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Implementation of the IPCC SRES Scenario A1B with the Land Use Modelling Platform

Contribution to the JRC PESETA II project

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1. Introduction

The JRC PESETA II project (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis, Ciscar et al., 2013) provides background information on how climate change could affect a broad set of impact areas across the EU, ranging from impact on agriculture to impacts on human health and habitat suitability of tree species. The PESETA II project is based on bottom-up biophysical impact models that take into account the relationship between climate change and biophysical impacts in a structural way, modelling the relevant interactions and mechanisms using the same climate scenarios.

The climate scenarios considered in the PESETA II project are the following:

1) KNMI-RACMO2-ECHAM5 (A1B)
2) METO-HC-HadRM3Q0-HadCM3Q0 (A1B)
3) DMI-HIRHAM5-ECHAM5 (A1B)
4) MPI-REMO-E4 (E1)

Demographic and economic models provide projections of future population structure and economic outlook, respectively, under specific scenarios. Linked to these macro drivers is the additional land required to support future societal needs. These requirements, usually computed at national or regional scale, may cause tight competition for land at local level. A spatially explicit land use model is able to take into account such competition, and identify regions where the projected land requirements might not be entirely satisfied.

The Land Use Modelling Platform (LUMP) has been chosen to simulate land-use changes under a subset of scenarios (the aggregate of the A1B Scenarios listed above[1]). The modular structure of this platform, together with its high spatial resolution (100m), makes LUMP a suitable tool in the context of PESETAII. First, it guarantees high flexibility in adapting to the input/output interface required by the macro-economic models developed within this project. Moreover, an important added value to the

[1] For the remainder of the document, the aggregate of the A1B Scenarios will be referred to as the AIB Scenario.

modelling chain of PESETAII is the capability of taking into account specific policies with spatial repercussions.

Specifically, this report outlines the contribution made to the PESETA II project using the land use model, as described in section 2 and 3. In addition, we looked at how hydropower potential would change in time depending on the climate scenario as modeled using LISFLOOD (Van der Knijff, 2010). This aspect is explained in section 4.

2. The Land Use Modelling Platform

The Land Use Modelling Platform (LUMP) was developed for the Institute for Environment and Sustainability of the European Commission Joint Research Centre (JRC-IES) to support the policy needs of different services of the European Commission, such as exploration of future policies and impact assessments of specific proposals.

LUMP is composed of three main modules: Land claims, Land allocation and Impact assessment indicators (Figure 1).

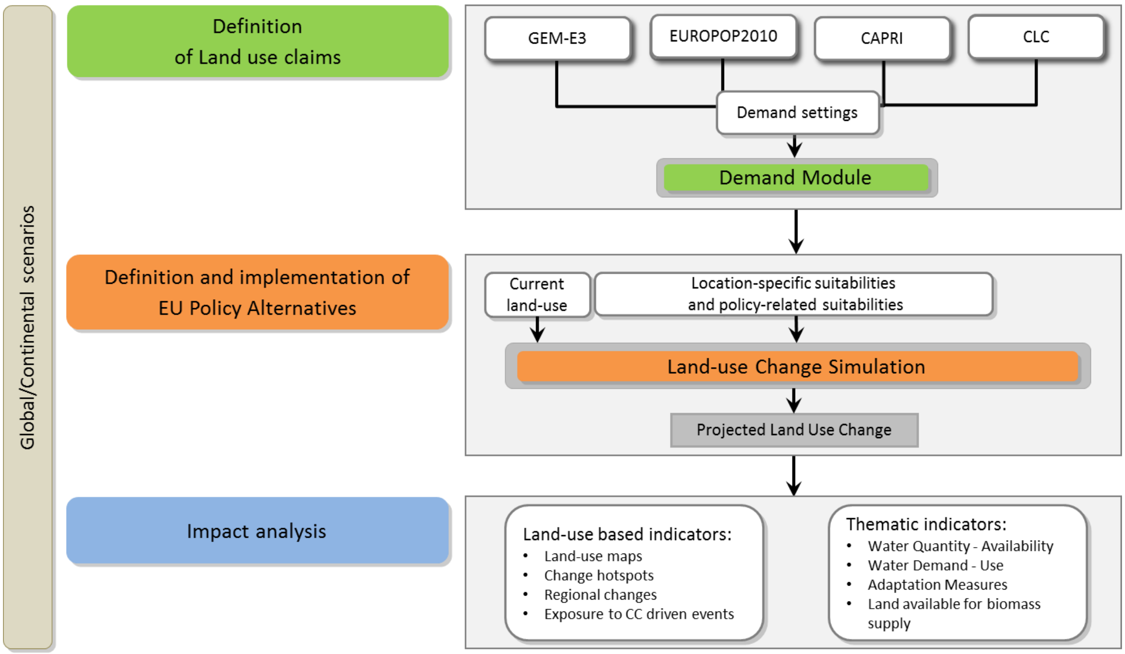

Figure 1. Main modules of the Land Use Modelling Platform.

The first module determines the amount of land claimed per sector. In this module the global and regional economic drivers are integrated into LUMP through a variety of interfaces with external, sector-specific models. Within this specific configuration of the model for the PESETAII Project, the datasets containing the land claims are expressed in hectares. The land claimed per sector and per region is then passed onto the next module, the land allocation module, which is able to resolve the land competition within each region.

The 100m resolution version of EU-ClueScanner land use model is at the core of the land allocation module of LUMP. The land claims are disaggregated spatially according to the overall suitability of the land for the simulated land uses. The overall suitability determines the probability for conversions between land uses. The suitability of a specific location for a specific land use type is function of biophysical and policy-related factors as well as the rules governing conversions, transition potentials and neighborhood relationships. All these aspects are calibrated statistically and/or defined according to empirical observations. The initial distribution of land use is based on the CLC 2006 map.

The third module illustrated in Figure 1 refers to the indicator module. It is by far the most subject to change, because the selection of the indicators is project-specific. This module is not further described in this section, as our focus here is on the potential future land use changes under the A1B scenario.

Land claims (module 1)

We can identify four major sources that helped us estimating future land use claims in the context of the PESETA II project:

1. The Common Agricultural Policy Regionalised Impact Modelling System (CAPRI) for agricultural land uses;
2. Corine Land Cover (CLC) for all modelled land use classes;
3. EUROSTAT EUROPOP projections for urban/residential land use;
4. General Equilibrium Model for Economy–Energy–Environment (GEM-E3) for industry, commerce and services land uses.

Among the sector-specific models that are linked to the LUMP is the Common Agriculture Policy Regionalised Impact (CAPRI) model (Britz, 2011b). A number of modifications were made to the EUCS100 model to accommodate CAPRI, among which modifications in the land use typologies, re-calibration and development of new crop suitability maps (Mubareka et al, 2013). The supply detail data of crops from the CAPRI model are used to define the demands for agricultural land in LUMP, i.e. arable land, permanent crops and pastures.

Historically, demographic and economic growth have always led to land use changes, namely the expansion of the built-up infrastructure. In this exercise, Urban and Industry-Commerce-Services (ICS) land uses were determined separately. Urban expansion was assumed to be a function of population growth, whereas ICS expansion was assumed as a function of the economic growth. Economic growth is, in turn, influenced by the demographic volume and structure. Therefore, in our approach, demography influences (directly or indirectly) both the expansion of urban and ICS land uses.

With regards to the economy, results from the simulation of the A1B Scenario using the general equilibrium model GEM-E3 were used. This scenario assumes a compound annual GDP growth rate of 2.49% for the EU countries in the period 2010-2030. GDP growth rates range from 1.3% to a maximum of 3%, depending on the country. On the demographic side, the most recent Eurostat projections were used (EUROPOP 2010). Demographic growth is much more modest for the same period, with a compound annual growth rate of only 0.21% for the countries under consideration. However, within the EU, the projected growth rates vary from -0.67% to 0.83%. Negative growth rates can be found in countries like Germany, Bulgaria, Romania, and in the Baltic, due to projected negative natural growth (drop in fertility), and/or negative net migration.

In order to estimate the future demand for urban land use, we first calculate the population density for each NUTS2 region in Europe, for the years 1990, 2000 and 2006. For that matter, the population density is defined as the average number of people per hectare of urban land (D = inhabitants / urban land). In a region with high population density, urban areas are normally more compact on average than in a region with low population density. The observed density trend between 1990 and 2006 is assumed to evolve linearly in the future. Finally, the projected population is divided by the projected population density in order obtain an estimate of future urban land demand. As such, the future urban land demand is the result of the interaction of population growth and the decreasing or increasing density of urban areas. From this interaction, different outcomes are theoretically possible (Figure 2). Minimum and maximum bounds for this estimate are finally computed in accordance to historical regional variability.

The results of this approach using input from A1B Scenario are shown in Figure 3. A general increase of the urban land is predicted, following roughly the trend observed in the period 2000-2006. By 2030, urban land should cover between 17.5 and 19 million hectares in Europe, which represents a medium increase of 21% compared to 2000. The minimum and maximum ranges are used as input to the allocation step of the LUMP, and the actual expansion of urban built-up is situated somewhere within that interval.

The extent to which the actual expansion of urban land is closer to the minimum or to the maximum depends chiefly on the dynamics between the different competing land uses. On Figure 3 (on the right), it can be seen that the growth of urban is not a linear function of the population growth. In fact, it has been observed that in the last decades urbanization happens at a faster pace than population growth (OECD 2012). The estimations done for PESETA II, assume that such process will continue in the future.

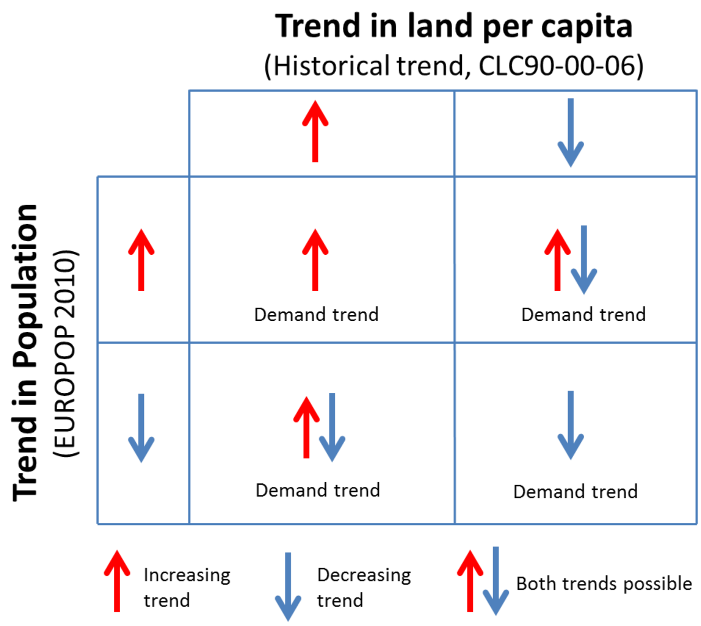

Figure 2. Possible trends of future urban land demand, depending on future population projections and observed population density trends.

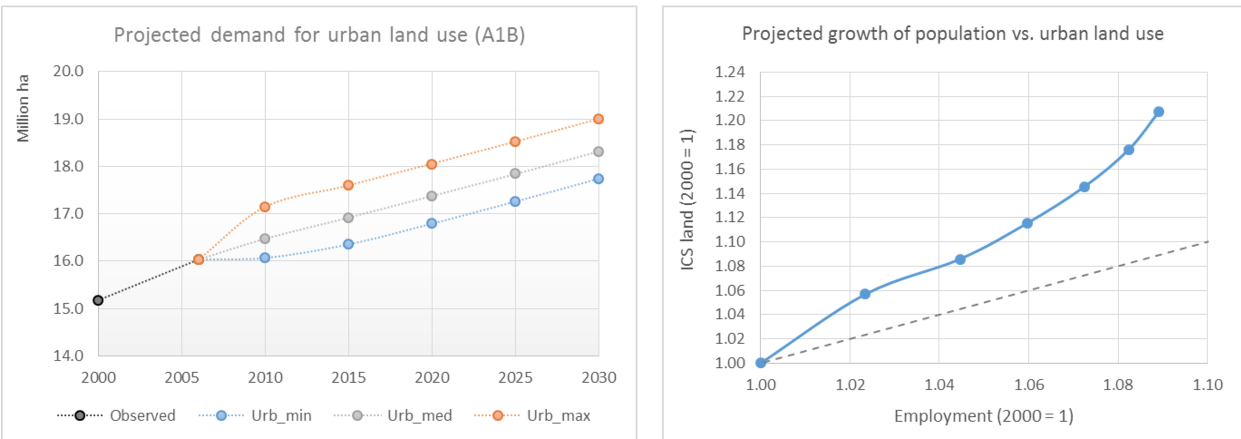

Figure 3. Projected demand for urban land use in Europe, 2000-2030.

The estimation of future demand for ICS land use is done in a similar fashion. A land use intensity indicator (Intensity = Employees / ICS land) is determined using historical data for the years 1990, 2000 and 2006. The intensity is linearly extrapolated to the simulation years. Finally, future estimates of the number of employees are divided by the projected land use intensity in order to derive future demand for ICS land use. Projected estimates of the number of employees are taken from the GEM-E3 model, A1B Scenario. Similarly, the estimates are done at regional level, and minimum and maximum bounds are determined according to historical land use change variability. The results of this approach are depicted in Figure 4, showing an overall increase to reach between 3.43 and 3.67 million hectares of industrial, commercial and services land use in Europe. The results of this estimation represent a slightly declining growth rate over the simulation period.

The expansion of built-up land (urban and ICS) is a relevant process in the context of environmental sustainability. The expansion of built-up infrastructure is essential to support a growing demography and economy, but it comes at certain environmental costs. Built-up involves the impermeabilization of the soil, and the conversion of natural or semi-natural to artificial land cover, often damaging ecosystems and hampering the flow/delivery of their goods and services. These changes are usually very costly to revert, and are therefore likely to remain in time.

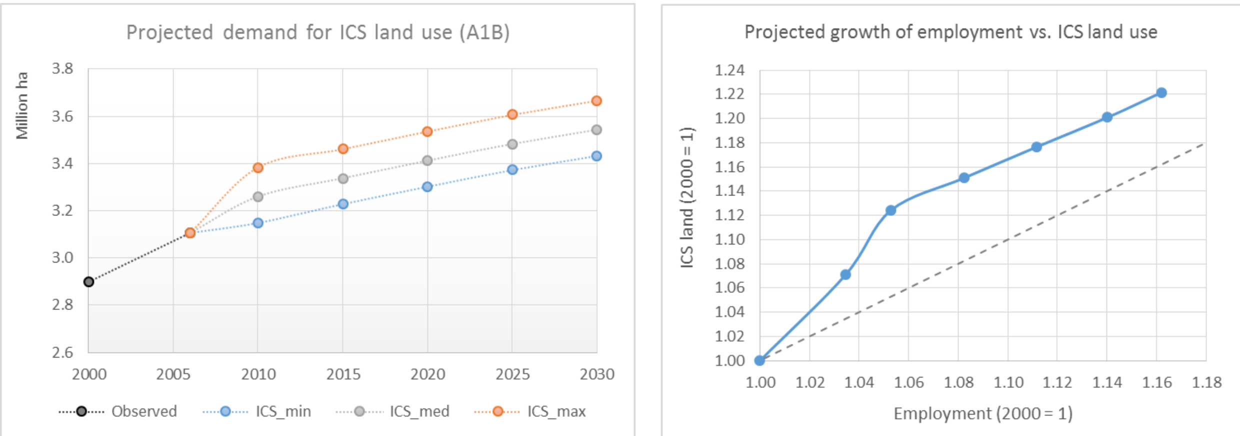

Figure 4. Projected demand for industrial, commerce and services land use in Europe, 2000-2030.

Claims for future forest land are determined by extrapolating the historical trend reported in the CORINE Land Cover time-series (1990, 2000 and 2006). Forestry claims are set only as a minimum cap in the model. By doing so, a maximum area of forest land use is not explicitly imposed and a minimum amount of forested land is ensured. Thus, in those NUTS regions where there is a negative trend in forested land, this land cover is only reduced if claims from other sectors are high and the currently forested land is suitable for other competing land uses.

Because there is no upper cap to the forest growth, the natural succession mechanism is not compromised, and abandoned agricultural land can eventually be converted into forest during the simulation.

Land allocation (module 2)

In the second module of the LUMP, the competition between land uses, whose claims were estimated in module 1, is resolved, based on the spatial characteristics of each raster cell. These spatial characteristics incorporate biophysical suitability, neighbourhood effects and policy-related effects. Details of each of these factors can be consulted in Lavalle et al. (2011a). The EUCS100 model is calibrated using multinomial logistic regression for both biophysical suitability and neighbourhood effects on a per-land-use basis, as described in detail in Loonen et al. (2007) and Lavalle et al (2011a). The land use model is calibrated using the observed land-use patterns in the refined version of the 2006 Corine Land Cover map (Batista et al., 2013). The series of pre-determined suitability maps used in the calibration of the model are the following:

Accessibility set

1. Accessibility maps to nearest cities
2. Accessibility to nearest towns
3. Distance to roads

Biophysical suitability set

1. Elevation
2. Slope
3. Crop suitability maps

The accessibility datasets are further described in Lavalle et al. (2011a) and the elevation and slope maps were derived from the Shuttle Radar Topography Mission (SRTM). These datasets are available at 100-m resolution. The crop suitability maps were derived specifically to accommodate CAPRI data. A series of crop suitability maps, referred to as the AGRI4CAST map series and further described in Baruth et al. (2006) for cereals, root crops and maize were used to calibrate EUCS100. Two other layers were used to refine the AGRI4CAST maps: the biomass potential map (Toth et al., 2011) and the CLC 2006 refined map.

The policy provisions that are taken into consideration in the implementation of the A1B Scenario are as follows (for further details, refer to Lavalle et al. 2011b):

1. Natura2000: Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora and Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds;

2. Nitrate Vulnerable Zones (NVZ): Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC);

3. Erosion sensitive areas: the current GAEC framework (Council Regulation (EC) No. 73/2009, Annex III);

4. Less Favoured Areas (LFA): this payment scheme promotes agriculture production in areas with natural handicaps (Articles 18 and 20 of Council Regulation (EC) 1257/1999).

These policy provisions are translated with a series of spatially-explicit rules and restrictions applied within the allocation algorithm.

The CLC land use map for year 2006 was refined in both spatial and thematic resolution using additional datasets, as described in Batista et al. (2013). The land use classes were then aggregated into parent classes and divided into two main categories: Simulated and non-simulated land classes. The classes that are not simulated between 2006 and 2030 include *Grey infrastructure* (roads, railways, mines), *Other nature* (glaciers, sand dunes, beaches), *Wetlands*, *Water bodies*. The simulated land use classes include *Urban*, *Industrial*, *Arable* (includes cereals, maize and root crops), *Permanent crops*, *Pastures*, *Forests*, *Semi-natural vegetation*, *Abandoned arable, Abandoned permanent crop* and *Abandoned pastures*. The land use class Arable is only applicable for the first year of the run, after which more detailed CAPRI aggregate classes are introduced into the system. Semi-natural vegetation and Abandoned classes are simulated, although no specific claims are provided for these. Changes to these classes are governed primarily by the dynamics of the active classes and by specific policy-driven layers. In particular, Abandoned arable land, Abandoned permanent crops and Abandoned pastures emerge as a consequence of the decline in the claims of the respective 'active' counterparts Arable land, Permanent crops, Pastures. Once land has been abandoned, it may remain in this state from one year to the next and gradually undergo a natural succession process. This implies that after a certain number of years, it is converted to semi-natural vegetation and eventually to forest. On the contrary, if the land claims for the agricultural commodities within the crop groups increases and favour the recovery of the region into a productive state, land may convert back to their active parent states (Arable land, Permanent crops or Pastures). As time passes, this recovery implies higher conversion costs, and thus lowers probability of taking place (Britz et al., 2011a).

3. Land use results

The resulting land-use map for the A1B Scenario and in 2030 is presented in Figure 5.

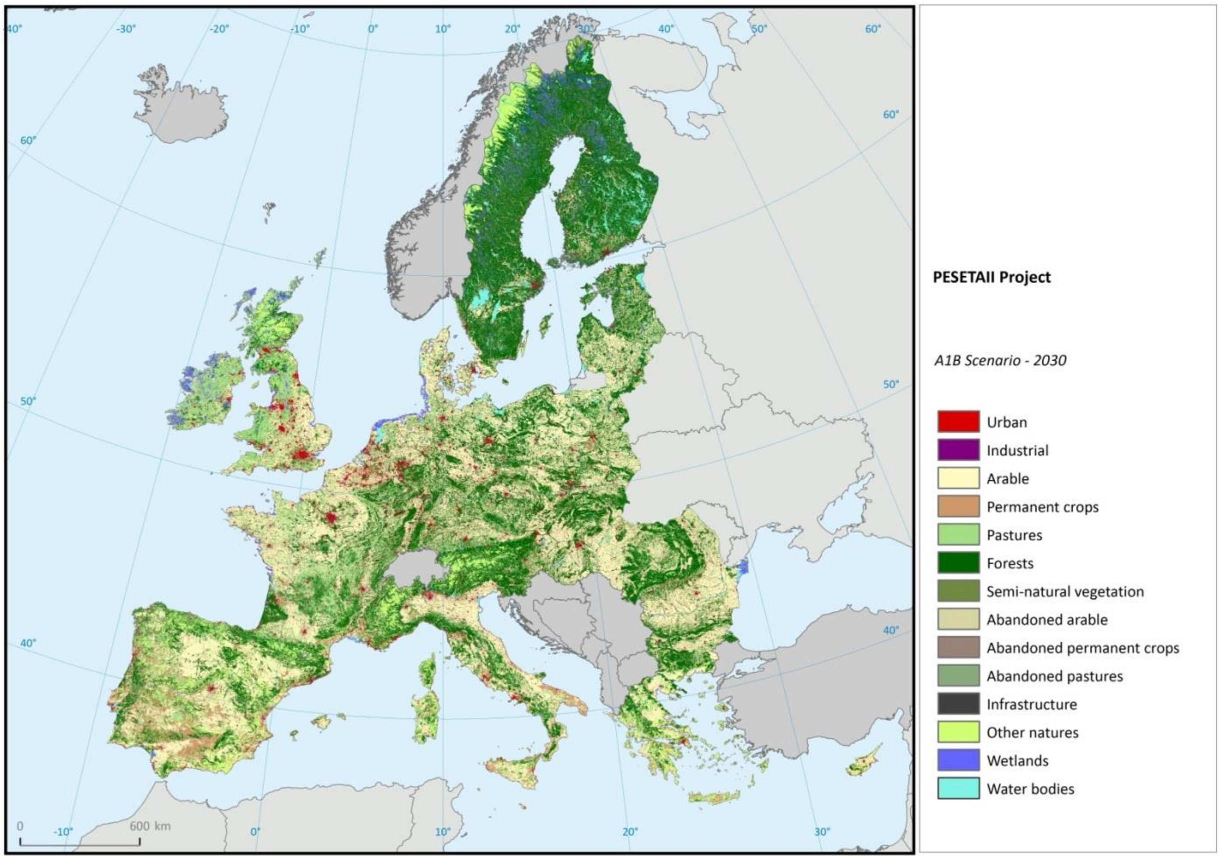

Figure 5. Projected land-use map for the year 2030, under the A1B Scenario.

In Figure 6 the contributions over the whole EU27 territory, per aggregated land use classes, on gains and losses for the simulation period 2010-2030, are reported. Of all the gains during this 20-year period in the EU27, measured as 100%, most are attributed to forest (nearly 50%) and agricultural land (arable land, permanent crops and pastures) (35%). Artificial land, comprising urban and ICS, contributes with less than 20%. On the loss side, the main land use to contribute is agricultural land (nearly 90%). The second larger contributor is semi-natural vegetation (almost 10%). Agricultural areas, thus, seem to be the most dynamic in absolute terms, as both considerable gains and losses occurred during the simulation period. Overall for the EU, Forest and Artificial land uses are net gainers, whereas agricultural areas and semi-natural vegetation show a net loss of acreage. Below we will look with more detail at country and region-specific trends.

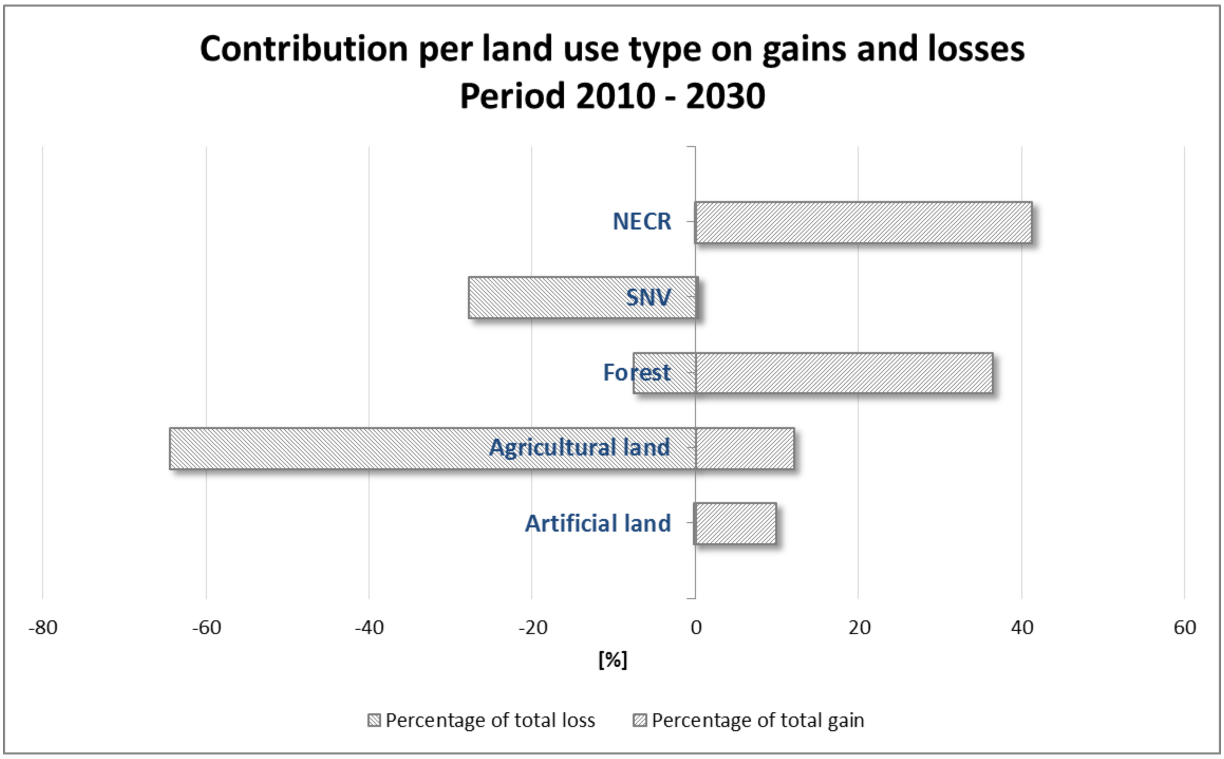

Figure 6. Gains and losses of aggregated land-use classes, at European level and under the A1B Scenario, for the simulation period 2010-2030.

In Figure 7, Figure 8 and Figure 9, the dynamics of aggregated land use categories are depicted for the years 2010 and 2030: built-up (urban and ICS), agricultural (arable, permanent crops and pastures) and natural (semi-natural vegetation and forest) land respectively. Figure 7 shows that the growth of impervious surfaces is higher in the UK, Ireland, Netherlands, Cyprus and Belgium the most. In these countries, the difference in built-up land share between the two years is greater than one percentage point. The share of agricultural land is decreasing in most Member States, but at a higher rate in the UK, Ireland and Denmark, and in some eastern countries such as Slovenia, Slovakia, Czech Republic and Poland (see Figure 8). The per-country share of natural land, mainly due to the growth in forest land, is increasing in nearly all Member States, with the exception of Spain, Portugal and Italy. The increase in natural land is more pronounced in Slovakia, Slovenia and Czech Republic (see Figure 9).

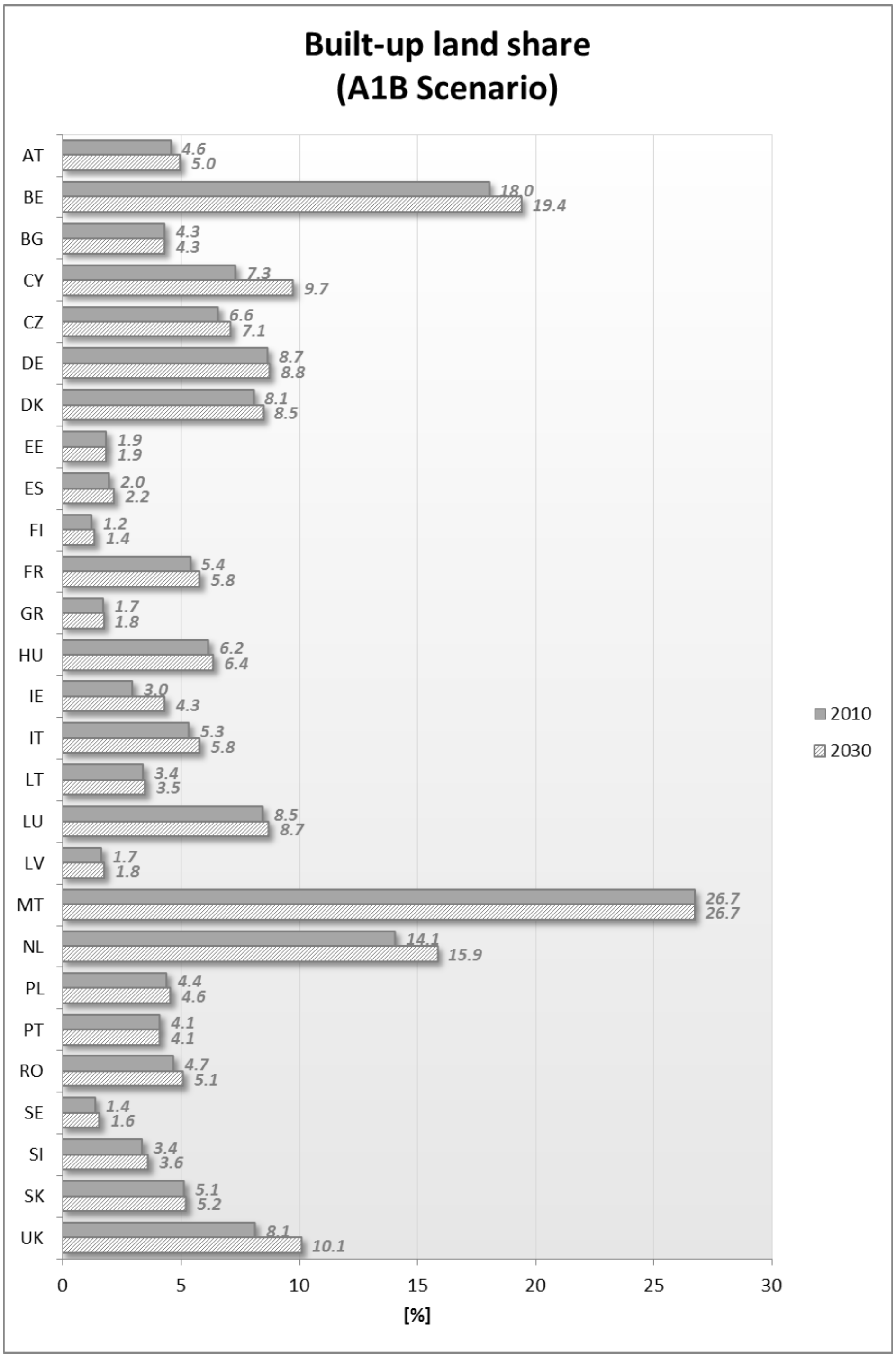

Figure 7. Share of built-up land on a per country basis, for the years 2010 and 2030, under the A1B Scenario.

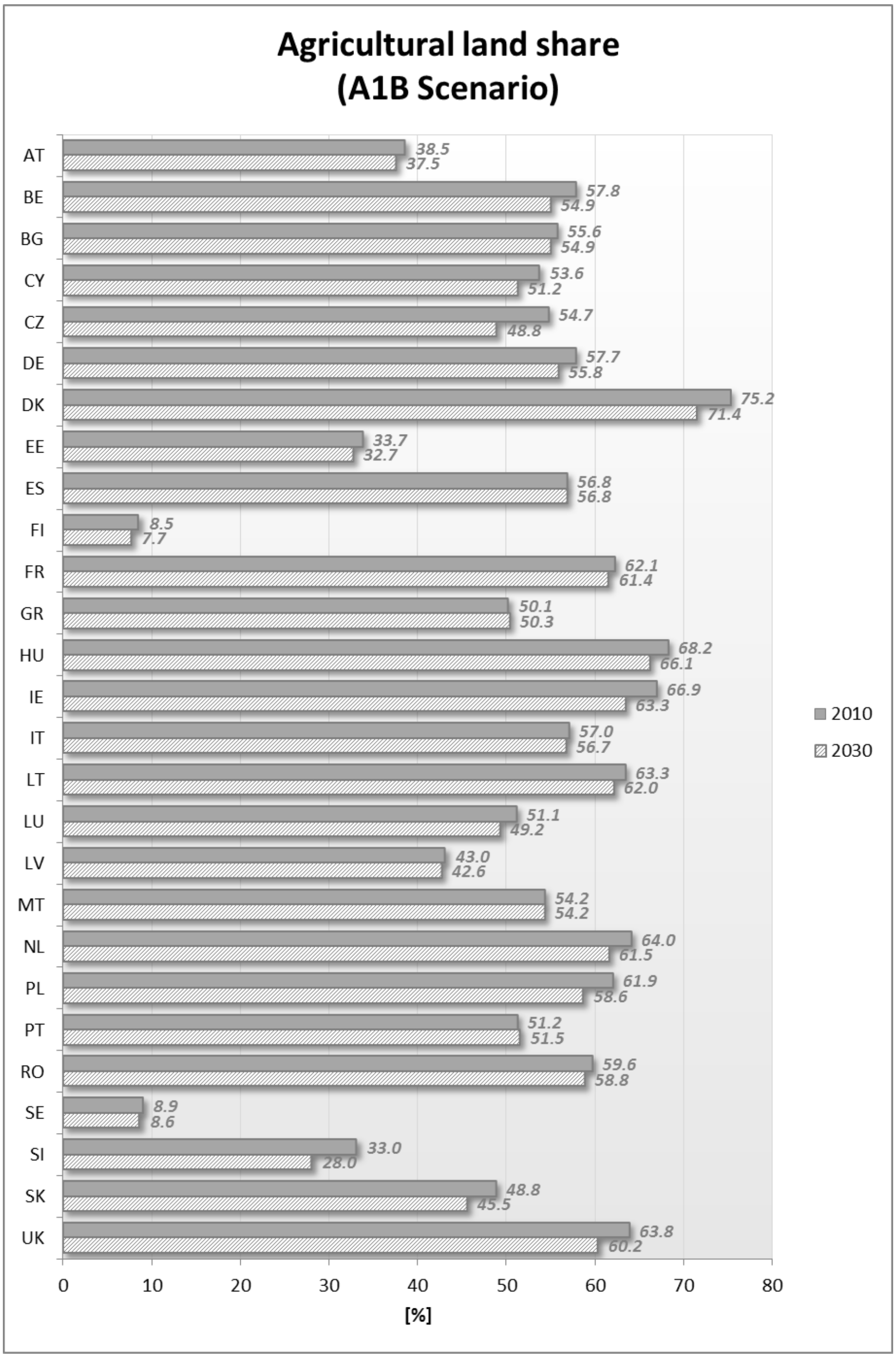

Figure 8. Share of agricultural land on a per country basis, for the years 2010 and 2030, under the A1B Scenario.

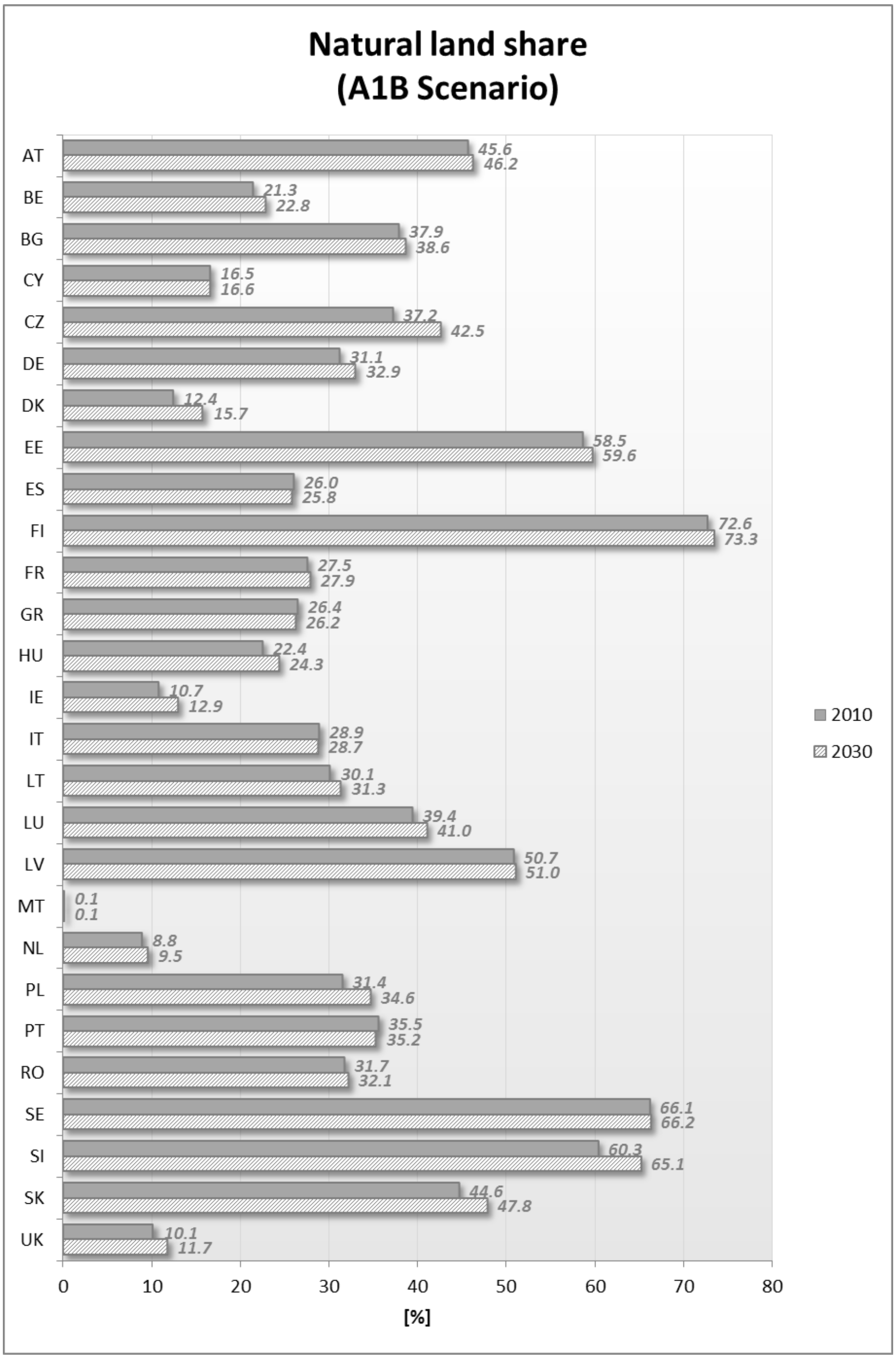

Figure 9. Share of natural land on a per country basis, for the years 2010 and 2030, under the A1B Scenario.

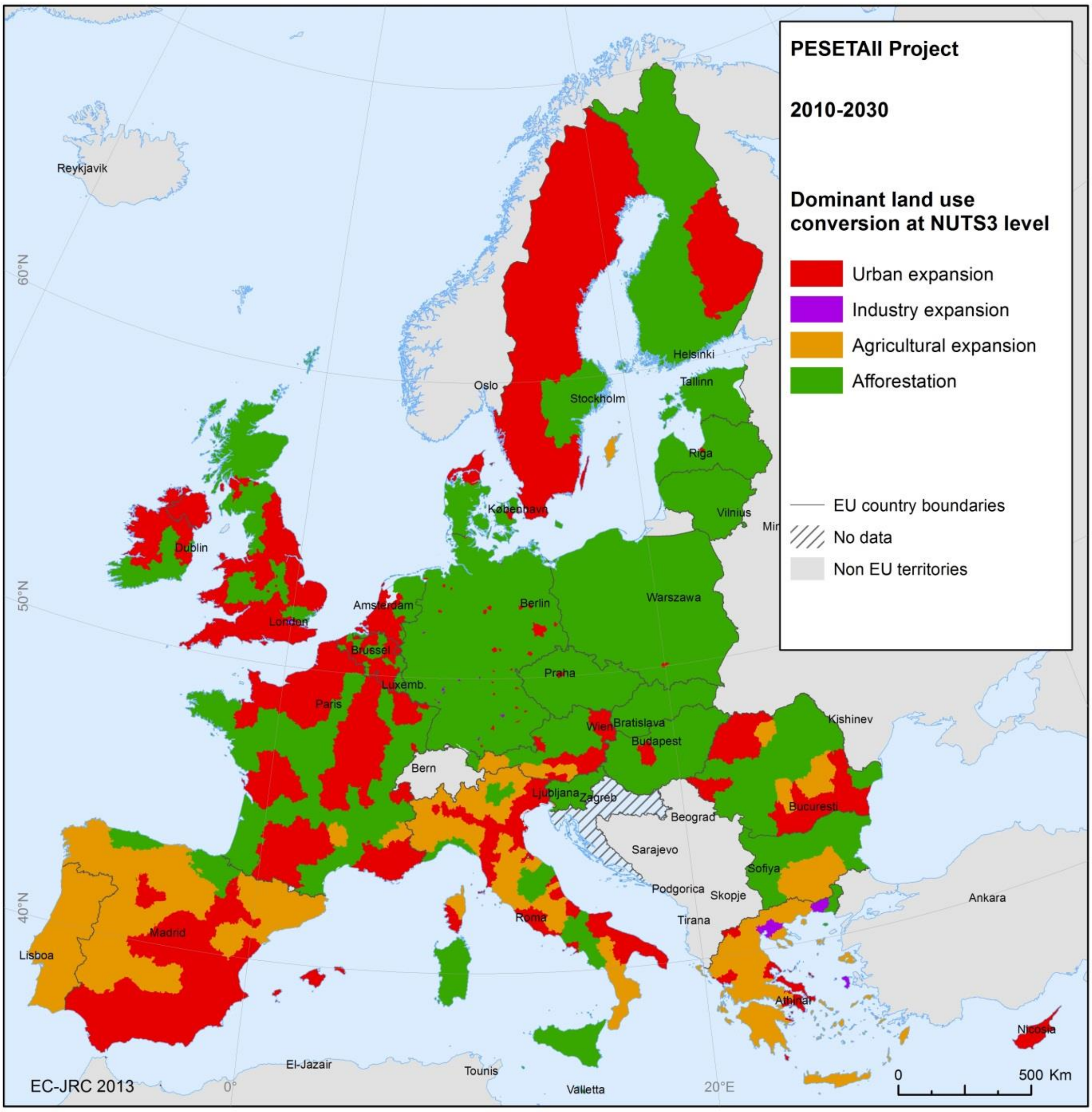

Figure 10. Dominant land-use conversions per NUTS3, under the A1B Scenario, for the simulation period 2010-2030.

The map in Figure 10 highlights the dominant land use conversions at NUTS3 level, among Urban, Industry, Agricultural or Forest expansion. The regions where the urban expansion is the most represented change are spread all across Europe. Nevertheless, it can be observed that the conversion to either urban land is especially present in the coastal regions and in regions where the population growth is expected to be higher, according to population projections (EUROPOP 2010). Built-up land expansion is the dominant land use conversion also in remote northern regions, for instance in Sweden and Finland: this is due to the stability of the landscape there, characterised by a dominant and stable presence of forested areas. As a consequence, even small increases in urban land can represent the dominant land use conversion at regional/local level. Agricultural expansion appears the dominant land use conversion mainly the southern Member States, especially Spain, Portugal, Italy and Greece.

For the exercise performed in PESETA II, the changes in land area potentially available for the production of biomass (as from LUMP) have been considered to estimate the biomass cost-curves in POLES for the A1B Scenario, and then extrapolated to other scenarios. The resulting changes in the EU energy mix, as simulated by POLES, are reported in Figure 11.

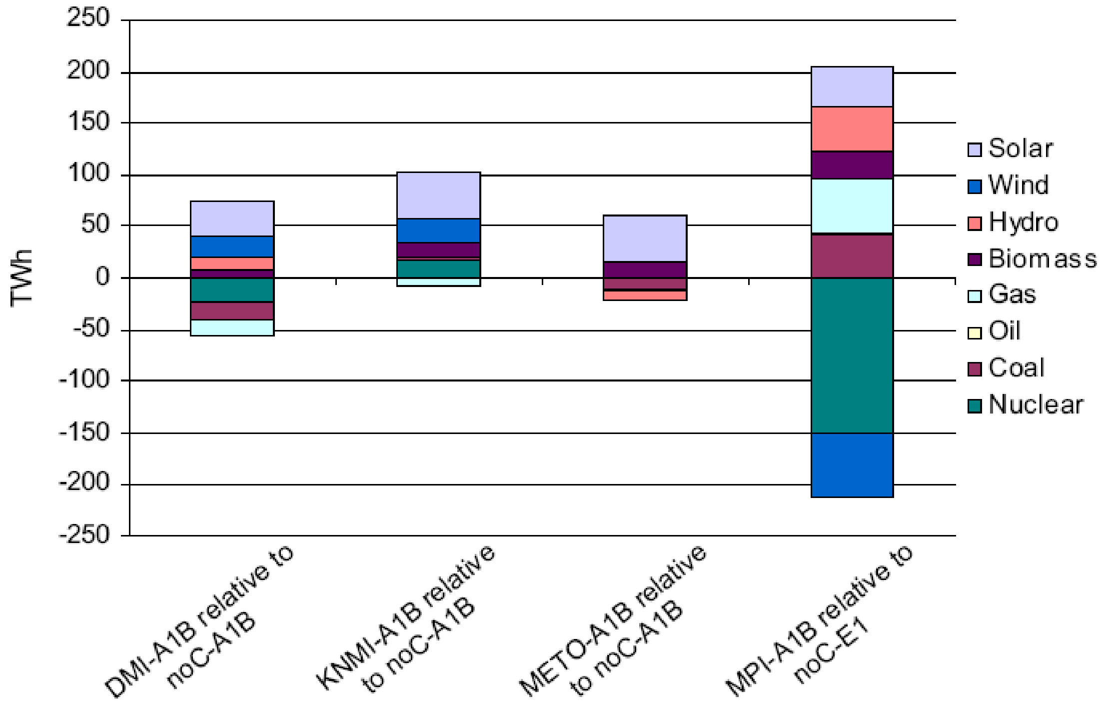

Figure 11. Change in EU27 total electricity generation by source in 2050, per climate change scenario compared to no climate change scenarios. *Source*: Dowling (2013).

As observed by Dowling (2013), the climate impacts on thermal and nuclear power generation, where increased cooling requirements lead to lower efficiencies, is the main driver of these results. The climatic impact on renewables is relatively minor and only marginally related to the increased renewable supply from climate change: the increase in renewables is chiefly due to the less-competitive thermal and nuclear power generation.

4. Evaluation of climate change impacts on potential hydropower generation in Europe

A brief study was made looking at the possible impact of the climate scenarios on future hydropower potential. This was done by assessing the evolution of predicted river discharges at point hydropower locations. Two datasets containing location and installed capacity information for European power stations were used: the Major Industrial Plant Database (IHS) and the World Electric Power Plants Database (PLATTS). After removal of duplicate entries and verification of the datasets we remained with 1387 hydropower stations for the whole of Europe (including non EU member states).

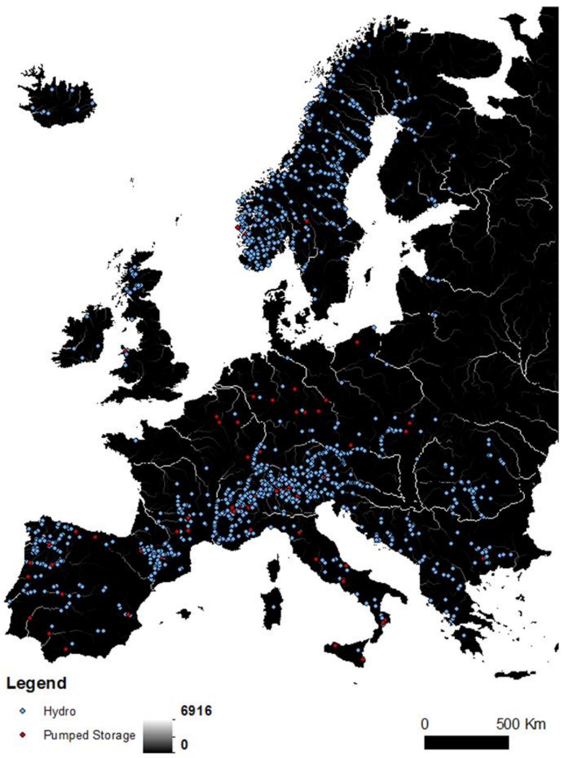

Figure 12. Point locations of major hydropower stations in Europe, based on the IHS and PLATTS datasets, overlain on the average A1B Scenario modelled discharge for 2006.

For these purposes we used the modeled discharge computed using the various climate scenarios in the LISFLOOD model. For each scenario, average annual discharge values were computed for the period 2000-2050. The relative change in river discharge extracted at the nearest river channel for all hydro electrical power plant locations for this timespan gives a first indication of the impact that the various climate scenarios will have on future hydropower potential in Europe.

The discharges extracted were summed per country and per hydropower plant type (run-of-river/hydro or pumped storage), and the relative changes in summed available discharge per country were delivered to be used as input in the POLES model. The annual average change in discharge per year over the period 2000 - 2050 was used to compute a 'climatic factor' that directly influences the predicted hydropower production trends in the POLES model. The computed changes in discharge are shown in Figure 13 for the averaged A1B Scenario and the E1 Scenario. Countries which are shown as being undefined in the figures lacked sufficient data to compute the factor (i.e. had an insufficient number of hydropower stations). It should be noted that for the purposes of this study we assumed the developed hydropower (number and capacity of stations) to remain constant over time.

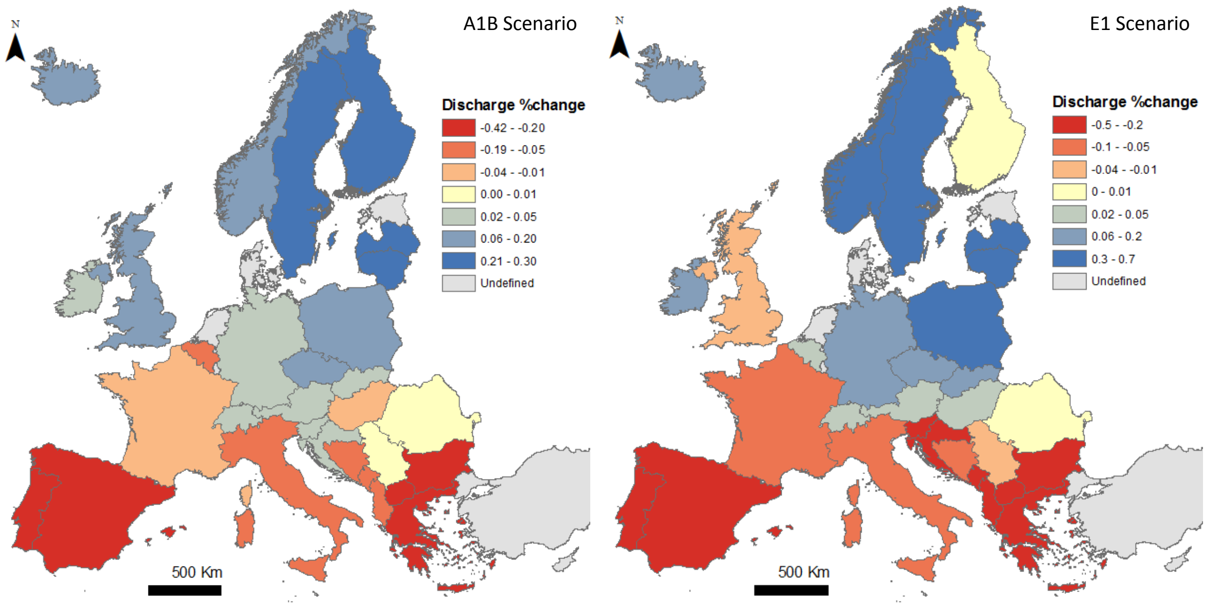

Figure 13. The resulting average annual change in river discharge for run-of-river stations, based on the average station discharge per country, over the period 2000 - 2050. The average of the values derived from the A1B Scenario runs (left) are compared to those from the E1 Scenario (right).

The results, as reported by Dowling, 2013 (Figure 14), suggests that the impacts of precipitation changes on hydropower in the EU are an order of magnitude less important than other climate related impacts, such as temperature, for what concerns heating and cooling demand and power plant outputs.

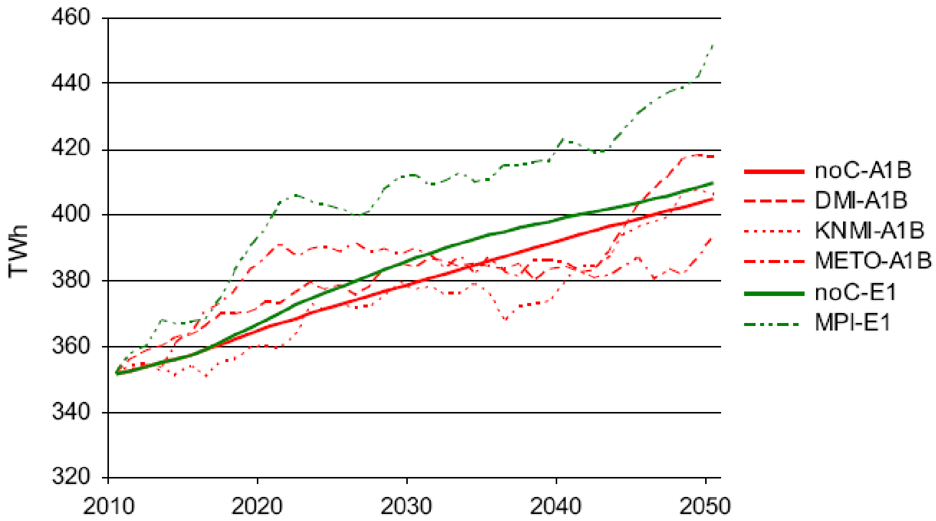

Figure 14. EU27 total electricity production from hydro, per scenario (TWh) ***Source*****: Dowling (2013).**

5. Final considerations

Climate change and land use are interrelated. The role of forests as carbon sinks is indeed crucial, as well as not negligible is the contribution of land use changes to the overall GHG emissions[2]. The importance of the climate change-land use nexus is crucial not only at global level, but also at national and local scales. In particular, when analyzing specific climate vulnerabilities at sub-national/local scales, the outlook of future land use patterns, under specific scenarios, can be a valuable information to identify problematic hotspots and optimize adaptation options.

The analysis carried out should be regarded as a preliminary exercise, whose aim was to test the feasibility of the interconnections between the macro-economic and the bio-physical models part of the PESETAII Project, using the Land Use Modelling Platform. In particular, a two-fold approach has been applied. The LUMP has been configured in order to implement the A1B Scenario: the resulting time-series of land use changes has been then used to test a first linkage with the energy model POLES, concerning the supply of biomass resources. The second part of the exercise has regarded future hydropower potential: the scope of this analysis was to test the sensitivity of the energy model, in terms of overall EU27 electricity production, to changes in hydro-electricity output driven by Climate scenarios. In the context of this exercise, the output from the hydrological model was not dependent on the land use/cover changes. However, it is worth noting that, at the time of writing, the linkage between the LUMP platform and the hydrological model LIFSLOOD has been already implemented and is fully operational (Burek et al., 2012 and De Roo et al., 2012).

In conclusion, this exercise demonstrated that it is possible to establish modelling linkages between land use, hydrological and energy models in the context of climate scenario impact assessment.

Steps have already been made to refine these methodologies and the implementation thereof will occur in the next phases of the PESETA work at the JRC, eventually evolving

[2] For additional information, please refer to the Intergovernmental Panel on Climate Change (IPCC), at http://www.ipcc.ch/ and http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html

towards a fully integrated dynamic system able to deliver land use-based indicators relevant to the climate change issue.

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Abstract

The Land Use Modelling Platform (LUMP) has been chosen to simulate land-use changes under a subset of scenarios (A1B). The modular structure of this platform, together with its high spatial resolution (100m), makes LUMP a suitable tool in the context of PESETAII. First, it guarantees high flexibility in adapting to the input/output interface required by the macro-economic models developed within this project. Moreover, an important added value to the modelling chain of PESETAII is the capability of taking into account specific policies with spatial repercussions.

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