18	16	63	210	52
Bosnia Herzegovina	0	0	0	0	0	0	0	0	0	0	0
Albania	0	0	0	0	0	0	0	0	6	13	0
Romania	84	11	99	76	0	96	208	0	140	1,236	0
Bulgaria	62	7	62	36	0	48	76	0	28	151	0
Lithuania	61	6	54	30	1	57	83	0	59	266	0
Latvia	43	3	35	14	0	37	41	0	52	184	0
Slovenia	25	1	25	6	0	20	14	0	14	32	0
Estonia	24	2	26	10	0	27	29	0	35	119	0
Cyprus	0	0	0	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0	1	0
	3,703	**197**	**1,699**	**525**	**351**	**1,050**	**932**	**484**	**2,757**	**7,454**	**786**

Sub scenario 2 PE potential PJ per year	2010		2015			2020			2050		
	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
China	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
India	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Rest of Asia											
Bangladesh	0	0	0	0	0	0	0	0	0	0	0
Nepal	0	0	0	0	0	0	0	0	0	0	0
Pakistan	0	0	0	0	0	0	0	0	0	0	0
Sri Lanka	0	0	0	0	0	0	0	0	0	0	0
North Korea	0	0	0	0	0	0	0	0	0	0	0
Mongolia	0	0	0	0	0	0	0	0	0	0	0
Indonesia	0	0	0	0	0	0	0	0	0	0	0
Cambodia	0	0	0	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0	0	0	0
Laos	0	0	0	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0	0	0	0
Vietnam	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Latin America											
Guatemala	0	0	0	0	0	0	0	0	0	0	0
Cuba	0	0	0	0	0	0	0	0	0	0	0
Dominican Republic	0	0	0	0	0	0	0	0	0	0	0
Haiti	0	0	0	0	0	0	0	0	0	0	0
Honduras	0	0	0	0	0	0	0	0	0	0	0
El Salvador	0	0	0	0	0	0	0	0	0	0	0
Nicaragua	0	0	0	0	0	0	0	0	0	0	0
Costa Rica	0	0	0	0	0	0	0	0	0	0	0
Jamaica	0	0	0	0	0	0	0	0	0	0	0
Brazil	0	505	0	2,284	0	0	3,641	0	0	9,817	0
Colombia	0	0	0	0	0	0	0	0	0	0	0
Argentina	2,830	236	2,585	1,299	0	2,217	3,022	0	2,488	11,691	0
Peru	0	0	0	0	0	0	0	0	0	0	0
Venezuela	0	0	0	0	0	0	0	0	0	0	0
Chile	0	0	0	0	0	0	0	0	0	0	0
Ecuador	0	0	0	0	0	0	0	0	0	0	0
Bolivia	0	0	0	0	0	4	11	0	22	230	0
Paraguay	0	0	0	0	0	24	18	0	38	145	0
Uruguay	161	19	0	163	0	0	476	0	0	1,366	0
Guyana	0	0	0	1	0	0	2	0	0	7	0
Suriname	0	0	0	0	0	0	0	0	0	0	0
	2,991	**761**	**2,585**	**3,747**	**0**	**2,246**	**7,170**	**0**	**2,548**	**23,256**	**0**

Sub scenario 2 PE potential PJ per year	2010		2015			2020			2050		
	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
Sub-Saharan Africa											
Nigeria	0	0	0	0	0	0	0	0	0	0	0
Ethiopia	0	0	0	0	0	0	0	0	0	0	0
Dem. Rep. of the Congc	0	0	0	0	0	0	0	0	0	0	0
South Africa	0	0	0	0	0	0	0	0	0	0	0
Tanzania	0	0	0	0	0	0	0	0	0	0	0
Kenya	0	0	0	0	0	0	0	0	0	0	0
Uganda	0	0	0	0	0	0	0	0	0	0	0
Ghana	0	0	0	0	0	0	0	0	0	0	0
Mosambique	0	0	0	0	0	0	0	0	0	0	0
Madagascar	0	0	0	0	0	0	0	0	0	0	0
Cameroon	0	0	0	0	0	0	0	0	0	0	0
Angola	0	0	0	0	0	0	0	0	0	0	0
Mali	0	0	0	0	0	0	0	0	0	0	0
Burkina Faso	0	0	0	0	0	0	0	0	0	0	0
Zimbabwe	0	0	0	0	0	0	0	0	0	0	0
Malawi	0	0	0	0	0	0	0	0	0	0	0
Niger	0	0	0	0	0	0	0	0	0	0	0
Senegal	0	0	0	0	0	0	0	0	0	0	0
Chad	0	0	0	0	0	0	0	0	0	0	0
Guinea	0	0	0	0	0	0	0	0	0	0	0
Rwanda	0	0	0	0	0	0	0	0	0	0	0
Burundi	0	0	0	0	0	0	0	0	0	0	0
Benin	0	0	0	0	0	0	0	0	0	0	0
Togo	0	0	0	0	0	0	0	0	0	0	0
Eritrea	0	0	0	0	0	0	0	0	0	0	0
Central African Republi	0	0	0	0	0	0	0	0	0	0	0
Republic of the Congo	0	0	0	0	0	0	0	0	0	0	0
Mauretania	0	0	0	0	0	0	0	0	0	0	0
Namibia	0	0	0	0	0	0	0	0	0	0	0
Botswana	0	0	0	0	0	0	0	0	0	0	0
Gabon	0	0	0	0	0	0	0	0	0	0	0
Egypt	0	0	0	0	0	0	0	0	0	0	0
Algeria	0	0	0	0	0	0	0	0	0	0	0
Libya	0	0	0	0	0	0	0	0	0	0	0
Marocco	0	0	0	0	0	0	0	0	0	0	0
Sudan	0	0	0	0	0	0	0	0	0	0	0
Tunisia	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Middle East											
Iran	0	0	0	0	0	0	0	0	0	0	0
Saudi Arabia	0	0	0	0	0	0	0	0	0	0	0
United Arab Emirates	0	0	0	0	0	0	0	0	0	0	0
Yemen	0	0	0	0	0	0	0	0	0	0	0
Israel	0	0	0	0	0	0	0	0	0	0	0
Jordan	0	0	0	0	0	0	0	0	0	0	0
Syria	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
world	**43,606**	**2,774**	**33,022**	**12,622**	**2,140**	**23,926**	**24,640**	**2,773**	**16,726**	**60,528**	**2,625**

Sub scenario 3 PE potential PJ per year	2010		2015			2020			2050		
	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
OECD Europe											
Germany	1,020	44	937	228	0	780	525	0	461	1,155	0
France	1,323	74	1,109	358	0	835	760	0	304	1,118	0
United Kingdom	638	35	563	181	0	440	401	0	201	763	0
Italy	753	32	658	160	0	518	356	0	314	874	0
Spain	1,625	43	1,551	226	0	1,326	526	0	1,157	1,608	0
Ploland	370	20	228	72	0	107	96	0	0	0	0
the Netherlands	96	4	82	19	0	64	42	0	21	62	0
Greece	357	8	269	37	0	180	70	0	12	20	0
Belgium Luxembourg	113	3	114	19	0	103	48	0	118	192	0
Czech Republic	248	12	228	63	0	193	148	0	293	842	0
Portugal	209	4	196	22	0	165	50	0	140	147	0
Hungary	148	12	128	61	0	99	134	0	99	545	0
Sweden	0	7	0	34	0	0	67	0	0	72	0
Austria	118	8	102	38	0	80	84	0	42	181	0
Slovakia	4	0	1	0	0	0	0	0	0	0	0
Denmark	102	6	93	30	0	76	71	0	44	170	0
Finland	0	3	0	14	0	0	26	0	0	33	0
Ireland	0	15	0	65	0	0	124	0	0	0	0
Norway	0	0	18	4	0	13	7	0	9	24	0
Switzerland	37	3	22	9	0	10	12	0	0	0	0
Turkey	0	0	0	0	0	0	0	0	61	0	187
	7,161	**335**	**6,298**	**1,641**	**0**	**4,990**	**3,547**	**0**	**3,275**	**7,807**	**187**
OECD North America											
USA	16,417	783	12,964	3,467	0	8,887	6,544	0	2,558	6,887	0
Canada	3,675	138	2,801	604	0	2,162	1,316	0	2,336	5,789	0
Mexico	0	0	0	0	0	0	0	0	0	0	0
	20,092	**921**	**15,765**	**4,071**	**0**	**11,049**	**7,859**	**0**	**4,894**	**12,676**	**0**
OECD Pacific											
Australia	7,122	430	3,811	1,465	1,200	1,670	1,813	1,660	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0	0
South Korea	0	0	0	0	0	0	0	0	0	0	0
New Zealand	901	4	236	0	566	183	0	565	184	0	567
	8,022	**434**	**4,048**	**1,465**	**1,767**	**1,854**	**1,813**	**2,225**	**184**	**0**	**567**
Transition Economies											
Russia	2,257	106	1,047	263	230	512	314	320	1,255	2,567	534
Usbekistan	0	0	0	0	0	0	0	0	0	0	0
Ukraine	310	16	48	0	74	16	0	50	56	85	126
Kazakstan	0	0	0	0	0	0	0	0	0	0	0
Azerbaijan	0	0	0	0	0	0	0	0	0	0	0
Tadzhikistan	0	0	0	0	0	0	0	0	0	0	0
Kirghizia	0	0	0	0	0	0	0	0	0	0	0
Georgian Republic	0	0	0	0	0	0	0	0	0	0	0
Turkmenistan	0	0	0	0	0	0	0	0	0	0	0
Serbia Montenegro	16	2	5	3	0	0	0	0	0	0	0
Belarus	88	2	20	0	30	9	0	27	15	0	47
Kroatia	25	1	19	6	7	14	10	14	46	148	42
Bosnia Herzegovina	0	0	0	0	0	0	0	0	0	0	0
Albania	0	0	0	0	0	0	0	0	0	0	0
Romania	80	11	90	69	0	90	194	0	183	1,612	0
Bulgaria	54	6	51	30	0	41	66	0	19	101	0
Lithuania	62	7	65	36	0	64	93	0	155	703	0
Latvia	43	3	41	17	0	38	42	0	109	384	0
Slovenia	23	1	20	5	0	16	11	0	7	17	0
Estonia	25	2	28	11	0	28	30	0	63	213	0
Cyprus	0	0	0	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0	1	0
	2,982	**156**	**1,436**	**441**	**342**	**827**	**760**	**411**	**1,907**	**5,829**	**748**

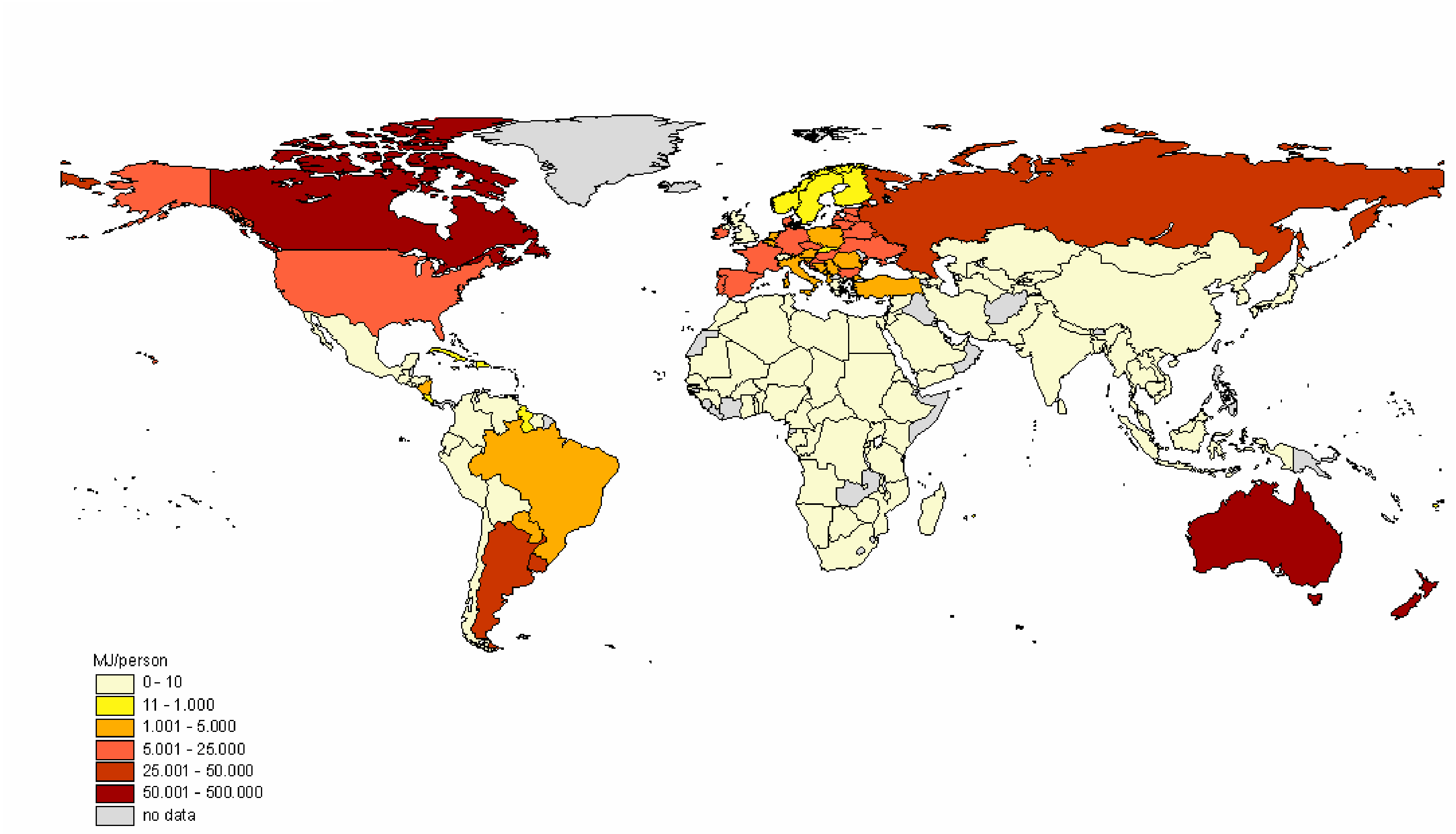
Sub scenario 3 PE potential PJ per year	2010		2015			2020			2050		
	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
China	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
India	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Rest of Asia											
Bangladesh	0	0	0	0	0	0	0	0	0	0	0
Nepal	0	0	0	0	0	0	0	0	0	0	0
Pakistan	0	0	0	0	0	0	0	0	0	0	0
Sri Lanka	0	0	0	0	0	0	0	0	0	0	0
North Korea	0	0	0	0	0	0	0	0	0	0	0
Mongolia	0	0	0	0	0	0	0	0	0	0	0
Indonesia	0	0	0	0	0	0	0	0	0	0	0
Cambodia	0	0	0	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0	0	0	0
Laos	0	0	0	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0	0	0	0
Vietnam	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Latin America											
Guatemala	0	0	0	0	0	0	0	0	0	0	0
Cuba	0	0	0	0	0	0	0	0	0	0	0
Dominican Republic	0	0	0	0	0	0	0	0	0	0	0
Haiti	0	0	0	0	0	0	0	0	0	0	0
Honduras	0	0	0	0	0	0	0	0	0	0	0
El Salvador	0	0	0	0	0	0	0	0	0	0	0
Nicaragua	0	0	0	0	0	0	0	0	0	0	0
Costa Rica	0	0	0	0	0	0	0	0	0	0	0
Jamaica	0	0	0	0	0	0	0	0	0	0	0
Brazil	0	434	0	1,571	0	0	2,447	0	0	0	0
Colombia	0	0	0	0	0	0	0	0	0	0	0
Argentina	2,597	218	2,215	1,113	0	1,854	2,526	0	0	0	0
Peru	0	0	0	0	0	0	0	0	0	0	0
Venezuela	0	0	0	0	0	0	0	0	0	0	0
Chile	0	0	0	0	0	0	0	0	0	0	0
Ecuador	0	0	0	0	0	0	0	0	0	0	0
Bolivia	1	0	1	1	0	5	12	0	0	0	0
Paraguay	10	0	10	2	0	26	19	0	0	0	0
Uruguay	136	18	0	151	0	0	434	0	0	0	0
Guyana	0	0	0	1	0	0	2	0	0	0	0
Suriname	0	0	0	0	0	0	0	0	0	0	0
	2,744	**670**	**2,226**	**2,839**	**0**	**1,885**	**5,440**	**0**	**0**	**0**	**0**

Sub scenario 3	2010		2015			2020			2050		
PE potential PJ per year	biogas	SRC	biogas	SRC	hay	biogas	SRC	hay	biogas	SRC	hay
Sub-Saharan Africa											
Nigeria	0	0	0	0	0	0	0	0	0	0	0
Ethiopia	0	0	0	0	0	0	0	0	0	0	0
Dem. Rep. of the Congo	0	0	0	0	0	0	0	0	0	0	0
South Africa	0	0	0	0	0	0	0	0	0	0	0
Tanzania	0	0	0	0	0	0	0	0	0	0	0
Kenya	0	0	0	0	0	0	0	0	0	0	0
Uganda	0	0	0	0	0	0	0	0	0	0	0
Ghana	0	0	0	0	0	0	0	0	0	0	0
Mosambique	0	0	0	0	0	0	0	0	0	0	0
Madagascar	0	0	0	0	0	0	0	0	0	0	0
Cameroon	0	0	0	0	0	0	0	0	0	0	0
Angola	0	0	0	0	0	0	0	0	0	0	0
Mali	0	0	0	0	0	0	0	0	0	0	0
Burkina Faso	0	0	0	0	0	0	0	0	0	0	0
Zimbabwe	0	0	0	0	0	0	0	0	0	0	0
Malawi	0	0	0	0	0	0	0	0	0	0	0
Niger	0	0	0	0	0	0	0	0	0	0	0
Senegal	0	0	0	0	0	0	0	0	0	0	0
Chad	0	0	0	0	0	0	0	0	0	0	0
Guinea	0	0	0	0	0	0	0	0	0	0	0
Rwanda	0	0	0	0	0	0	0	0	0	0	0
Burundi	0	0	0	0	0	0	0	0	0	0	0
Benin	0	0	0	0	0	0	0	0	0	0	0
Togo	0	0	0	0	0	0	0	0	0	0	0
Eritrea	0	0	0	0	0	0	0	0	0	0	0
Central African Republi	0	0	0	0	0	0	0	0	0	0	0
Republic of the Congo	0	0	0	0	0	0	0	0	0	0	0
Mauretania	0	0	0	0	0	0	0	0	0	0	0
Namibia	0	0	0	0	0	0	0	0	0	0	0
Botswana	0	0	0	0	0	0	0	0	0	0	0
Gabon	0	0	0	0	0	0	0	0	0	0	0
Egypt	0	0	0	0	0	0	0	0	0	0	0
Algeria	0	0	0	0	0	0	0	0	0	0	0
Libya	0	0	0	0	0	0	0	0	0	0	0
Marocco	0	0	0	0	0	0	0	0	0	0	0
Sudan	0	0	0	0	0	0	0	0	0	0	0
Tunisia	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Middle East											
Iran	0	0	0	0	0	0	0	0	0	0	0
Saudi Arabia	0	0	0	0	0	0	0	0	0	0	0
United Arab Emirates	0	0	0	0	0	0	0	0	0	0	0
Yemen	0	0	0	0	0	0	0	0	0	0	0
Israel	0	0	0	0	0	0	0	0	0	0	0
Jordan	0	0	0	0	0	0	0	0	0	0	0
Syria	0	0	0	0	0	0	0	0	0	0	0
	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
world	**41,000**	**2,517**	**29,772**	**10,459**	**2,108**	**20,604**	**19,422**	**2,636**	**10,260**	**26,311**	**1,502**

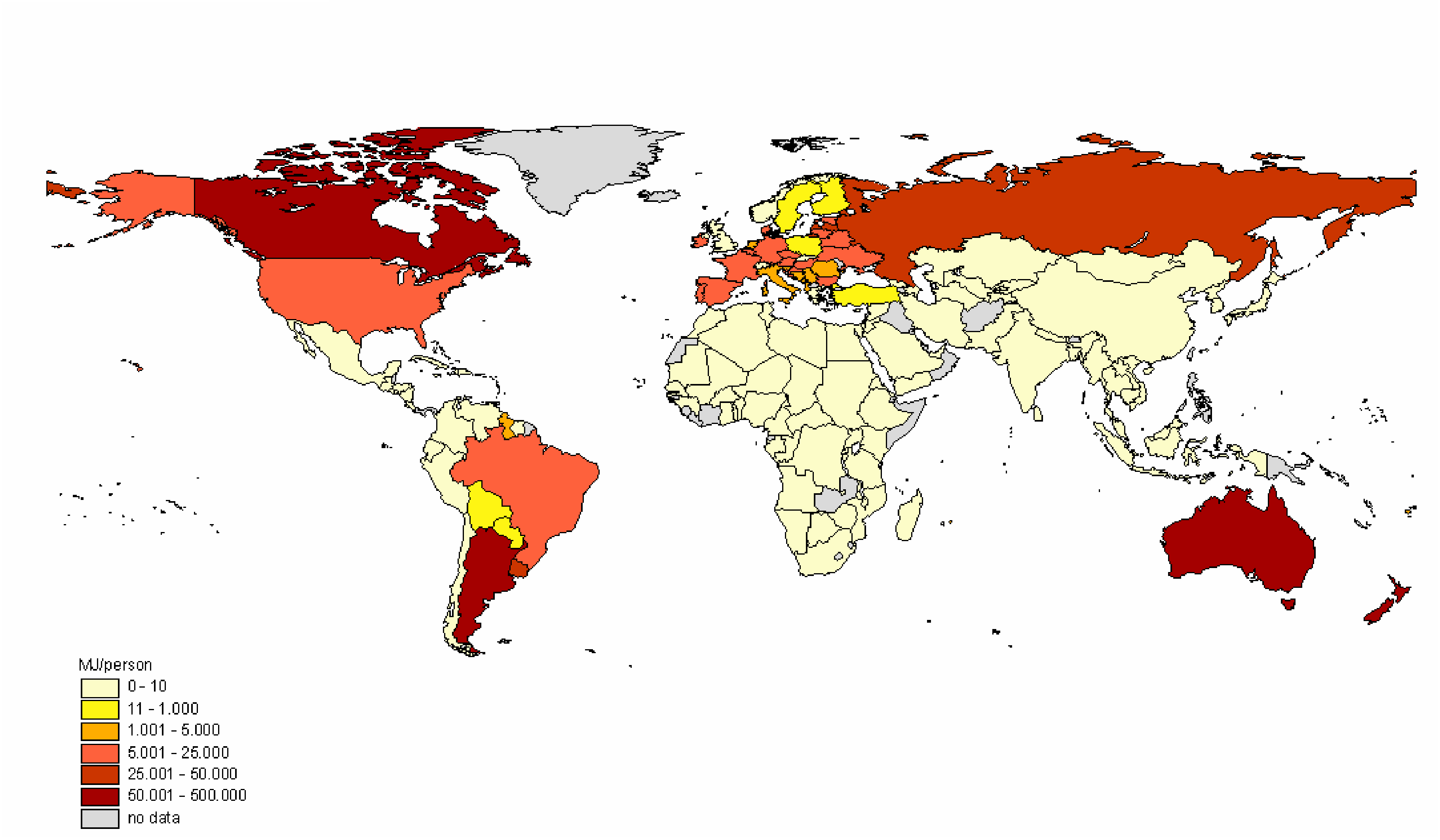
Annex 2: Maps of energy crop potentials

On the following pages the country specific energy crop potentials are visualized on world maps. To compare the potentials of all countries the data are converted in MJ per person.

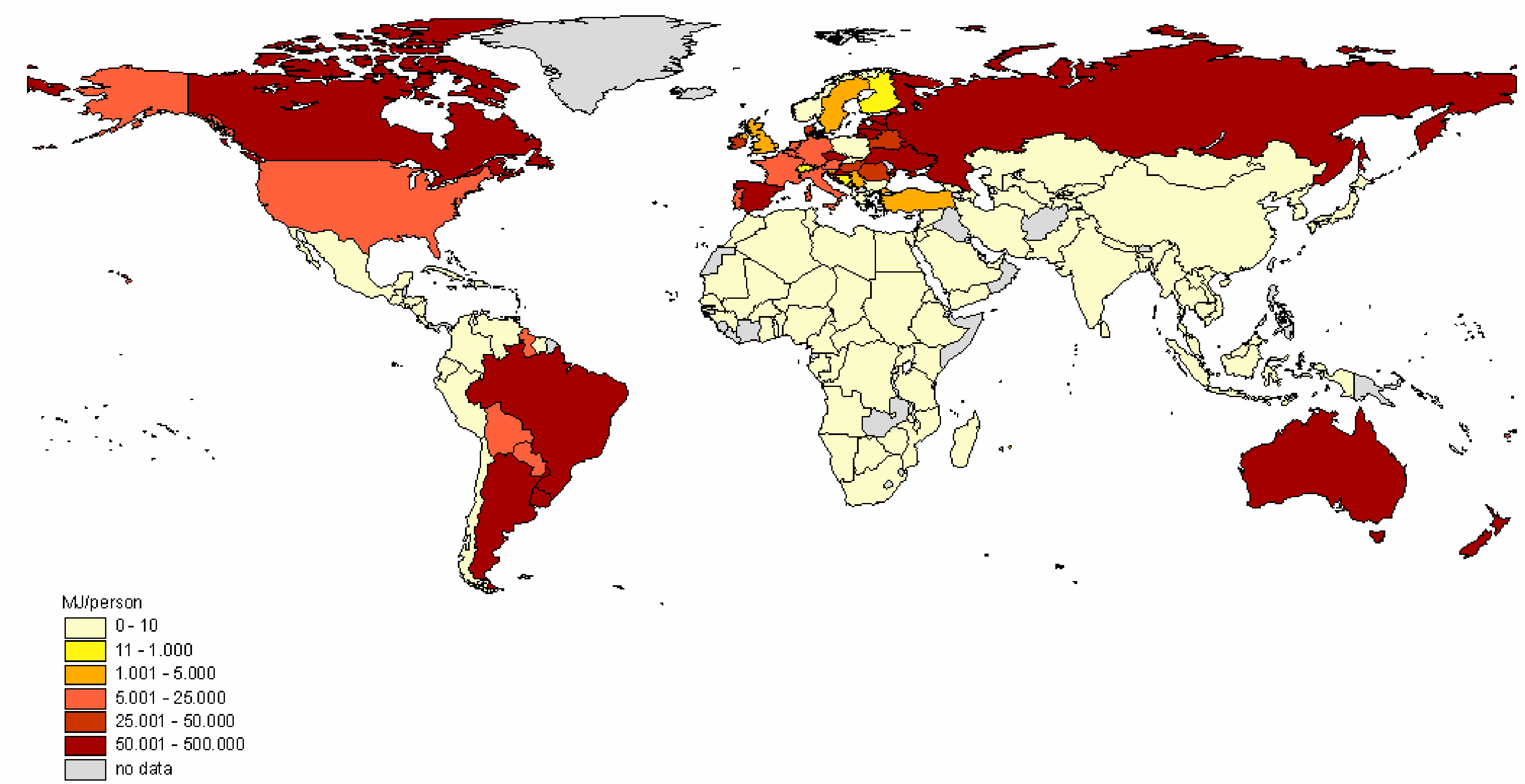
BAU scenario 2010



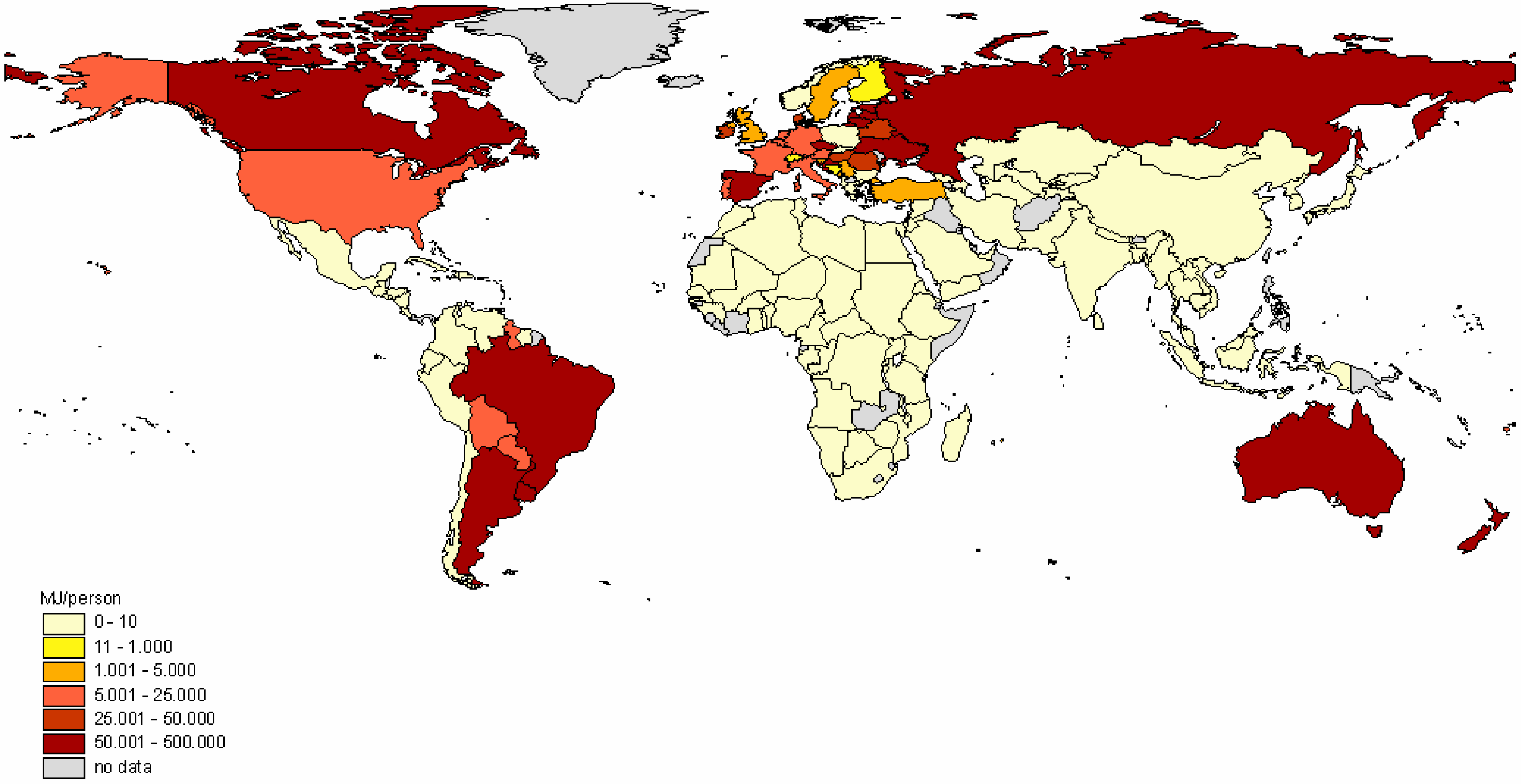
BAU scenario 2015



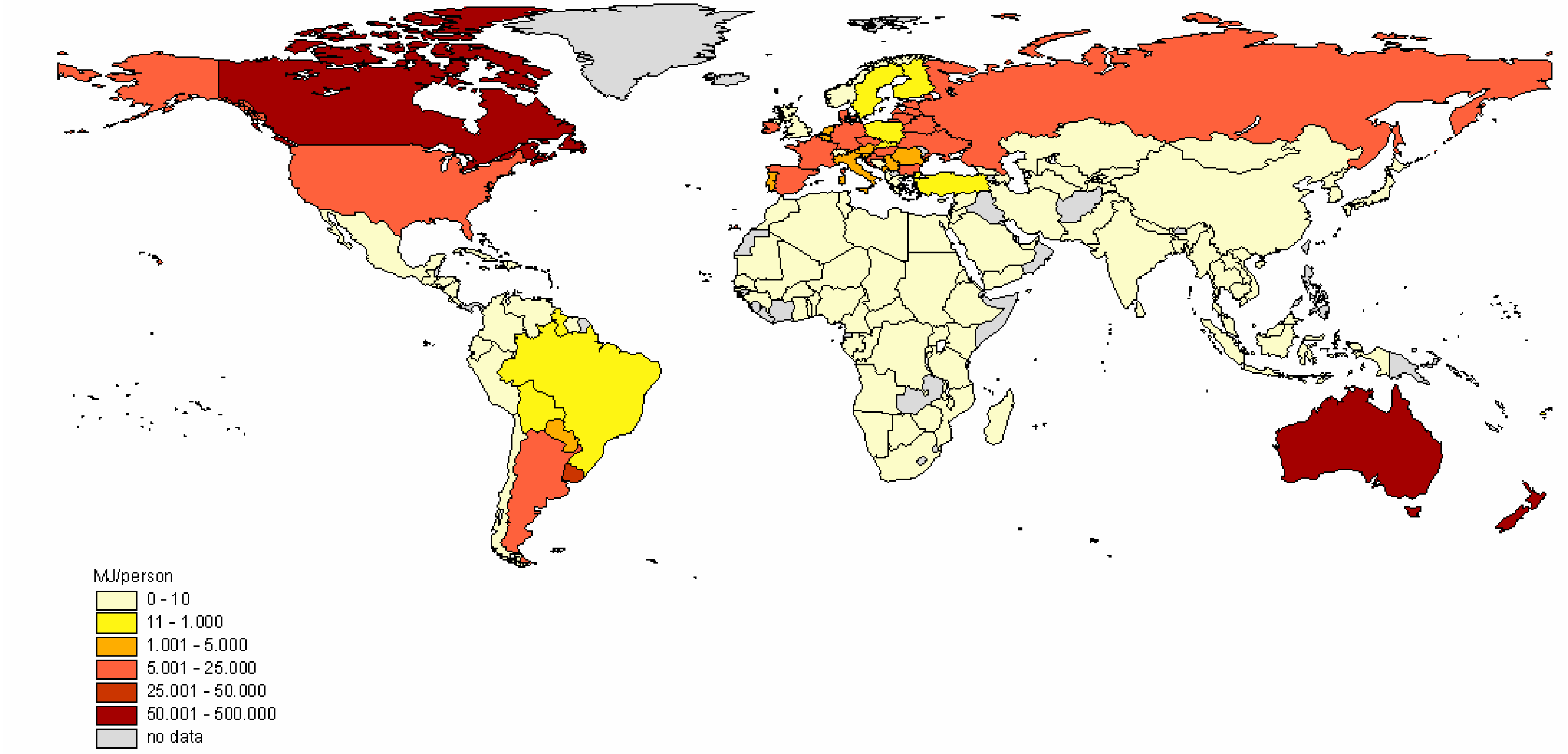
BAU scenario 2020



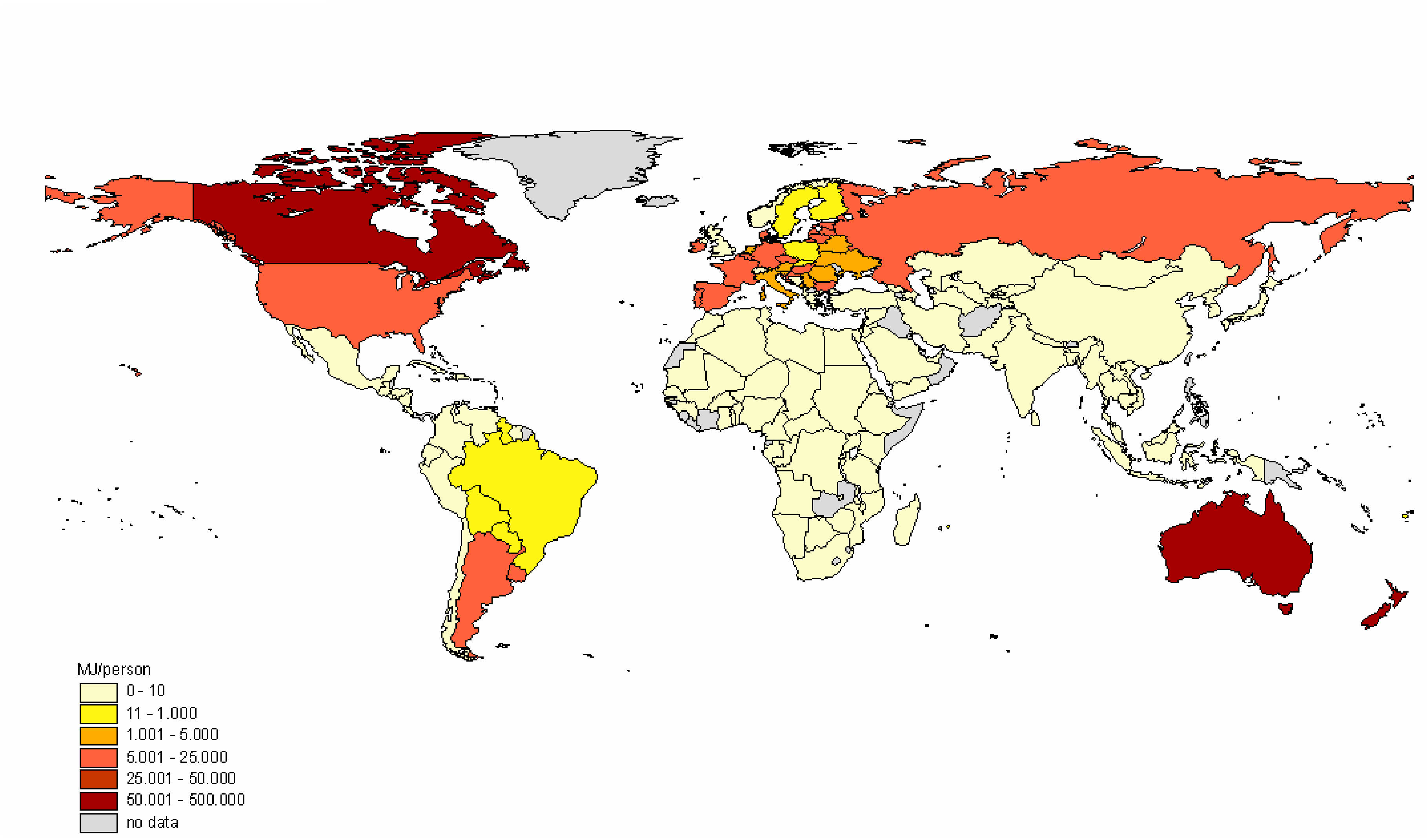
BAU scenario 2050



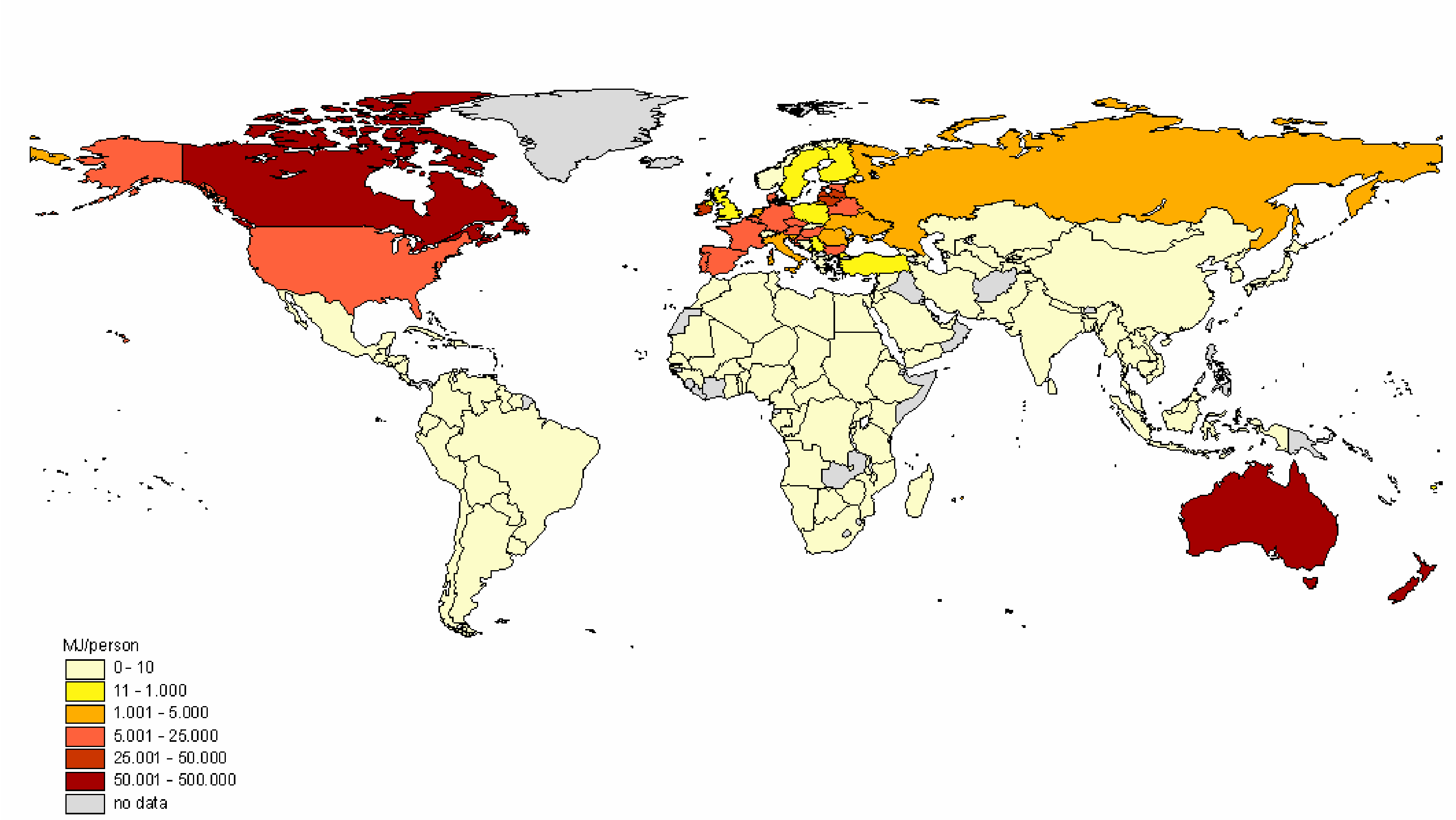
Basic scenario 2010



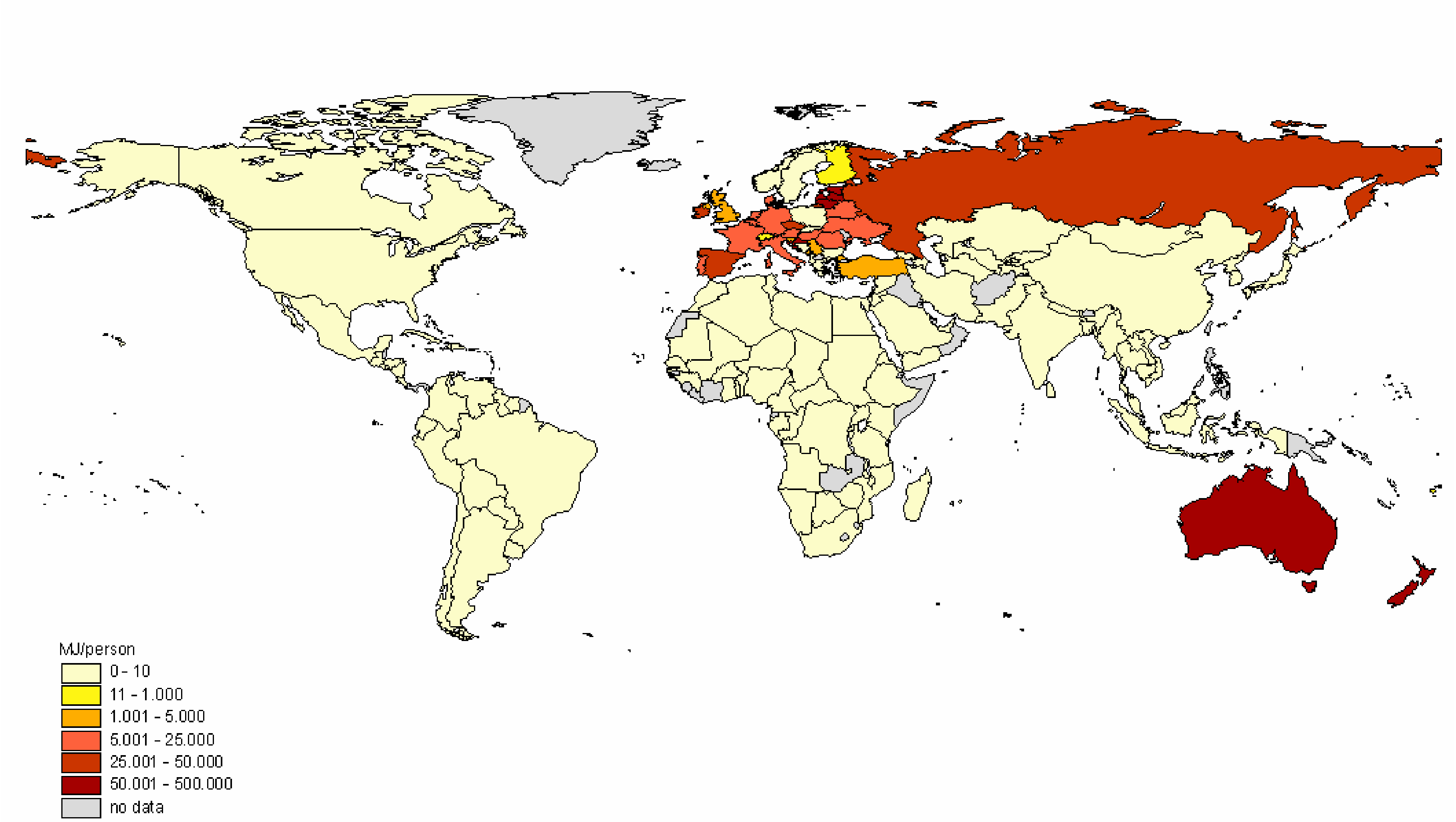
Basic scenario 2015



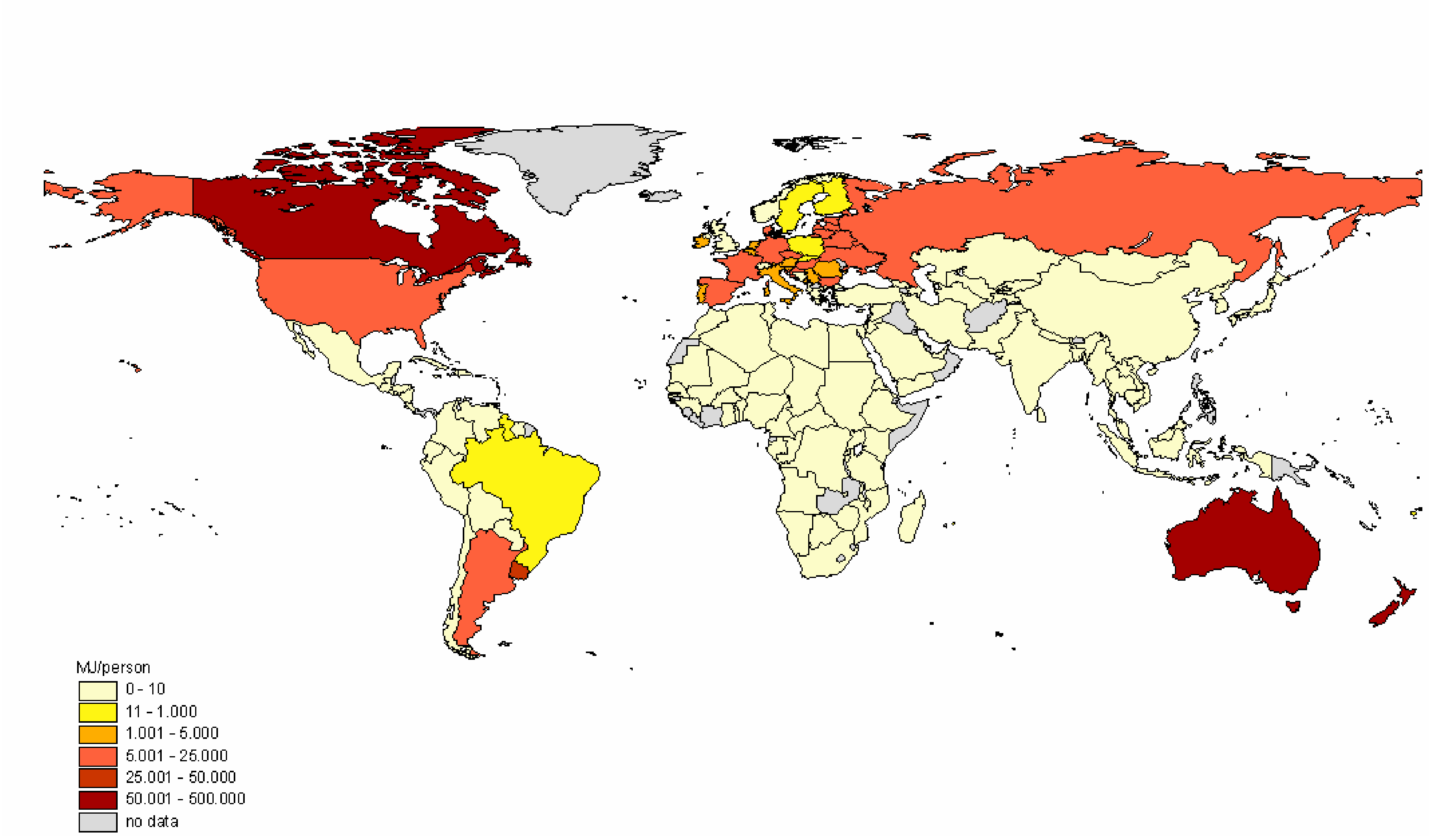
Basic scenario 2020



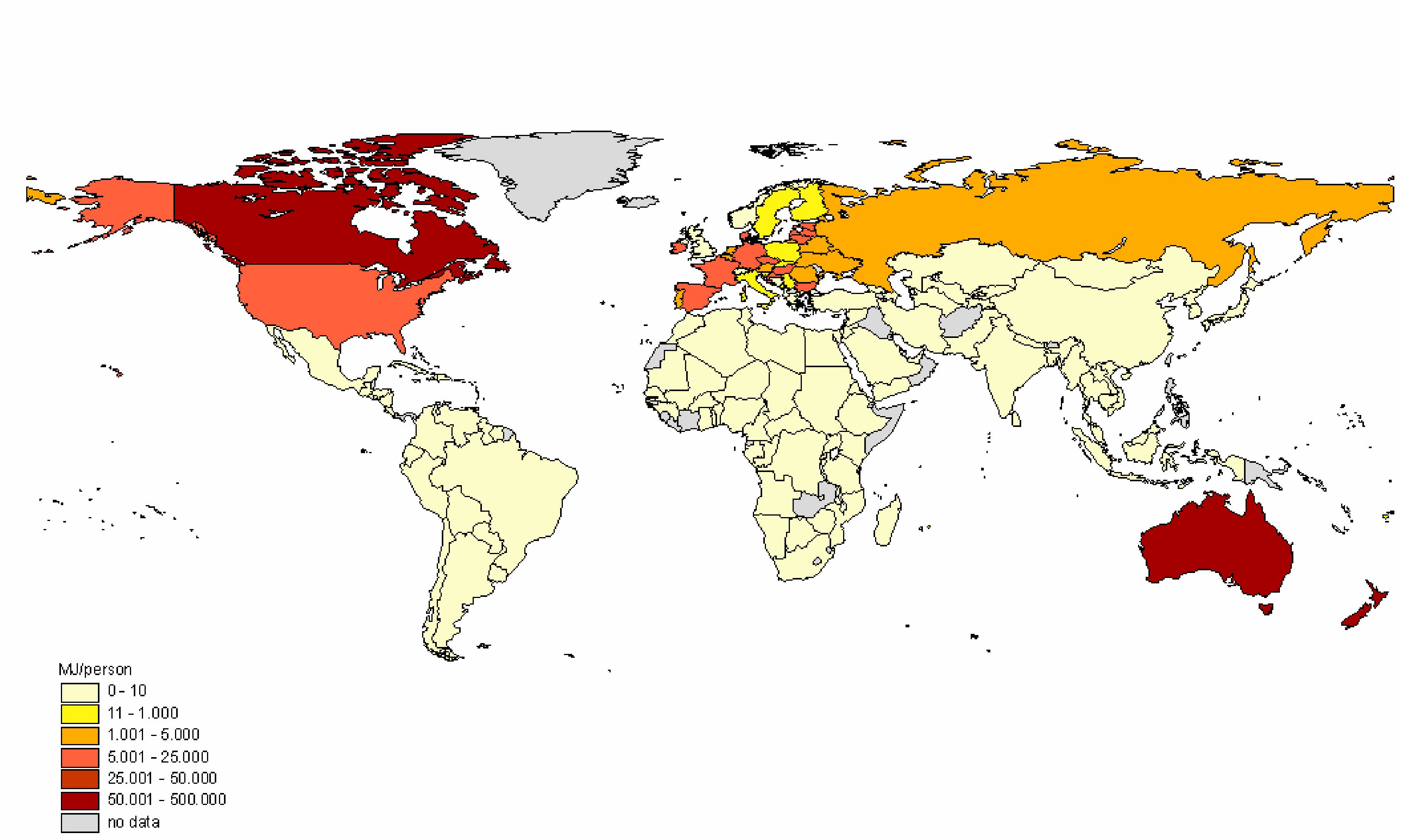
Basic scenario 2050



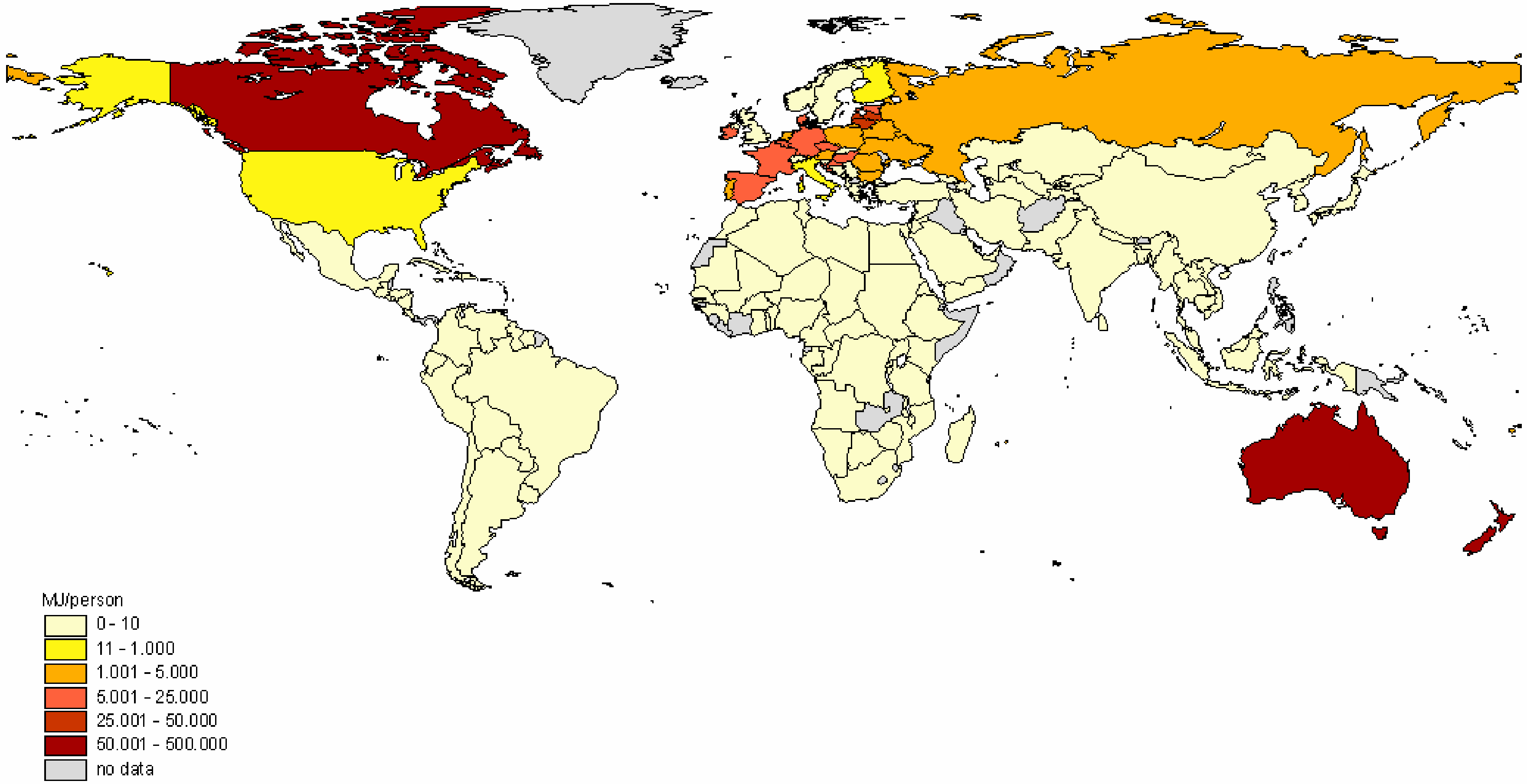
Sub 1 scenario 2010



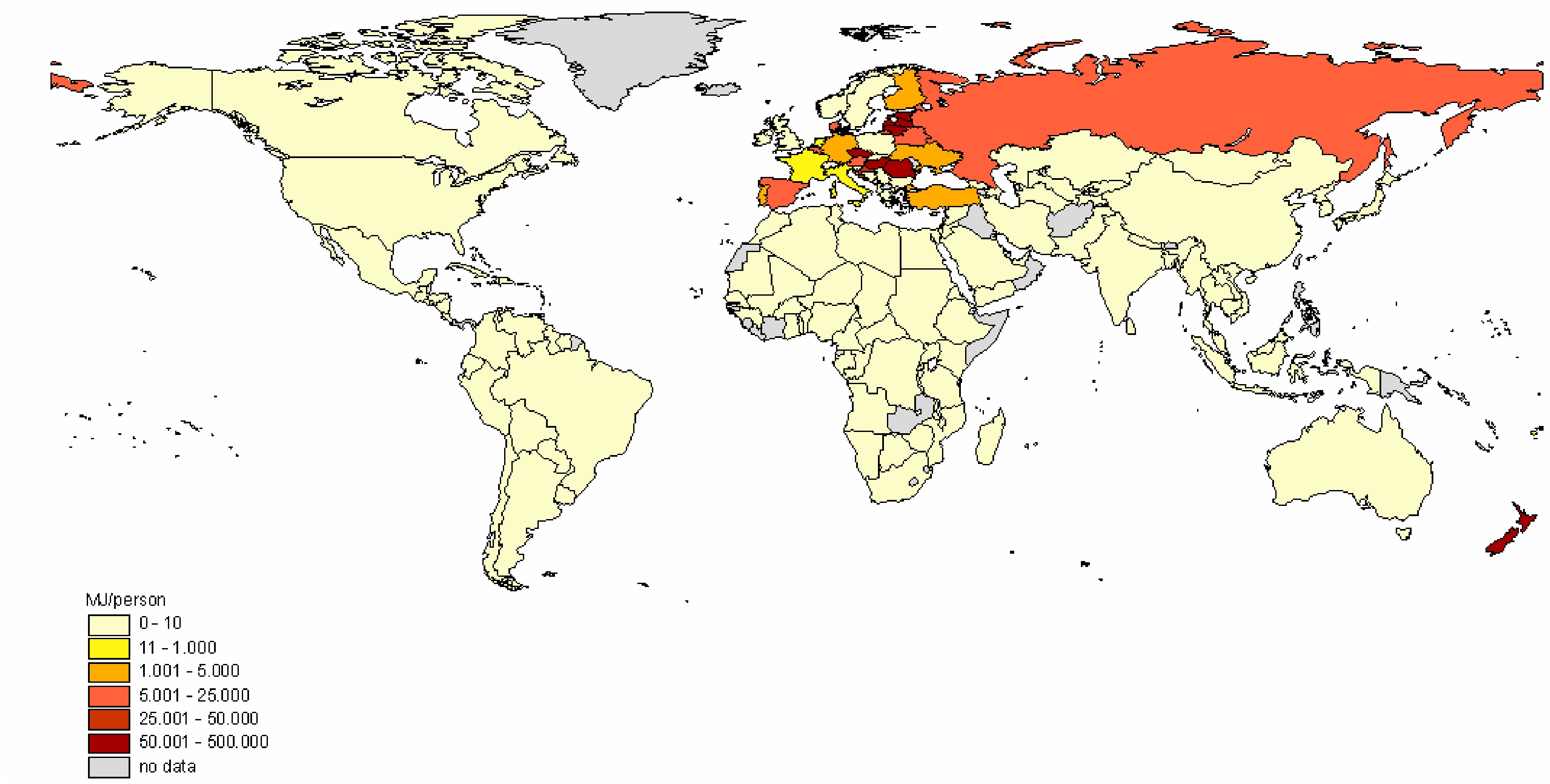
Sub 1 scenario 2015



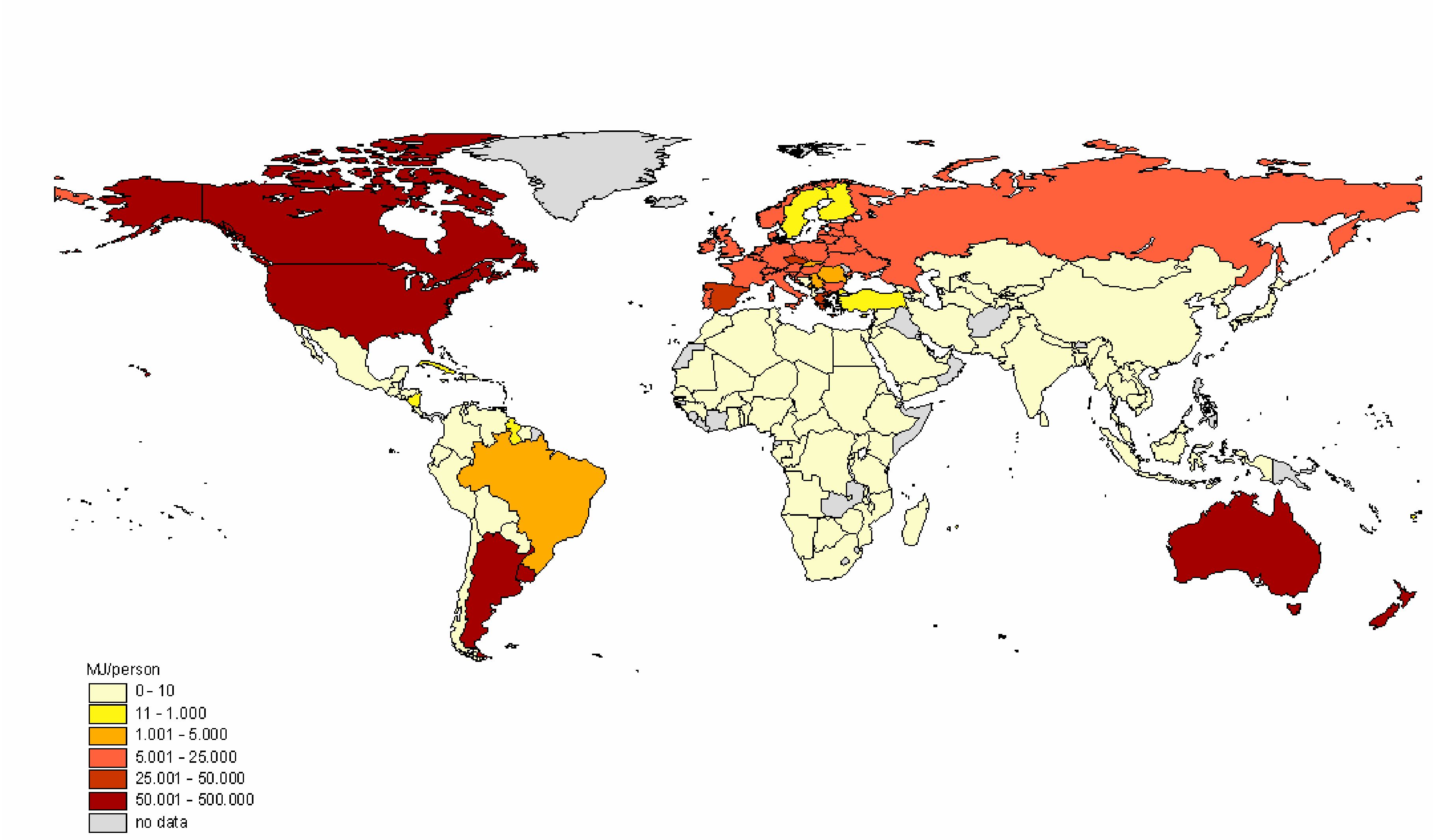
Sub 1 scenario 2020



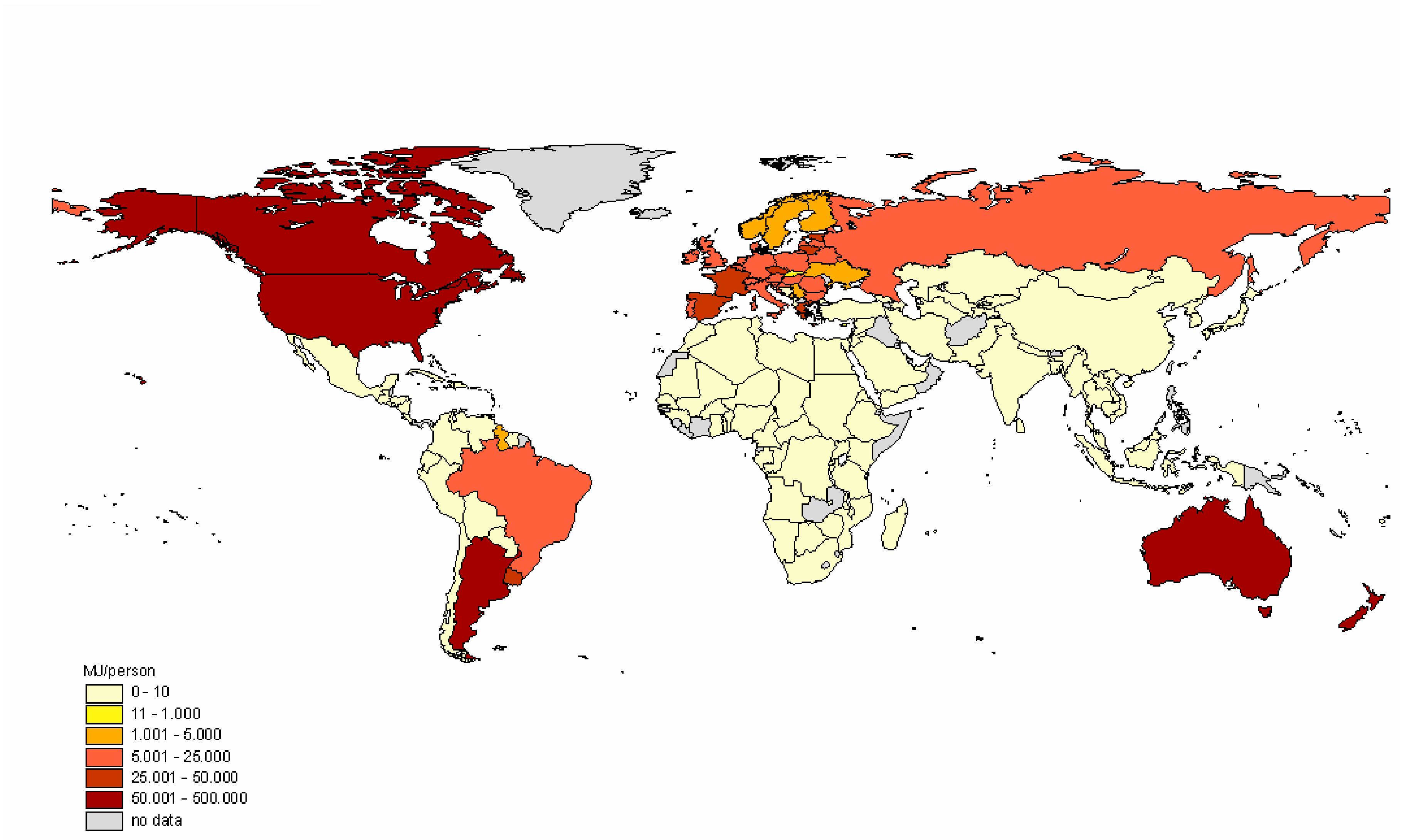
Sub 1 scenario 2050



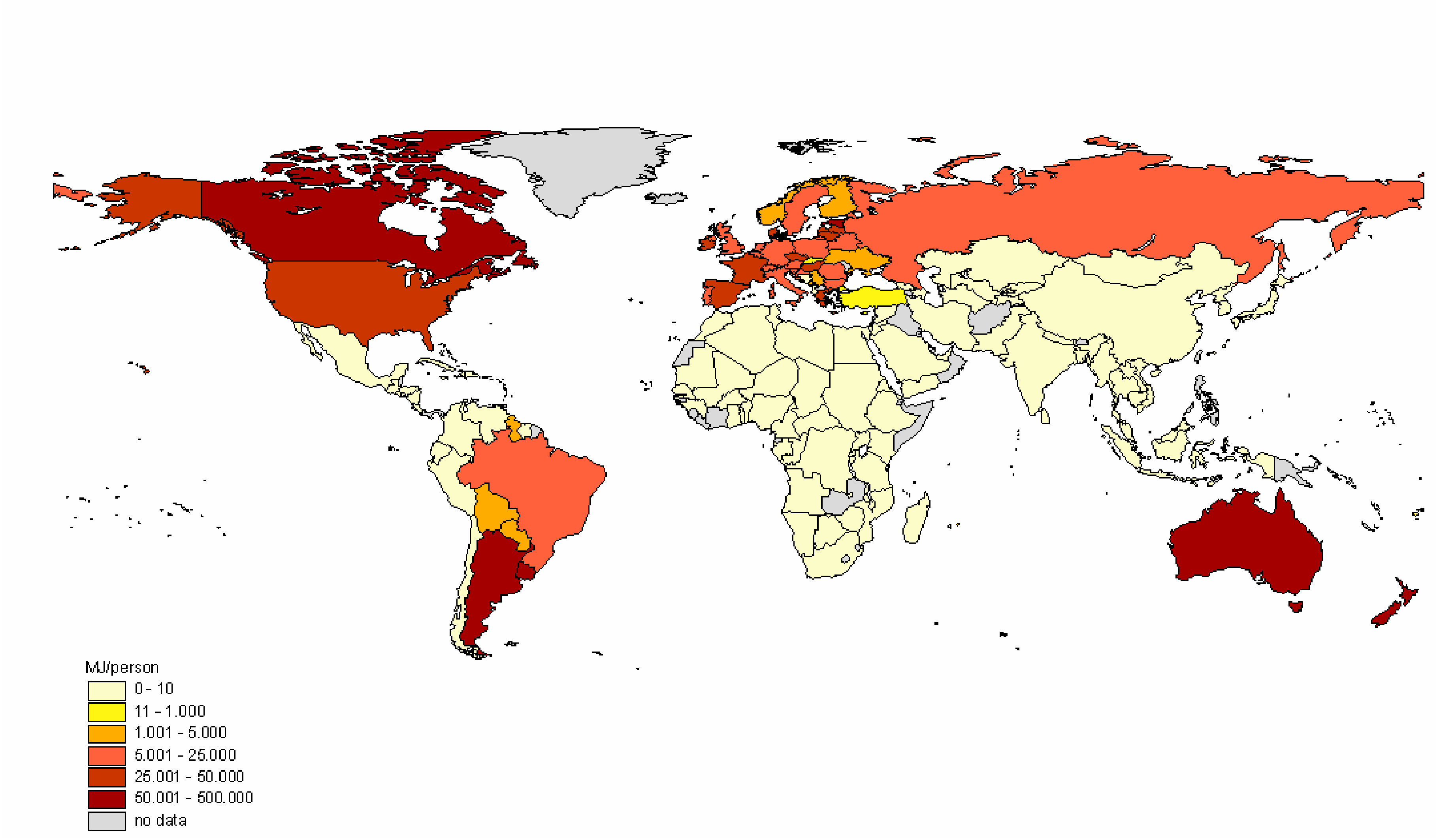
Sub 2 scenario 2010



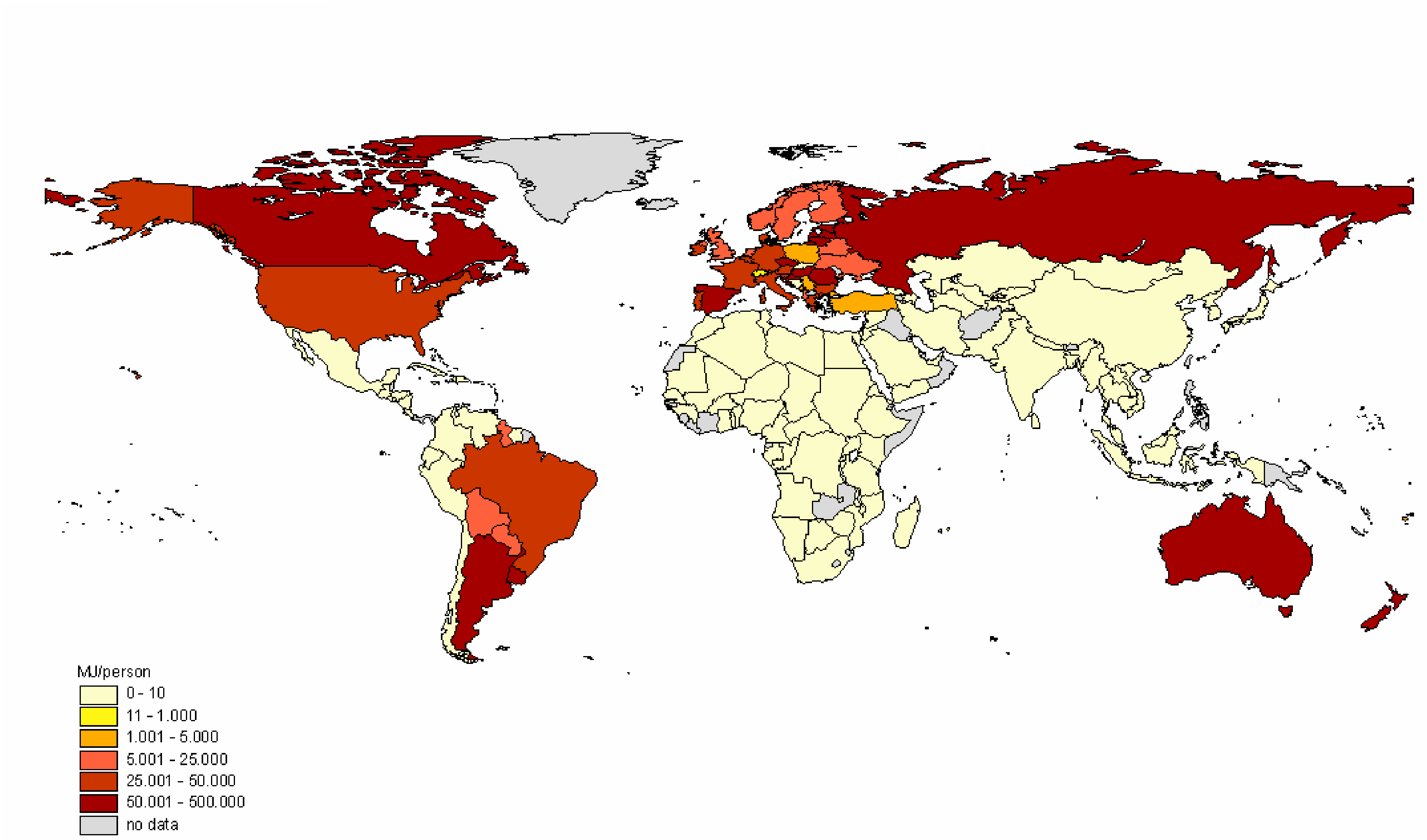
Sub 2 scenario 2015



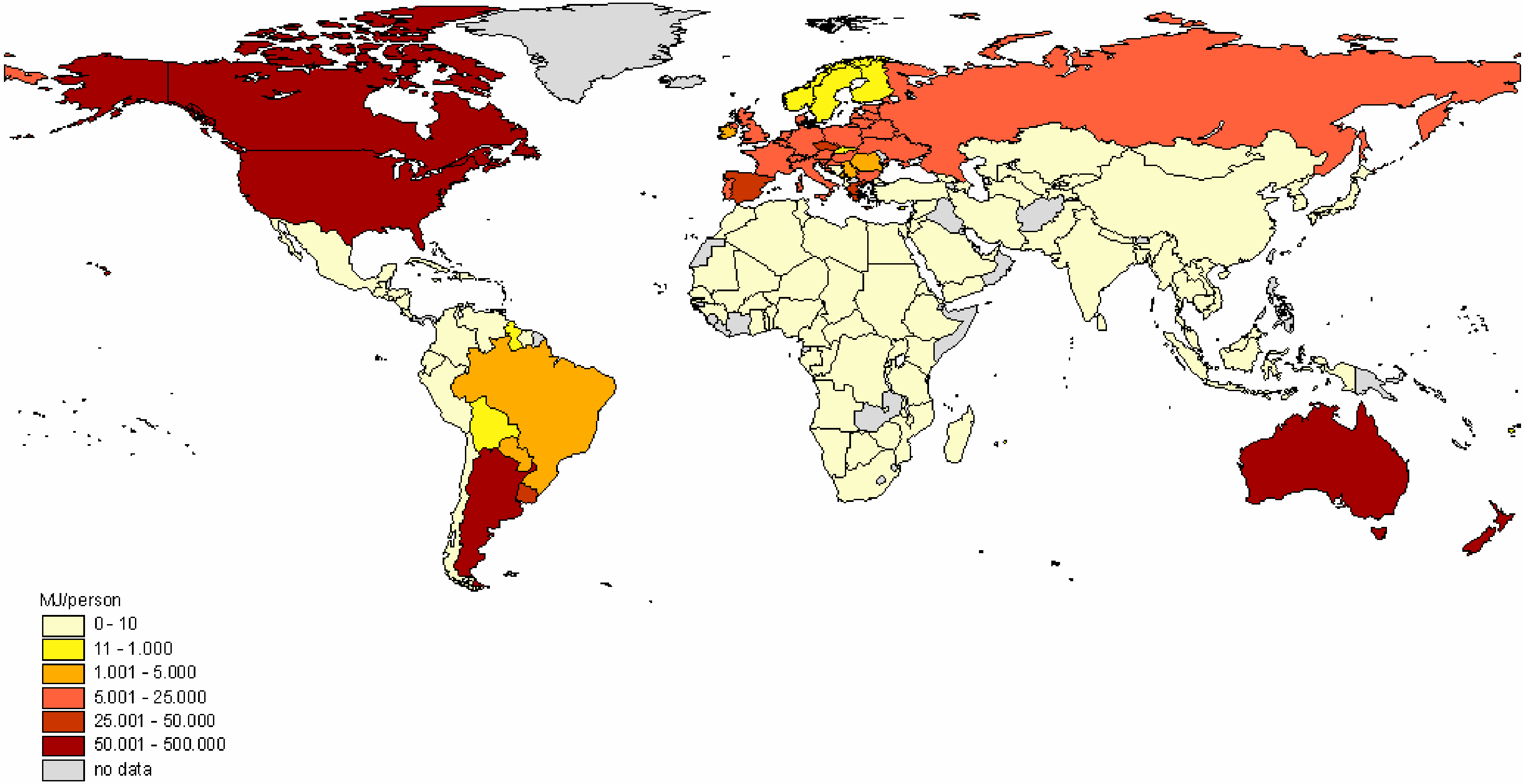
Sub 2 scenario 2020



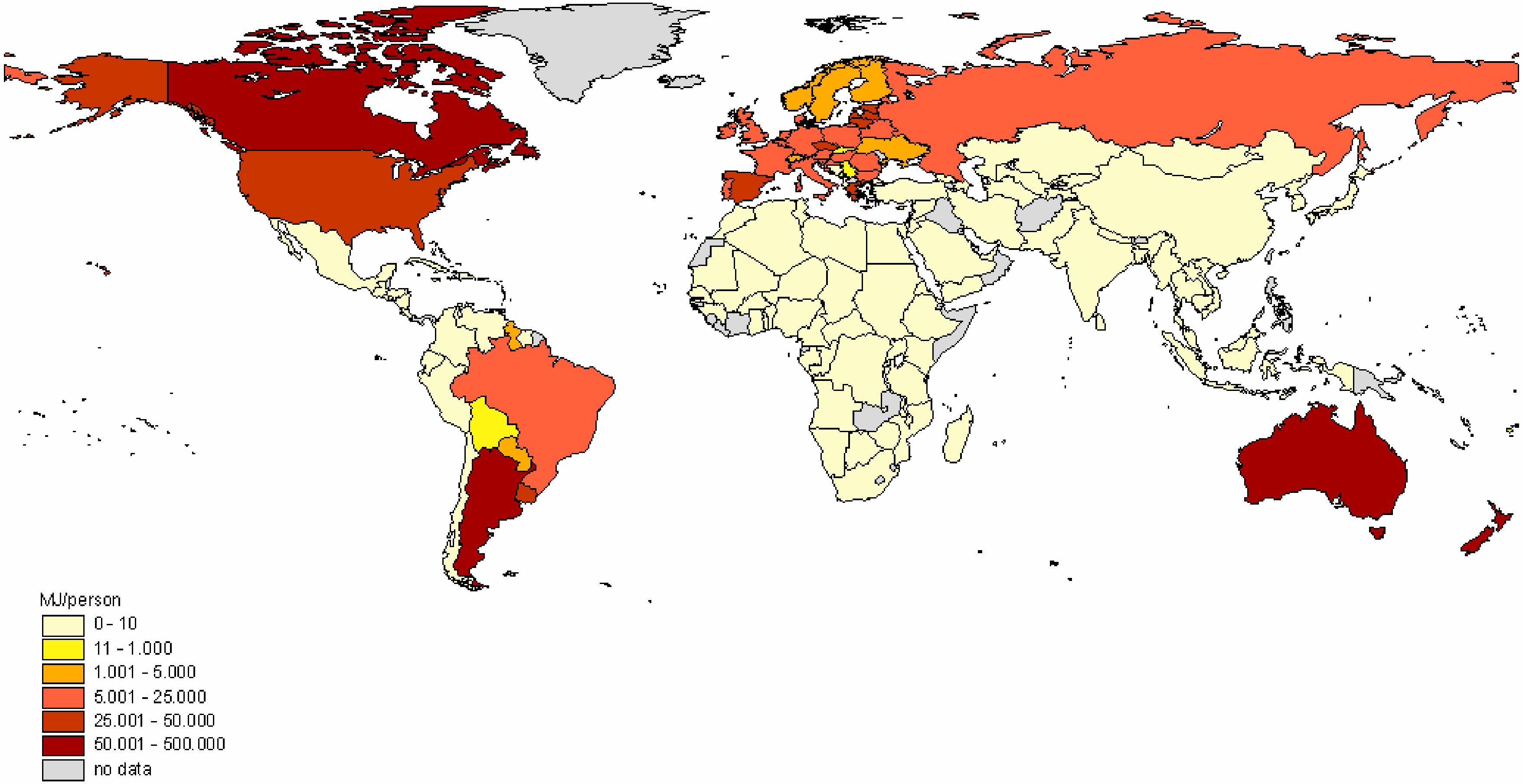
Sub 2 scenario 2050



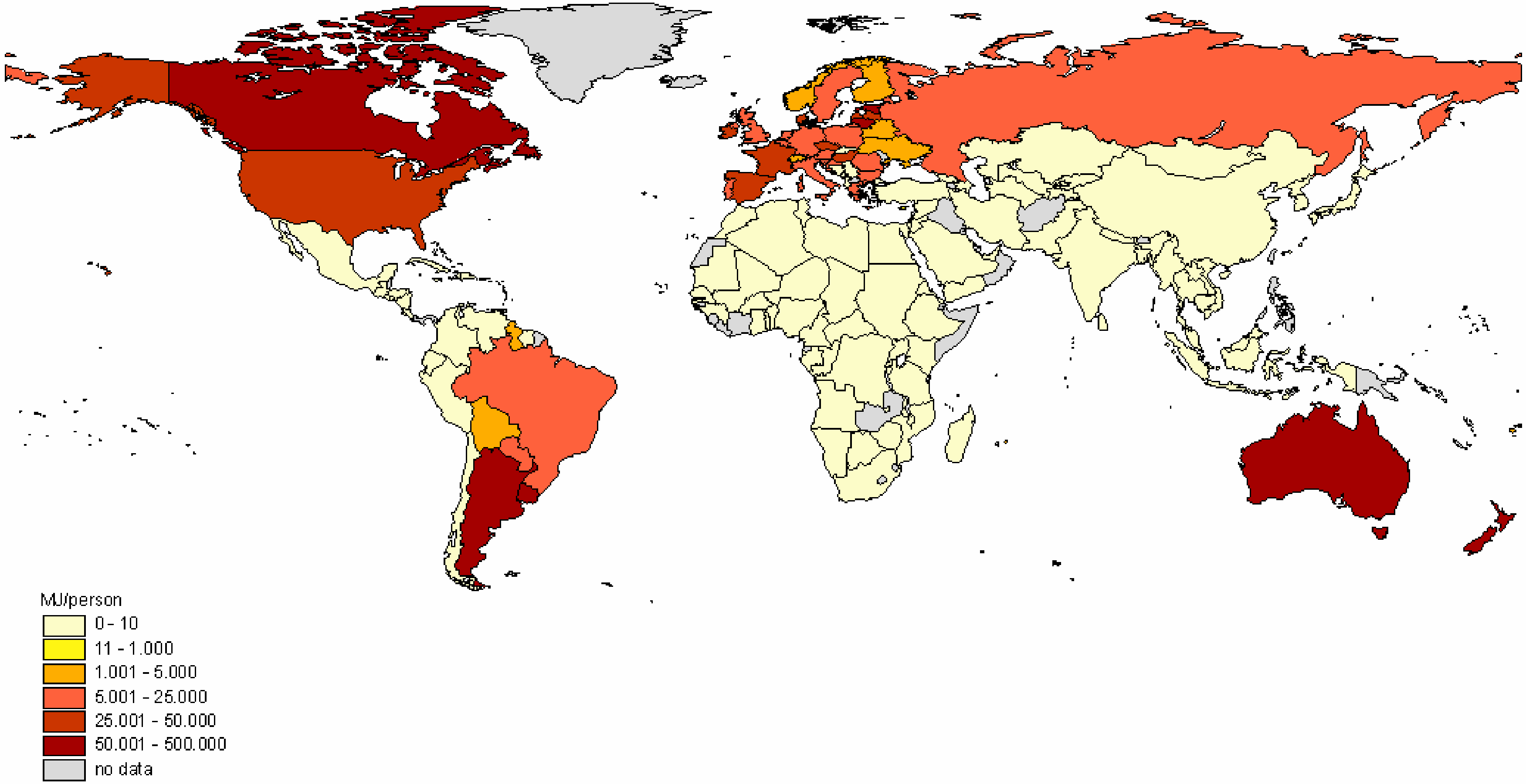
Sub 3 scenario 2010



Sub 3 scenario 2015



Sub 3 scenario 2020



Sub 3 scenario 2050