European
Commission

JRC TECHNICAL REPORTS

Regional patterns of energy production and consumption factors in Europe

Exploratory Project EREBILAND - European Regional Energy Balance and Innovation Landscape

Claudia Baranzelli, Carlo Lavalle, Alessandra Sgobbi, Jean-Philippe Aurambout, Marco Trombetti, Chris Jacobs-Crisioni, Jorge Cristobal, D'Artis Kancs, Boyan Kavalov

2016

EUR 27697 EN

Joint
Research
Centre

Regional patterns of energy production and consumption factors in Europe

JRC Science Hub
https://ec.europa.eu/jrc

JRC100024

EUR 27697 EN

ISBN 978-92-79-54577-1 (PDF)

ISSN 1831-9424 (online)

doi:10.2788/357099 (online)

How to cite: Baranzelli C, Lavalle C, Sgobbi A, Aurambout J, Trombetti M, Jacobs C, Cristobal Garcia J, Kancs D, Kavalov B. Regional patterns of energy production and consumption factors in Europe - Exploratory Project EREBILAND - European Regional Energy Balance and Innovation Landscape; EUR 27697; doi:10.2788/357099

Table of contents

Abstract 5
1. Introduction 7
2. The EREBILAND Exploratory Project 8
3. Methodology 14
3.1 Modelling tools 14
3.1.1 Territorial modelling: LUISA 14
3.1.2 Energy modelling: JRC-EU-TIMES 17
3.1.3 Economic modelling: RHOMOLO 19
3.2 Data sources and data integration 21
3.3 Disaggregation methodology 25
3.3.1 Electricity generation 26
3.3.1.1 Non-renewable sources 30
3.3.1.2 Renewable sources 31
3.3.2 Energy demand 31
3.3.2.1 Energy demand: road transport sector 32
3.3.2.2 Energy demand: residential sector 35
3.3.2.2 Energy demand: ICS sector 36
4. Results 37
4.1 Electricity production 37
4.1.1 Electricity generated by biomass 38
4.1.2 Electricity generated by biogas 39
4.1.3 Electricity generated by coal (lignite) 40
4.1.4 Electricity generated by coal (hard coal) 41
4.1.5 Electricity generated by gas 42
4.1.6 Electricity generated by geothermal 43
4.1.7 Electricity generated by hydroelectric 44
4.1.8 Electricity generated by nuclear 45
4.1.9 Electricity generated by oil 46
4.1.10 Electricity generated by solar 47
4.1.11 Electricity generated by on-shore wind 48
4.1.12 Electricity generated by off-shore wind 49
4.2 Energy demand: road transport sector 50
4.2.1 Energy demand supplied for the process car - diesel 51
4.2.2 Energy demand supplied for the process car – gas, LPG 52
4.2.3 Energy demand supplied for the process car - gasoline 53
4.2.4 Energy demand supplied for the process heavy duty truck - diesel 54

4.2.5 Energy demand supplied for the process light duty truck - diesel 55
4.2.6 Energy demand supplied for the process light duty truck - gasoline 56
4.2.7 Energy demand supplied for the process inter-city bus - diesel 57
4.2.8 Energy demand supplied for the process urban bus – gas, diesel, gasoline 58
4.2.9 Energy demand supplied for the process motorcycles - gasoline 59
4.2.10 Energy demand supplied for the process car – hybrid, electric, hydrogen. 60
4.2.11 Energy demand supplied for the process heavy duty truck – gas and light duty truck - LPG 61
4.3 Strategy for the validation of the results 62
5. Conclusions.. 63
References 64
List of abbreviations and definitions 68
List of figures.. 69
List of tables... 71
Appendix A... 72
A.1 LUISA platform 72
A.1.1 The demand module 74
A.1.2 The land allocation module 75
A.2 Energy modelling: JRC-EU-TIMES 75
A.2.1 End-use energy services and materials demand 77
A.2.2 Characteristics of current and future energy related technologies 78
A.2.3 Present and future sources of primary energy supply and their potentials .. 80
A.3 Economic modelling: RHOMOLO 82
A.3.1 The underlying general equilibrium framework 82
A.3.2 Product market imperfections 83
A.3.3 Labour market imperfections 84
A.3.4 R&D and innovation 84
A.3.5 New Economic Geography features of the model 85
A.3.6 Solving the model: dynamics and inter-temporal issues 85
A.3.7 Disaggregating energy sectors in RHOMOLO 86
A.3.8 Simulating cohesion policy investments in energy infrastructure............... 87

Abstract

The Resilient Energy Union with Forward Looking Climate Change Policy is one the ten priorities of the overarching Agenda for Jobs, Growth, Fairness and Democratic Change of the European Commission. The Communication on the Energy Union package and its Annex clearly identify EU-wide targets and policy objectives.

The Exploratory Project EREBILAND (European Regional Energy Balance and Innovation Landscape) aims at supporting efficient patterns of regional energy supply and demand in Europe. Integration of spatial scales, from EU-wide to regional or local, and a cross-sector approach, are at the core of the project.

The approach is based on territorial disaggregation of information, and the development of optimisation scenarios at regional scale. It is centred around the Land Use-based Integrated Sustainability Assessment (LUISA) modelling platform for the assessment of policies and investments that have spatial impacts, in interaction with the JRC-EU-TIMES model – a bottom-up, technology-rich model representing the EU28+ energy system – and the model RHOMOLO that integrates economic and some social dimensions of regional development.

Based on currently operational and up-to-date tools available within the EC, the purpose of the EREBILAND project is to:

- provide an overview of the current trends of regional energy production and consumption patterns, and
- link these patterns to the structural characteristics of the regions, among which: population density and urbanisation trends, development of different economic sectors, and availability of resources and technological infrastructure.

This report presents the outcomes of the EREBILAND Project during its first year.

In particular, electricity generation and energy consumed by transport sector are analysed, under the EU Energy Reference Scenario 2013, throughout the period 2015 - 2030.

Main results of the analysis dedicated to the **electricity generation** are:

- Electricity generation from biomass increases in the large majority of European regions; a slight decrease can be found only in regions producing electricity already in 2015 above the EU28 average (in Denmark).
- Electricity produced from biogas experiences less steep changes then biomass, with almost 50% of NUTS2 decreasing or not changing considerably the amount of electricity produced from this source.
- Coal: electricity generated from lignite undergoes a significant reduction in all regions using this fuel already in 2015. Conversely, trends in electricity generated from hard coal are more stable, with some regions experiencing an increase: the average change is higher than 50% (a few regions in Eastern European countries), but steeper increases can be found in Austria, Sweden and the United Kingdom.
- The amount of electricity generated from gas generally decreases across Europe from 2015 to 2030, with an average decrease higher than 90%.
- Geothermal is the least diffuse source used to generate electricity in Europe and only few regions are represented.
- Hydroelectric: the amount of electricity generated from this source is in general forecasted to increase in Europe from 2015 to 2030. Exceptions are a few regions in Bulgaria, Czech Republic, Germany, Spain, Greece, Hungary, Portugal, Romania, Sweden and most NUTS2 in the UK.
- Electricity generated from nuclear is forecasted to decrease in the majority of the regions with active nuclear power plants in 2015.

- Oil: the majority of the regions generating electricity from this fuel in 2015, experience a decrease in 2030. Notable exceptions are a few regions in Austria, Belgium, Germany, Greece, Hungary, Italy, Poland and Slovenia.
- Electricity produced from solar is forecasted to increase in almost three quarters of European regions. The only regions where electricity from solar is forecasted to decrease are located in Greece and Romania.
- Wind: electricity generated from wind, both on- and off-shore, is in general forecasted to increase in Europe. The largest increases in electricity generated from on-shore wind (above 5 times the 2015 generation levels) can be found in few regions in Czech Republic, Finland, Lubuskie in Poland, the north-est NUTS2 in Romania, Western Slovakia and Slovenia.

Main results of the analysis dedicated to **energy consumption of the transport sector** are:

- In more than two thirds of European regions, the energy supplied to cars (fuel: diesel) decreases from 2015 to 2030, with an average decrease of almost 20%.
- The energy supplied to cars (fuels: gas and LPG) is forecasted to decrease throughout all European regions. The decrease is more gradual in few regions in Denmark, Portugal, Greece, Spain and Italy.
- Energy supplied to cars (fuel: gasoline) is forecasted to decrease in more than 80% of the European regions, with an average decrease of 27%.
- The energy supplied to heavy duty trucks (fuel: diesel) is forecasted to progressively decrease from 2015 to 2030 in 66% of the European regions, with an average decrease of more than 8%.
- The energy supplied to light duty trucks (fuel: diesel) is forecasted to steeply decrease throughout European regions.
- The energy supplied to light duty trucks (fuel: gasoline) is forecasted to increase in more than 90% of European regions, with an average increase of more than 40% from 2015 to 2030. The highest increases (above 70%) take place in eleven regions in Germany, Walloon Brabant in Belgium, Flevoland in the Netherlands, Lower Austria and Eastern Macedonia and Thrace.
- The energy supplied to inter-city buses running on diesel is forecasted to increase from 2015 to 2030 in the large majority of European regions, with an average increase of more than 19%.
- The energy supplied to urban buses (fuels: gas, diesel and gasoline) is going to moderately increase from 2015 to 2030 in almost 90% regions throughout EU-28, with an average growth of 15%.
- Energy supplied to motorcycles (fuel: gasoline) is forecasted to increase in more than 80% of European NUTS2, with an average growth of 16%.
- Energy supplied to cars (fuels: hybrid, electric and hydrogen) is forecasted to increase throughout Europe, in general with sharp increases.
- Energy supplied to heavy duty trucks (fuel: gas) and light duty trucks (fuel: LPG) is forecasted to increase in all European regions from 2015 to 2020. In most NUTS2 this trend is kept or even accelerates between 2020 and 2030. The only regions where the trend is reversed (lower energy supplied in 2030 compared to 2020) are located in Poland, Greece, Finland (only Åland) and Croatia (only Jadranska Hrvatska).

1. Introduction

The Resilient Energy Union with Forward Looking Climate policy is one the ten priorities of the overarching Agenda for Jobs, Growth, Fairness and Democratic Change of the European Commission. The Communication on the Energy Union package [1] and its Annex [2] clearly identify EU-wide targets and policy objectives.

The strategic goal of reaching a "sustainable, low-carbon and climate-friendly economy" [1] is composed of five connected dimensions, which, in turn, correspond to different policy areas: (1) Energy security, solidarity and trust; (2) A fully integrated European energy market; (3) Energy efficiency contributing to moderation of demand; (4) Decarbonising the economy; and (5) Research, Innovation and Competitiveness.

In order to achieve this goal, integrated governance and monitoring process are put forward as the essential instrument needed to integrate and coordinate energy-related actions at different levels. This governance process shall ensure integration across different spatial scales, from European to local, and promote coherence among different policy areas.

With this aim, the first State of the Energy Union looks at the progress over the last nine months and it identifies key issues that require specific political attention in 2016 [3]–[5]. Across these five dimensions that were previously identified, the integration of spatial dimensions and the coordination of policy sectors represent recurrent issues which underlie the State of the Energy Union policies conclusions [3].

This is particularly the case for the third (energy efficiency) and fourth (decarbonisation) dimensions of the Resilient Energy Union. On one hand, recorded data show that high-efficiency technologies should be further promoted by EU Member States, while it is highlighted that further efforts are needed in order to get a better integration of renewable energy into the market and more consistency between support schemes and electricity markets [3].

Investment strategies and policy incentives, which target both the energy production system and the demand side, should be designed so to encourage the optimum use of available resources and technological infrastructure, focusing the efforts in regions where the demand for energy is forecast to increase.

2. The EREBILAND Exploratory Project

The EREBILAND (European Regional Energy Balance and Innovation Landscape) project aims at supporting efficient patterns of regional energy supply and demand in the EU. The issue of energy scarcity and efficient use of available resources is intrinsically of a multi-disciplinary and territorial nature: integration of spatial scales, from EU-wide to regional or local, and a cross-sector approach, are at the core of the project.

Energy targets are set at EU level, but their realisation requires an implementation strategy that is tailored at EU Member States and regional level. National and regional specifics have to be taken on board when defining the priority of intervention for different sectors, from restructuring the energy sector to setting up efficiency targets for different categories of energy users.

For instance, in order to achieve better integration of renewable energies in the overall energy market, it is essential to carefully evaluate the availability of resources, taking also into account present and prospective competing uses. As an example, fostering through policy incentives the energy from solar or biomass in a region where the availability of the necessary resources are scarce (solar radiation, land where to place solar panels or plant dedicated energy crops, etc.), would lead to inefficient use of natural resources, such as land, and lost opportunities for public investment. These assets would have been otherwise dedicated to more suitable and efficient (also from an ecological perspective) applications.

Similarly, the energy generation from non-renewable sources does not only entail depletion of the fossil fuel itself, but it has to be also evaluated from a wider perspective, taking into consideration the depletion of other natural resources involved in the energy production process, such as water and land, which can find alternative and more efficient uses.

In a typical situation, installing and running a power plant in a region implies that:

- requirements of energy users are satisfied: in some cases, the closer the facility to the main users, the better, in order to minimise transmission and distribution losses;
- the fuel used by the producing plant is unavailable to other uses: for instance, biomass from forests cannot be used for material uses (e.g. in the pulp&paper industry, particulate board industry, etc.); or energy crops are planted instead of crops dedicated to the production of food for humans and feed for animals;
- the production of energy competes with other users (e.g. other industries, people living in settlements, etc.) for natural resources, such as: water, which can be used to cool down a power plant or a steel working plant, to irrigate crops or as drinking water; clean air, polluted by the power plant and unavailable to people for recreational activities, for example; etc.

This balancing exercise has to take into account that the energy sector has its own specificity in each Member State; in the same way, energy consumption levels of different sectors, from residential to industrial, vary from country to country, also as function of structural characteristics. As an example, *Figure 1* reports final energy consumption in 2013, for EU-28 (frame A) and Poland only (frame B).

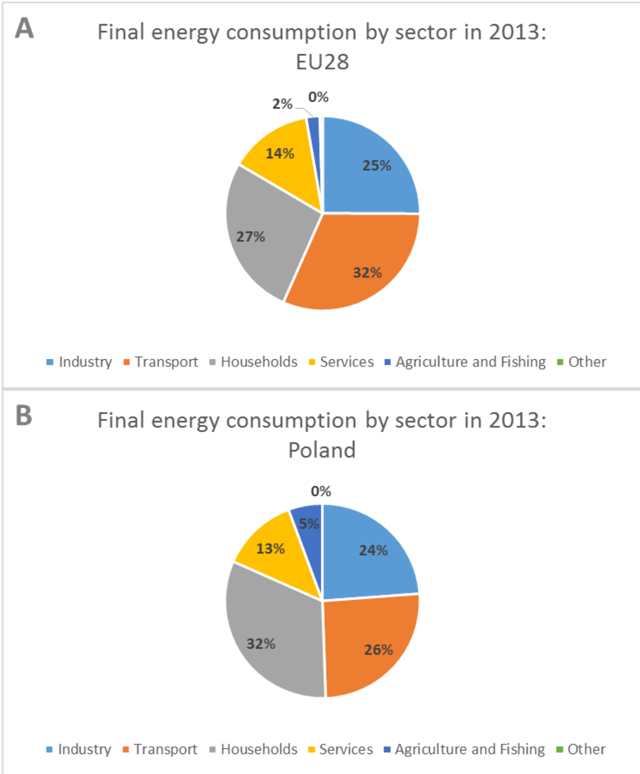

Figure 1. Final energy consumption by sector in EU-28 (frame A) and Poland (frame B), in 2013. Data source: EU Commission, DG ENER

The relative consumption levels by sectors are similar in EU-28 and Poland –residential and transport sectors are the two largest energy consumers. Nevertheless, the residential sector dominates in Poland (32%), whereas the transport sector is the leader in EU-28, followed by.

Specific characteristics of the Polish residential sector might be a reason for these differences. Poor building insulation can be common with other Member States, but other factors, such as the higher percentage of houses connected to district heating in Poland compared to the average EU level, can also play a role. In particular, heat (i.e. energy) losses during transmission and the more or less diffuse presence of heat meters, can potentially leads to inefficiency.

Figure 2 offers a closer look at the Polish energy sector at regional level. The bar chart on the left hand side reports the regional shares of total national electricity production for the years 2000, 2005 and 2010. Regional differences in the relative contribution to the national level of power generation are quite large. In 2010, seven regions, among which Warminsko-Mazurskie in northern Poland, produce less than 2% of the total Polish electricity. In the other extremity, just two regions (Lódzkie and Slaskie) provide more than 10% of the total national power generation.

When looking at the contribution of renewable energies to the regional electricity generation in Poland in 2005 and 2010, large differences are also evident (right-hand chart in *Figure 2*). In some regions, renewable sources account for more than 30% of regional electricity. In a few cases (e.g. Warminsko-Mazurskie, PL62) the relative share of renewables more than doubled between 2005 and 2010, even though their absolute contribution to the total national production is very small compared to other regions. In other cases, such as Kujawsko-Pomorskie (PL61), the share of renewables was quite high already in 2005.

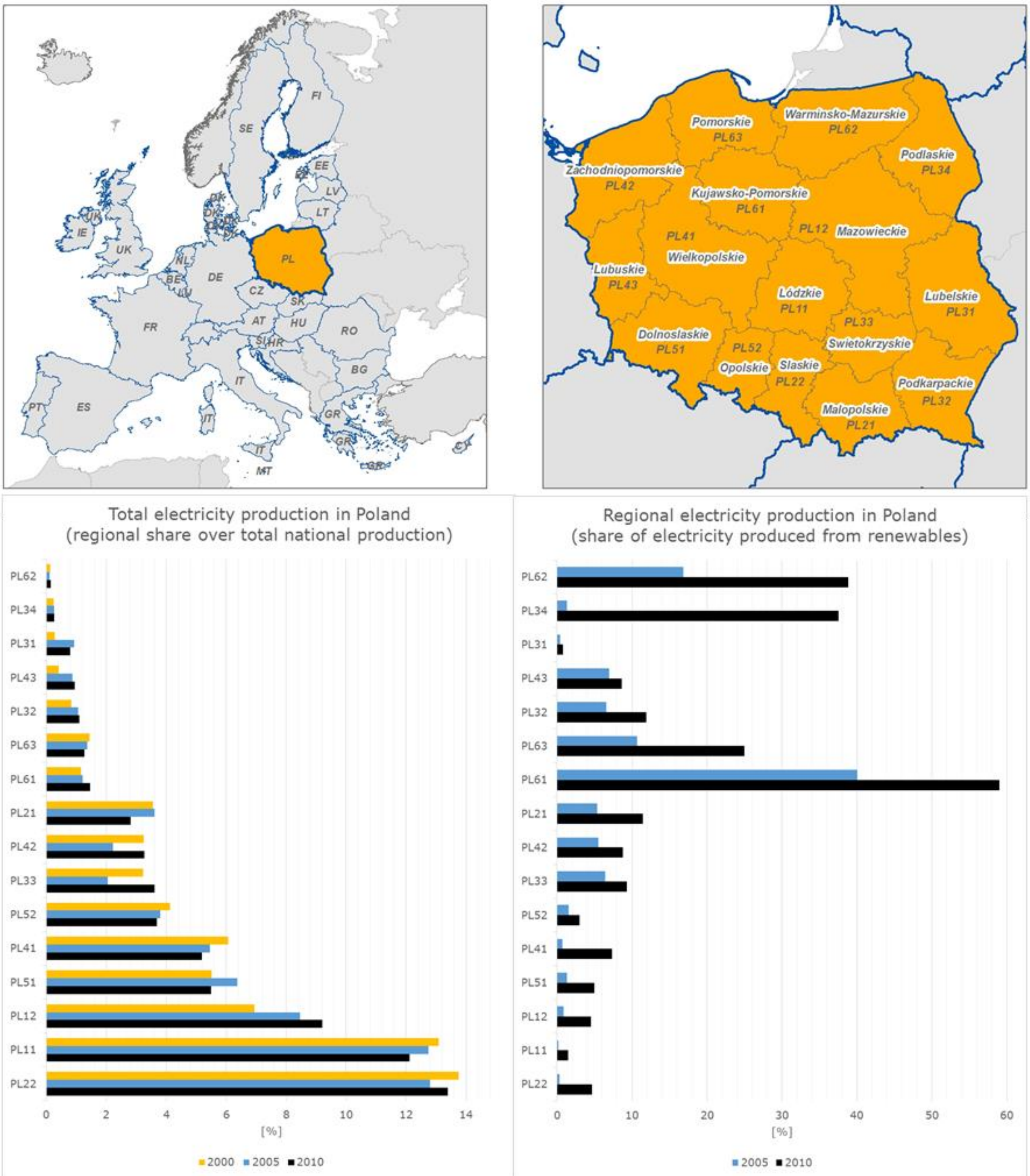

Figure 2. Electricity production in Poland, according to reported national statistics. Data source: Central Statistical Office of Poland

These national and regional differences are important for assessing the likelihood of success of EU policies in general and of energy policies in particular. The regional characteristics of the EU territory have therefore to be well understood, explained and duly taken into account. Some EU regions like Slaskie in the south of Poland, are peculiar with a rather high concentration of energy users (densely populated areas and industrial sites) and consequently – a higher (in proportion) share of electricity generation compared to the national average production, but at the same time – a very low share of renewable sources in the fuel mix. Due to the wide presence of natural protected areas e.g. Natura2000 sites and Nationally Designated Areas, the potential for incremental expansion in the use of renewables will likely be modest.

Based on the operational and up-to-date tools, which were available within the EC-JRC by 2015, the purpose of the EREBILAND project is therefore to:

- provide an overview of the current trends of regional energy production and consumption patterns,
- link these patterns to structural characteristics of the regions, among which: population density and urbanisation trends, development of different economic sectors, availability of resources and technological infrastructure.

The same tools were also configured in order to evaluate alternative scenarios, so to assess the implications of different policy strategies on the economic development of regions, sustainable use of resources and citizens' well-being.

The approach is based on the disaggregation of both current and projected data, with the final objective to develop optimisation scenarios at regional scale.

In order to achieve these goals, a suite of modelling tools is deployed, to cover the territorial, economic and energy dimensions.

The concept of dynamic land function is at the core of the methodology. Land functions are instrumental to better understand territorial processes and impacts of policy options. A land function can, for example, be physical (e.g. related to hydrology or topography), ecological (e.g. related to landscape or phenology), social (e.g. related to housing or recreation), economic (e.g. related to employment, production or infrastructure) or political (e.g. impacts of policy decisions). One patch of land is generally perceived to fulfil many functions. Land functions are temporally dynamic. They depend on the characteristics of land parcels and are constrained and driven by natural, socio-economic and technological processes.

The EREBILAND project aims at providing a tool with the following advantages:

- *Thematically integrated*:

Specialised models and data sources are brought together, in order to describe relevant single sectors with the highest possible level of detail, while maintaining EU-wide coverage and ensuring their coherent representation.

- *Built upon existing tools already in use to inform policy makers*:

The modelling tools that are incorporated in the EREBILAND project, are already known and used by EU policy makers to assess their respective sector activities.

- *Scalable and versatile*:

The tools implemented in EREBILAND are at the forefront of the respective research fields and are designed to serve policy makers. They can therefore answer different policy questions (see few examples at the end of the chapter) in different territorial contexts (e.g. urban/rural regions, coastal areas, lagging regions, etc.) or specific thematics (e.g. economic viability of renewable energy resources, upgrade of technological infrastructure, etc.).

- *Easily updated*:

The EREBILAND project is not a stand-alone, isolated mapping exercise, but it is implemented through already operational modelling tools. The regional maps, presented in the following section, can be updated when new data become available, depending on specific policy questions.

Figure 3 provides an overview of EREBILAND structure, its conceptual blocks and their linkages.

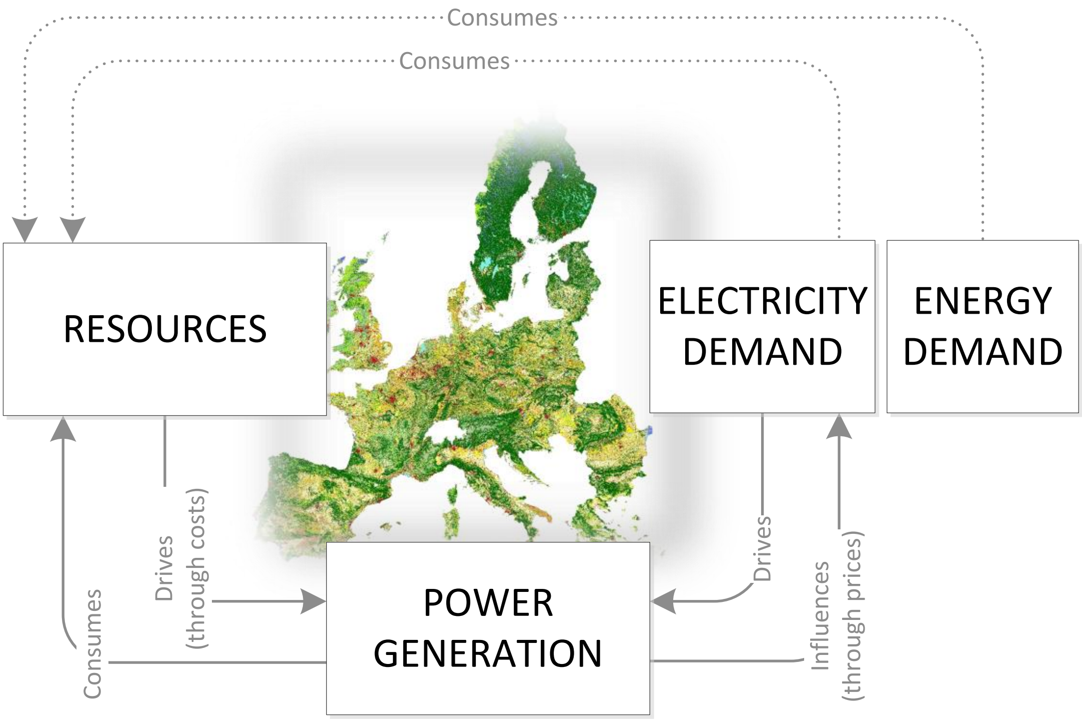

Figure 3. Conceptual scheme of the EREBILAND project. Direct linkages are represented by solid lines; indirect linkages are represented by dotted lines

The costs of a resource (be it natural gas, land to place solar panels or biomass residues), are functions not only of its quantity, but also its quality and other characteristics, such as transportation distance. Biomass is a typical example where transportation costs usually represent more than half of the total delivery costs at the bio-refinery or power plant.

The electricity demand of different sectors drives power generation at both aggregate level (regardless of the fuel type) and for specific fuels (also as effect of specific implemented policies). Electricity demand and hence, generation can impact the availability and prices of resources, both directly (e.g. biomass, natural gas, coal, etc.) and indirectly (e.g. water, land). Through pricing, electricity supply can directly affect single sectors – private households, industries, etc. and the structure of their demand.

The above linkages are also influenced by policies. These can be sector-specific e.g. in the energy sector, specific industrial polluting activities, environmental measure, etc. and/or horizontal (cross-sectorial) e.g. regional policies.

Policies can influence:

- *The availability of resources*: through various protection schemes. The use of specific resources as fuels or playing an essential role in the production process (e.g. water needed to cool down power plants) might be regulated and limited, according to specific criteria or specific use/depletion rate, etc. [6][7], [8]. Incentives might also be in place, e.g. to encourage the use of specific forms of energy. For example, the Renewable Energy Directive is the main legislative reference to support the use of renewable energy sources [9];
- *Energy demand*: through taxation and incentives;
- *Electricity production*: through taxation and incentives.

The project EREBILAND will aim to cover the components represented in *Figure 4*. Some of the sectors are to be investigated for all EU Member States, while others are to be assessed for specific cases only.

On the demand side, the focus will be on the residential, industrial (combining Industry, Commerce and Services altogether) and transport sectors. The agricultural sector will not be included in the analysis, because it represents a marginal share of the overall final energy consumption at EU level (2% in 2013; Data source: EU Commission, DG ENER.). An analysis of the related emissions will also be provided.

On the production side, various fuels will be investigated, both fossil and renewable ones.

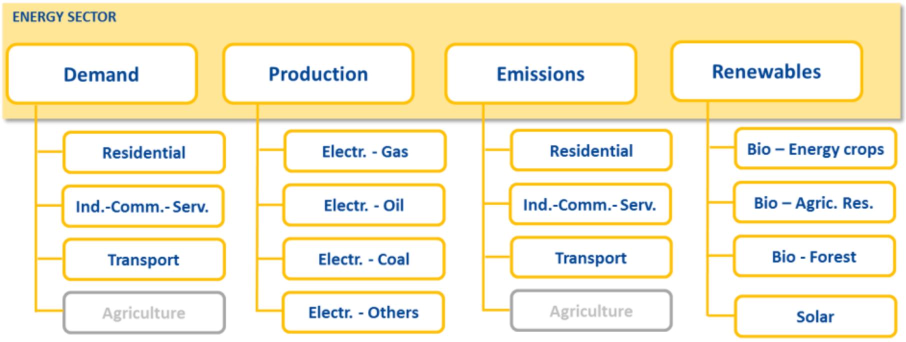

Figure 4. Thematic coverage of the project

The work planned under the EREBILAND project is to be carried out over a period of two years. The expected outputs are the followings:

- *I year*:

  Development of a methodology for regional disaggregation of energy production and consumption patterns, data and information for which are originally available at national level;

  Discussion of the first disaggregated results for energy production and consumption (by main sectors) for the EU, under a baseline scenario (EU Reference Scenario 2013) [10], [11].

- *II year*:

  Completion of the disaggregation for projected years by decade up to 2030 and 2050.

  Development of case studies (Member States) for the residential sector (demand side) and renewable energies (production side), at regional level.

3. Methodology

The methodology of the EREBILAND project is presented in *Figure 5*. The linkages between LUISA, JRC-EU-TIMES and RHOMOLO models are highlighted, focusing on the main modelling interfaces (input / output exchange amongst models).

The project activities related to data integration, not directly involving modelling interfaces, are discussed in section 3.2.

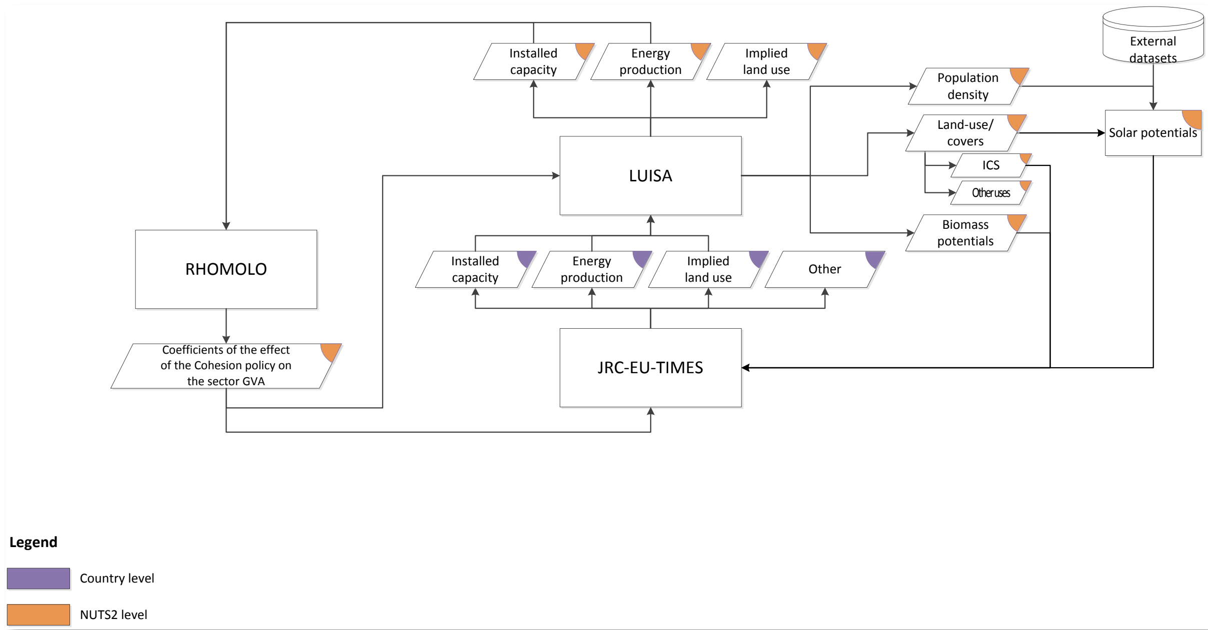

Figure 5. EREBILAND modelling workflow

3.1 Modelling tools

In this section, a brief description of the three models included in the EREBILAND project is provided.

The methodology of the EREBILAND project can be applied to different scenarios or policy options. As a first, necessary step, it is of outmost importance to align the main modelling assumptions so as to have a coherent implementation of the baseline scenario. These mainly refer to demographic and macro-economic assumptions, such as population trends and GDP/GVA changes over time, and policy settings, in order to take into account the current policy provisions.

During the first year of EREBILAND, the EU Reference Scenario 2013 has been assumed as baseline scenario and all needed verifications have been carried in order to ensure coherence of assumptions among LUISA, JRC-EU-TIMES and RHOMOLO.

3.1.1 Territorial modelling: LUISA

Scenario-based modelling can be used to investigate multiple possible evolutions of a given territory (city, region, country or even the entire world) in the future. Models can be used to simulate the impacts of a policy measure (e.g. an investment in an economic sector, definition of zoning plans, construction of a road or installation of a technological infrastructure) or of wider trends, such as those related to climate or demography.

The Land-Use-based Integrated Sustainability Assessment (LUISA) Modelling Platform was developed by the Directorate General Joint Research Centre (DG JRC) of the European Commission (EC). It is based upon the new concept of 'Land Functions' and contributes to the evaluation of impacts of policies and socio-economic trends on European cities and regions.

Land functions are instrumental to better understand territorial processes and highlight the impacts of policy options. A land function can be societal (e.g. provision of housing, leisure and recreation), economic (e.g. provision of production factors - employment, investments, energy – or provision of manufacturing products and services – food, fuels, consumer goods, etc.) or environmental (e.g. supply of ecosystem services). One parcel of land is generally perceived to fulfil many functions. Land functions are temporally dynamic. They depend on the characteristics of land parcels and are constrained and driven by natural, socio-economic, and technological processes.

A rich knowledge base is needed to satisfy the European-wide coverage and multi-thematic nature of territorial processes. LUISA integrates geographically referenced information from diverse sources and ensures consistency of data nomenclature, quality and resolution. This allows for cross-country / region / city comparisons. Spatial and thematic resolutions can be adjusted in order to resolve local features and provide continental patterns.

The LUISA platform was specifically designed to assess territorial impacts of European policies by providing a vision of possible future options and quantitative comparisons amongst policy options. The platform accommodates multi-policy scenarios, so that several interacting and complementary dimensions of the EU are represented.

At the core of LUISA is a computationally dynamic spatial model that simulates discrete land-use changes based on biophysical and socio-economic drivers. The main macro assumptions, which underpin the land-use model, are provided by several external models that cover demography, economy, agriculture, forestry and hydrology. LUISA is also consistent with given energy and climate scenarios, which are modelled further upstream. The model was initially based on the Land Use Scanner and CLUE models ([12] [13] [14], but in its current form LUISA is the result of a continuous development effort by the JRC [15]. The model is written in GeoDMS - an open source, high-level programming language. The model projects future land-use changes at fine spatial resolution of 1 hectare (100 × 100 metres), where the most relevant land-use types are represented (see Section 2.4). LUISA is usually run for all EU Member States. It can also be used for more detailed case studies or expanded to cover pan-European territory. For an overview of LUISA's main characteristics we refer to *Table 1*.

The goal of LUISA is not to provide forecasts. Its main objective and hence, asset, is the capability of simulating comparable scenarios. As a starting point, the 'baseline' scenario captures the policies already in place, assuming the most likely socio-economic trends and 'business-as-usual' dynamics (typically as observed in the recent past). The baseline serves as a benchmark to compare other scenarios, where future conditions and/or policies are assumed to change. This approach to impact assessments provides sound and consistent input to the decision-making process.

Two elements are crucial for the assessments with the LUISA integrated modelling framework: 1) The definition of the coherent multi-sector baseline scenario to be used as benchmark for evaluating the alternative options; 2) A consistent and comprehensive database of socio-economic, environmental and infrastructural information.

The baseline scenario provides the basis for comparing policy options and should ideally include the full scope of relevant policies at European level. A comprehensive baseline integrated in a modelling platform such as LUISA serves to capture the aggregated impact of the drivers and policies that it covers. Sensitivity analysis can be helpful to identify linkages, feedbacks, mutual benefits and trade-offs amongst policies. Since 2013, LUISA has been configured and updated to be in line with the EC's 'Reference scenario' [16], which has been used as a baseline in subsequent impact assessments. Various aspects of the model, such as sector forecasts and land suitability definitions are updated whenever pertinent.

The second element refers to the wealth of data that are needed to satisfy the European-wide coverage and the multi-thematic nature of territorial impact assessments. The principal input datasets required by LUISA must comply with the following characteristics:

- EU-wide (ideally pan-European) coverage;
- Geographically referenced to bring information together and infer relationships from diverse sources;
- Consistency of data nomenclature, quality and resolution to allow cross-country / region comparison;
- Adjustable spatial and thematic resolutions to resolve local features and provide continental patterns.

LUISA has three main modules: a 'demand module', a 'land-use allocation module' and an 'indicator module'. The demand and land-use allocation modules are explained in the following sections.

The main output of the allocation module is land-use maps. Potential accessibility and population distribution maps are also endogenously computed by the model as a result of the simulation, and are themselves important factors for the final projected land-use maps. From these outputs, and in conjunction with other modelling tools which have been coupled with LUISA, a number of relevant indicators can be computed in the indicator module. The indicators capture policy-relevant information from the model's outputs for specific land-use functions, for example water retention or accessibility. When computed for various scenarios, geographical differences in indicators can be identified and impacts can be related to certain driving factors, which were assumed in the definition of the scenarios.

A detailed description of LUISA's land-use classification, demand and land allocation modules, can be found in Annex A. The indicators available in the LUISA platform are not reviewed systematically.

Table 1. Main LUISA characteristics

Spatial extent	All EU countries
Spatial resolution	100 metres
Thematic resolution	8 main land-use classes (+ agricultural breakdown + 'abandoned' land uses)
Temporal resolution	Yearly
Time span	2006-2050
Primary outputs	Land-use maps, land-use changes, potential accessibility, population distribution map
Secondary outputs	Spatially explicit thematic indicators

3.1.2 Energy modelling: JRC-EU-TIMES

The JRC-EU-TIMES model is a linear optimization bottom-up technology-rich model [1, 2] owned and run by the JRC-IET. It is an improved version of previous, pan-EU energy system models developed in several EU-funded projects, such as NEEDS, RES2020, REALISEGRID and REACCESS. It models, at the country scale, the energy systems of the EU-28, Switzerland, Iceland and Norway for the period of 2005 to 2050.

The JRC-EU-TIMES explicitly considers two energy supply sectors – primary energy supply and electricity generation. Five energy demand sectors are covered: industry, residential, commercial, agriculture and transport. *Figure 6* illustrates the reference energy system of JRC-EU-TIMES.

The objective of the TIMES model is to satisfy demands for energy, materials and services while minimising (via linear programming) the discounted net present value of energy system costs. The costs of energy systems are subject to several constraints, such as: supply limits for primary resources; technical limitations governing the creation, operation, and abandonment of each technology; balance constraints for all energy forms and emissions, and timing of investment payments and other cash flows. TIMES addresses these constrains by simultaneously allocating equipment investments and operations, primary energy supplies and energy trades.

JRC-EU-TIMES was validated by external and internal experts in December 2013. Since then, its techno-economic parameters for selected technologies and renewable energy potentials assumptions have been updated, based on new available information.

JRC-EU-TIMES is appropriate for assessing the role of energy technologies and their innovation for meeting Europe's energy and climate change related policy objectives. Examples of questions that can be addressed with this model include:

- What are the critical drivers for the deployment of the different low-carbon technologies across EU in the sectors addressed by the model?
- What cost reductions and/or performance improvements are needed to make emerging innovative energy technologies competitive?
- Which energy technology portfolio allows meeting EU and national RES targets and what are the associated costs to the energy system?

- What is the role of bioenergy in supporting support decarbonisation of the energy system?

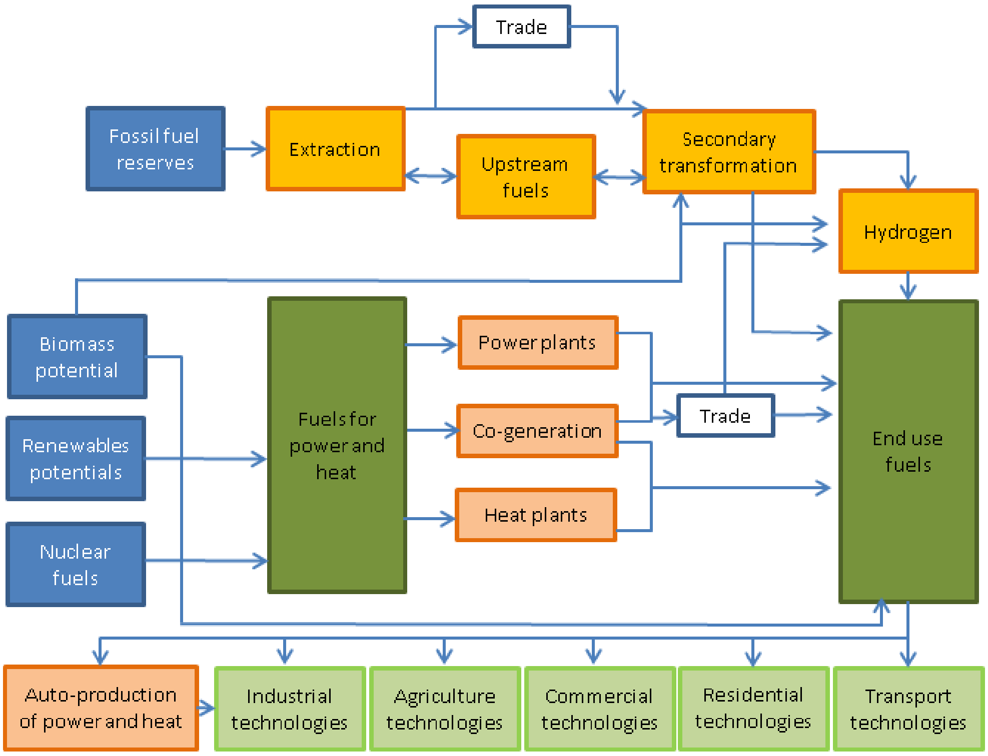

Figure 6: Structure of the reference energy system in the JRC-EU-TIMES model

Figure 7 summarises the key characteristics of the JRC-EU-TIMES model. Its main drivers and exogenous inputs are:

- the end-use energy services and materials demand;
- characteristics of the existing and future energy related technologies, such as efficiency, stock, availability, investment costs, operation and maintenance costs, and discount rate;
- present and future sources of primary energy supply and their potentials;
- policy constraints and assumptions. An extensive description of the model, including inputs and output values, can be found in [17].

The JRC-EU-TIMES model is described in full detail in Annex I.

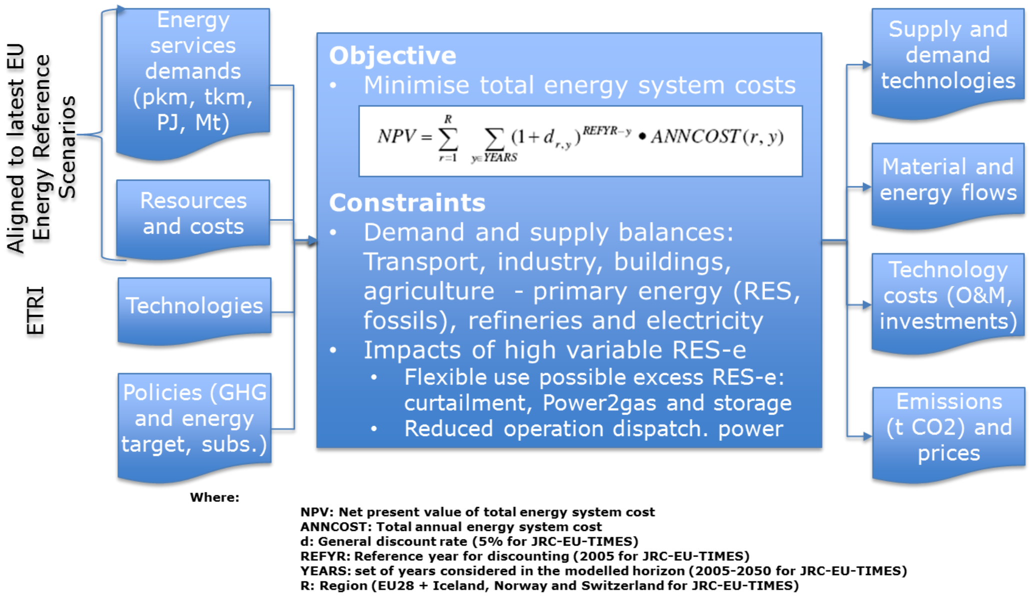

Figure 7: Simplified structure of the JRC-EU-TIMES model

3.1.3 Economic modelling: RHOMOLO

RHOMOLO is a dynamic spatial general equilibrium model of the European Commission. It is developed and used by Directorate-General Joint Research Centre (DG JRC) to undertake the ex-ante impact assessment of EU policies and structural reforms. Recently, the RHOMOLO model has been used together with the Directorate-General for Regional and Urban Policy for impact assessment of Cohesion Policy, and with the European Investment Bank for impact assessment of EU investment support policies.

RHOMOLO provides sector-, region- and time-specific model-based support to EU policy makers on structural reforms, growth, innovation, human capital and infrastructure policies. The current version of RHOMOLO covers 270 NUTS2 regions of the EU28 MS and each regional economy is disaggregated into NACE Rev. 1.1 industrial sectors [18], [19].

Main characteristics that makes the RHOMOLO model depart from standard computable general equilibrium models include:

- the modelling of market interactions is generalised by introducing imperfect competition in labour and product markets;
- a full asymmetric bilateral trade cost matrix is used for all EU regions, in order to capture a rich set of spatial market interactions and regional features;
- implementation of an inter-regional knowledge spill-over mechanism which originates from research and development activities within a country.

RHOMOLO is built following the same micro-founded general equilibrium approach as the QUEST model of Directorate-General for Economic and Financial Affairs (DG ECFIN), and is often used in combination with it.

RHOMOLO relies on an equilibrium framework à la Arrow-Debreu where supply and demand depend on the system of prices. Policies are introduced as shocks to the existing equilibrium of prices, which drive the system towards a new equilibrium by clearing all the markets after the shocks.

Given the regional focus of RHOMOLO, a particular attention is devoted to the explicit modelling of spatial linkages, interactions and spill-overs between regional units of analysis. For this reason, models such as RHOMOLO are referred to as Spatial Computable General Equilibrium (SCGE) models.

Each region is inhabited by households, whose preferences are captured by a representative consumer who consumes with a love for variety (Dixit-Stiglitz, 1977). Households derive income from labour (in the form of wages), capital (profits and rents) and transfers (from national and regional governments). The income of households is split between savings, consumption and taxes.

Firms in each region produce goods that are consumed by households, government or firms (in the same sector or in others) as an input in their production process. Transport costs for trade between and within regions are assumed to be of the iceberg type and are sector- and region-pair-specific. This implies a 5 x 267 x 267 asymmetric trade cost matrix derived from the European Commission's transport model TRANSTOOLS.

The different sectors of the economy are split into two categories: homogeneous-good-producing perfectly competitive sectors and imperfectly competitive sectors supplying the differentiated goods.

Perfectly competitive sectors are characterised by undifferentiated products produced under constant returns to scale technology. As for the imperfectly competitive sectors, they are instead populated by a finite (though possibly high) number of firms producing differentiated products, whose specific characteristics are visible to consumers.

Regional markets are assumed to be segmented, which implies that firms can optimally choose a different price in every regional market served.

Unemployment in RHOMOLO is modelled through a wage curve. In the context of RHOMOLO, an important advantage of modelling labour markets via a wage curve is the combination of operational applicability and sound micro-foundations, which make it an ideal choice for a high-dimensionality model with heterogeneous skills in each region. In addition, it is the standard approach followed in CGE models to model unemployment (see, for example, [20]).

The structure of the RHOMOLO model engenders different endogenous agglomeration and dispersion patterns of firms, by making the number of firms in each region endogenous [21].

RHOMOLO contains three endogenous location mechanisms that bring the agglomeration and dispersion of firms and workers about: the mobility of capital, the mobility of labour, and vertical linkages. In addition to these effects, RHOMOLO adds some stability in location patterns by calibrating consumer preferences over the different varieties in the base year. Through calibration, the regional patterns of intermediate and final consumption observed in a given moment of time are translated into variety-specific preference parameters, which ensure a given level of demand for varieties produced in each region, including peripheral ones.

In the current version of RHOMOLO, energy sectors are part of a more aggregated group of industrial sectors labelled 'Manufacturing'. Hence, it is not possible to run policy simulated related to energy, such as improvements in energy efficiency. However, a number of cohesion policy measures are directly targeted at energy production and use. Some examples include: Electricity (storage and transmission), Electricity (TEN-E storage and transmission), Natural gas, Natural gas (TEN-E), Renewable energy (wind), High efficiency co-generation and district heating, etc.

In the current version of RHOMOLO it would not be possible to assess impacts of such cohesion policy investments in energy infrastructure. Therefore, within the EREBILAND project, sector breakdown of industrial activities will be disaggregated into several energy sectors in the RHOMOLO model. It is envisaged to disaggregate the following energy-based activities from the current aggregated group of industrial sectors labelled 'Manufacturing':

1. Mining of coal and lignite; extraction of peat;
2. Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction excluding surveying;
3. Electricity, gas, steam and hot water supply.

Having these three energy-based activities as separate industrial sectors in RHOMOLO, it would be possible to use RHOMOLO together with JRC-EU-TIMES to assess socio-economic impacts of the cohesion policy investments in energy infrastructure at the regional level. One possible scenario could be first to assess how cohesion policy investments in energy affect energy supply and use of different industrial sectors and final demand of households and government using the JRC-EU-TIMES model. Second, these simulated changes in the input-output coefficients and final demand could be fed into the RHOMOLO model, where the socio-economic impacts on GDP, employment, investment, trade, etc. could be assessed at the regional and sector level. Also other types of energy policy simulations will be possible with the extended RHOMOLO model.

3.2 Data sources and data integration

EREBILAND brought together an extensive knowledge base built by merging data belonging to the three single models (LUISA, JRC-EU-TIMES and RHOMOLO), and acquiring new input data ad-hoc for EREBILAND. Within the scope of the project, various datasets and databases have been obtained, analysed and used in the methodology. The data were used for different purposes - directly for downscaling, or for validation and comparison.

The data used can be classified according to their source (simulation models, private providers, completed or on-going projects, and open-source initiatives) and main characteristics. An overview of the data is provided in *Table 2*.

In addition to the knowledge base listed in *Table 2*, other types of sources, such as scientific literature or technical publications, have been consulted in order to underpin modelling assumptions and define parameters' levels. These sources are not listed in the table below, but are presented in the relevant sections and reported as references in the Bibliography.

Table 2. EREBILAND knowledge base

Name	Provider	Update	Geograpghical coverage	Temporal detail	Spatial detail	Thematic detail	Type of data source
PowerVision	PLATTS	2015	EU-Continent	2015	1:5,000	Fuel type and techonology type	Private company
WEPP	PLATTS	2015	EU-Continent	2015	LAU2	Fuel type and techonology type	Private company
Worldwide Wind Farms Database	The Wind Power	2015	EU-Continent	2015	*na*	Techonology type	Private company
IHS	IHS	2010	EU-Continent	2010	1:500,000	Fuel type and techonology type	Private company
Land-use/cover projections	JRC-H8	2014	EU28	2010-2050	Grid (100mx100m)	17 simulated land use/cover classes	Model output (LUISA)
Population density projections	JRC-H8	2014	EU28	2010-2050	Grid (100mx100m)	-	Model output (LUISA)
Accessibility projections	JRC-H8	2014	EU28	2010-2050	Grid (100mx100m)	-	Model output (LUISA)
DB Task 32 [22]	IEA	2009	EU-Continent	2009	*na*	Fuel type and techonology type	Project (completed)
Suitability for Solar PV	JRC-H8	2014	EU28	2010	Grid (100mx100m)	-	Model output (LUISA)
Energy and emissions from transport	DG ENV	2010	EU28	2020	NUTS0/NUTS2	Vehicle type, driven kilometres, and driving conditions	Model output (TREMOVE)

Average Annual Daily Traffic [23]	UNECE	2010	EU-Continent*	2010	NUTS0	Vehicle type and road type	International organisation
Open Street Map [24]	OpenStreetMap contributors	2015	EU-Continent	2015	*na*	Road type	Project (open source)
Road Network	TeleAtlas	2014	EU-Continent	2014	1 / 5m (accuracy)	Road type	Private company

Notes:

** Available countries are: Austria, Bulgaria, Croatia, Czech Republic, Denmark, France, Germany, Lithuania, Macedonia, Poland, Romania, Russia, Serbia, Slovakia, Sweden, Switzerland, Turkey and the United Kingdom.*

One of the key layers used for the disaggregation of electricity production, is WEPP from the PLATTS provider.

Data recorded in WEPP include: ownership, location, and engineering design data for power plants of various sizes and technologies operated by regulated utilities, private power companies and industrial or commercial auto-producers.

The use of this dataset required an extensive preliminary analysis and processing, which involved: (1) the set-up of a geocoding procedure to convert addresses to geographic coordinates, and (2) extensive quality check of the resulting geocoded version of the dataset.

The geocoding procedure has been set-up so to cope with the heterogeneity of format and detail level of the addresses originally reported in WEPP. The resulting dataset consists of georeferenced producing units/plants whose geographical coordinates are accurate at municipal level. Units/plants for which there were not sufficient information to reach this level of spatial accuracy, were discarded. Geocoder Nominatim [25] has been used, along with GoogleV3 [26] for a sample-based validation.

An overview of the number of geocoded units/plants is reported in *Table 3* and, at country level, in *Table 4*. The units/plants originally recorded in WEPP, but not included in the geocoded dataset, represent 18% of the total number of units/plants (continental Europe) and 16% of the ones located in European MS (EU28). Reasons of exclusions can be: lack of detailed enough addresses or erroneous geocoding output.

It is worth noting that the highest share of the excluded units/plants are wind installations (nearly 900 units across EU28): this category of power plants (both on- and off-shore wind) is however covered by a dedicated dataset (*Worldwide Wind Farms Database*).

Table 3. Number of producing units/plants in WEPP

	Units/plants in the original WEPP	**Successfully geocoded units/plants**	
	[#]	**[#]**	**[%]**
EU-Continent	57,872	47,328	82
EU28	49,980	42,009	84

Table 4. Number of producing units/plants in WEPP, per country

Country	**Total number of successfully geocoded units/plants**
AUSTRIA	1,261
BELGIUM	913
CHANNEL ISLANDS	32
CZECH REPUBLIC	1,133

DENMARK	1,315
ENGLAND & WALES	2,249
ESTONIA	154
FINLAND	667
FRANCE	3,777
GERMANY	10,283
GREECE	912
HUNGARY	434
IRELAND	423
ISLE OF MAN	31
ITALY	5,655
LATVIA	131
LITHUANIA	123
LUXEMBOURG	180
MALTA	53
The NETHERLANDS	1,804
NORTHERN IRELAND	166
POLAND	1,351
PORTUGAL	1,005
SCOTLAND	812
SLOVAKIA	441
SLOVENIA	207
SPAIN	4,401
SWEDEN	2,096

3.3 Disaggregation methodology

The methodology to disaggregate energy production and energy consumption patterns from national to regional level, is presented in this section.

All considered sectors are discussed: for electricity generation and transport a higher level of details is provided and first results are presented in the Results section.

3.3.1 Electricity generation

The methodology developed to disaggregate national electricity production figures at regional level, is presented in *Figure 8*.

National figures of electricity production provided by JRC-EU-TIMES are disaggregated at regional level, using an index composed by different proxies, including: location, technical characteristics and operational status of producing power plants (from the data layers described in section 3.2); run load hours (as simulated by the JRC-EU-TIMES model) and co-firing shares (from the scientific and technical literature).

The technical characteristics of power plants considered are:

- Installed capacity, or operating capacity;
- Main fuel type: per broad categories, such as natural gas, crude oil, etc.;
- Secondary fuel type: per broad categories (as for the main fuel);
- Technology type of unit: such as gas turbine, diesel engine, steam turbine, etc.
- Type of boiler;
- Steam pressure;
- Steam type (type of steam turbine e.g. tandem compound steam turbine, etc.);
- Operational status: planned, in operation, in decommissioning, etc.;
- Year: beginning of operational phase.

Load hours are defined as the total number of hours during which, over a year, a power plant has been producing electricity. This information is provided by the JRC-EU-TIMES model, as one national figure per fuel/technology combination. At present, load hours were included in the disaggregation methodology for the following types of fuel: biogas, natural gas, as well as for hydro. For the missing fuels and resources (biomass, geothermal, hard coal, lignite, wind, crude oil and solar), two cases are possible: values for load hours do no differ significantly among different fuel/technology combinations (according to the JRC-EU-TIMES simulation); and it is not possible to match the fuel/technology combinations between the power plant data layer (WEPP) and the ones by which JRC-EU-TIMES provides the load hours.

The disaggregation methodology produces results at point or grid level (where the location of the producing power plants is estimated), and are then re-aggregated at regional scale (NUTS2).

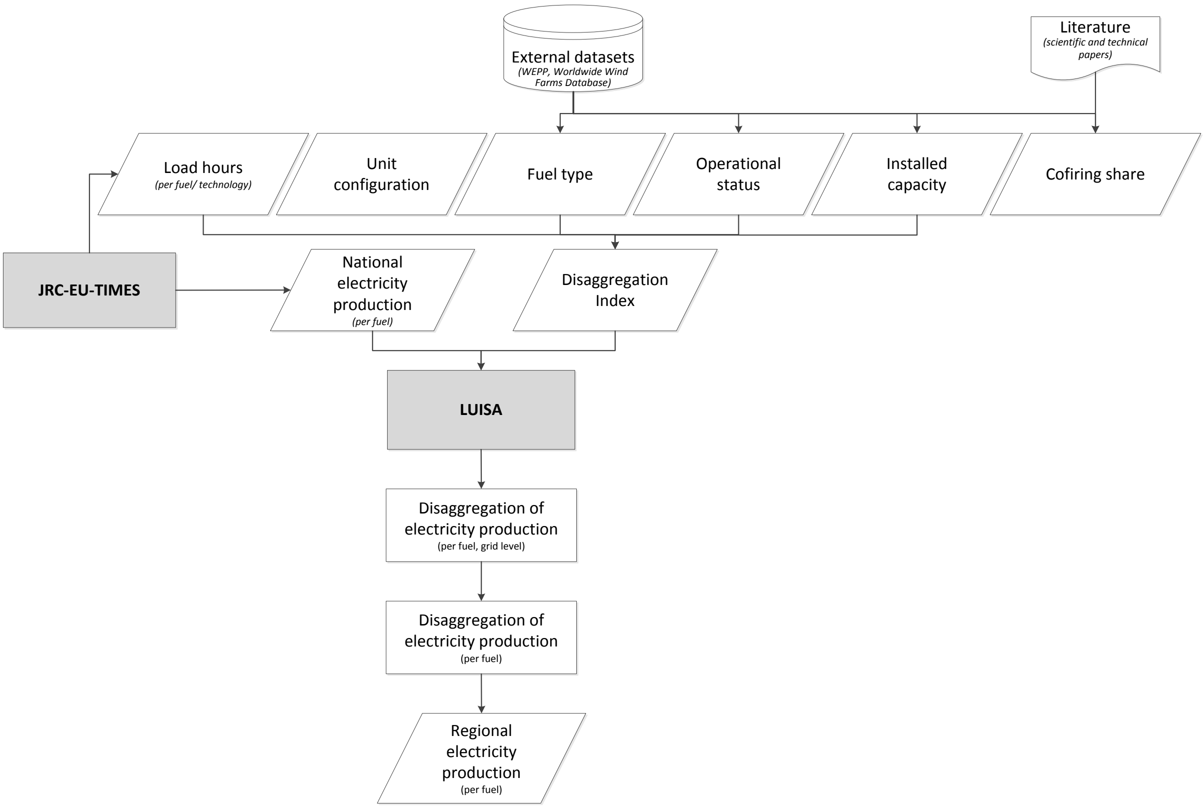

Figure 8. Workflow for the disaggregation of electricity production. The boxes representing the models involved (JRC-EU-TIMES and LUISA) are shaded in grey

The application of the methodology is clearly influenced by the quality of the available data. When there were considered not reliable or needing further checking, details have been generalised (thematically or geographically). Both automated and manual control checks have been carried out as much as possible.

From a spatial perspective, all data that have been used, possess a level of precision at least at municipal level.

From a thematic perspective, the different levels of detail, provided by various components of the methodology, needed to match. As a results, the disaggregation procedure has been defined for broad categories of fuels (column "EREBILAND" of the following tables). The corresponding categories (fuel/technology) of JRC-EU-TIMES, for both electricity generation classification and load hours, and power plant data layer (WEPP), are reported in Table 5, Table 6 and Table 7.

Table 5. Correspondences between the output categories of the disaggregation and the electricity generation classification originally provided by the JRC-EU-TIMES model

EREBILAND	JRC-EU-TIMES Electricity generation classification
Biomass	ELECHPBIOBRFHTH
Biogas	ELECHPBGS

Gas	ELECHPGAS
Geothermal	ELECHPGEO
Oil	ELECHPOIL
Hydroelectric	ELEHYD
	ELEOCE
Nuclear	ELENUC
Solar (excluding solar roofs)	EEPP_PV [Existing Electricity plant - PV]
	EUPVSOLL101 [Solar PV utility scale fixed systems large > 10MW thin films]
	ELECSP
Wind off-shore	ELEWOF
Wind on-shore	ELEWON
Hard coal	CHPAUTOGENSOLID00
	CHPCOMSCOH
	EAUTOGENSOLID00
	ECHP_coal_CCGT
	ECHP_coal_OCGT
	ECHP_coal_thermal
	EEPP_coal_CCGT
	EEPP_coal_thermal
	EUSTCOHcon01
	EUSTCOHsup01
	EUSTCOLcon01
	EUSTCOLsup01
	EUSTIISGAS101
	PUSCOH
	PUSCOL
Lignite	ECHP_lignite_thermal
	EEPP_lignite_thermal

Table 6. Fuel categories correspondences between the output categories of the disaggregation and the WEPP data

EREBILAND	**WEPP Fuel type**
Hardcoal	"BIT", "BIT/ANTH", "BIT/SUB", "WSTBIT", "ANTH/BIT", "ANTH", "BIT/LIG", "SUB", "BIT/WSTBIT", "GOB/BIT", "None"
Lignite	"LIG", "LIG/BIT", "LIG/SUB"
Biomass	"BIOMASS", "BL", "HZDWST", "LIQ","MBM", "MEDWST", "PWST", "REF", "RPF", "TIRES", "WOOD"
Biogas	"AGAS", "BGAS", "DGAS", "LGAS", "WOODGAS", "WSTWSL", "WSTGAS", "WSTH"
Gas	"BFG", "CGAS", "COG", "CSGAS", "FGAS", "GAS", "H2", "LNG", "LPG", "MGAS", "OGAS", "REFGAS", "RGAS", "TGAS"
Hydroelectric	"WAT"
Geothermal	"GEO"

Nuclear	"UR"
Oil	"INDWST", "JET", "KERO", "NAP", "OIL", "SHALE"
Solar (PV)	"SUN"

Table 7. Correspondences between the output categories of the disaggregation and the load hours categories originally provided by the JRC-EU-TIMES model

JRC-EU-TIMES fuel type	JRC-EU-TIMES technology	JRC-EU-TIMES aggregated technology	WEPP categories
BIOGAS	CHP: Steam Turb condensing.MUN.IND CHP: Steam.Turbine.MUN.PUB	Steam turbine	"ECE", "CC", "FC", "ORC", "ST", "ST/S" WEPP fields: UTYPE
	CHP: Int Combust.BGS.PUB	Internal combustion	"GT", "GT/C", "GT/H", "GT/S", "IC", "IC/H" WEPP fields: UTYPE
GAS	Existing CHP plant - naturalgas_CCGT Existing CHP plant - naturalgas_OCGT Existing CHP plant - naturalgas_thermal	Combined cycle (CHP): heat and power	"CC", "CCSS", "CCSS/P", "FC", "GT", "GT/C", "GT/CP", "GT/H", "GT/S", "GT/T", "IC/CD", "IC/H", "ORC", "ST/C", "ST/CP", "ST/D", "ST/S", "ST/T" WEPP fields: UTYPE
	Existing Electricity plant - naturalgas_CCGT Existing Electricity plant - naturalgas_OCGT Existing Electricity plant - naturalgas_thermal Gas Turbine Combined Cycle Gas Advanced Peak Device Gas Conventional OCGT CHP: Int Combust.GAS.PUB	Gas turbine (no CHP), no heat recovery	"IC", "RSE", "ST", "TEX" WEPP fields: UTYPE
HYDRO	Pumped Hydro ELC Storage: DayNite	Pumped hydro	"PS" WEPP fields: FUELTYPE

	Lake large scale cheap hydroelectricity > 10 MW Lake large scale expensive hydroelectricity > 10 MW	All hydro >10 MW	"CONV" WEPP fields: FUELTYPE and MW (> 10 from MW)
	EPLT: Hydro.With Dam.Base-year EPLT: Hydro.Run of River.Base-year Run of River hydroelectricity	All hydro <10 MW	"CONV" WEPP fields: FUELTYPE and MW (< 10 from MW)

3.3.1.1 Non-renewable sources

Among non-renewable resources, gas and oil have been considered as two aggregated categories. On the opposite, coal has been differentiated in two sub-categories: hardcoal and lignite. The motivation for this choice is related to the different type of procurement of these two fuels: lignite is largely of local origin i.e. the power plant is located close to the mining site; on the opposite, power plants using hard coal can use coal both of local origin and imported.

As highlighted in the workflow in *Figure 8*, a layer containing information on biomass co-firing options, when the main fuel is coal (hard coal or lignite) was included. Based on technical and scientific publications ([27], [28], [29], [30] and [31]), a simple model has been developed in order to estimate potential co-firing shares, i.e. to estimate the amount of biomass that, considering the technical characteristics of the power plant, is likely to be fired along with coal.

This model seems to be valid for direct co-combustion only, where coal and biomass are burnt together. In general, co-firing can be direct, indirect or parallel. The main difference between these firing options is related to the economic viability. While all the three variants exist in reality, direct co-firing is the most common alternative [29], and it is by far the option requiring the lowest investment cost and allowing for the highest conversion efficiency.

In order to calculate the quantity of biomass that should be collected in the region for the co-firing process the following equations [28] shall be used:

$$Biomass\ required = \frac{[Gross\ Heat\ Input \times Biomass\ Cofired\ Ratio]}{Heat\ value\ of\ biomass} \quad \text{[kg]} \tag{1}$$

The heat value of the chosen biomass is expressed in [MJ/kg] and it can be obtained from [27] – Table 12 pp. 2274.

The main assumption of the model is that the gross heat input to the boiler remains the same for both neat coal firing (before retrofitting) and for biomass co-firing(after retrofitting) options:

$$Gross\ Heat\ Input = \frac{Annual\ Power\ generation}{\eta_{0,bm}} \times 3.6 \quad \text{[MJ]}$$

(2)

The annual power generation (in kWh) can be calculated from the installed capacity reported in the WEPP database, assuming the hours of operation per year (around 8000) and capacity factor of the plant.

The overall efficiency of the plant with co-firing ($\eta_{0,bm}$) can be calculated as:

$$\eta_{0,bm} = (\eta_b - EL) \times \eta_{rp} \qquad [-]$$

(3)

Being η_b the boiler efficiency which usually ranges between 82% and 89% and being η_{rp} the rest of power efficiency (non-boiler efficiency), which usually is assumed as 40 – 43%.

EL is the efficiency loss of boiler (on a percentage basis) from biomass co-firing that is estimated based on the result obtained by pilot plant test as function of biomass co-firing ratio:

$$EL = 0.0044 \times biomass\ cofiring\ ratio^2 + 0.0055 \qquad [-]$$

(4)

The biomass co-firing ratio (measured in percentage of biomass on a mass basis) can be calculated with the maximum reported values, depending on the type or combinations of biomass fuel (see [27]). These values are then adapted to percent on a mass basis since they appear as %th or vol%. Calculations of maximum shares take into account limitations to the usable biomass fractions due to slagging and fouling, corrosion and deactivation of the DeNOx catalyst.

3.3.1.2 Renewable sources

Categories of renewable sources included in the analysis are: solar (PV), wind, hydropower, biogas and biomass.

The total amount of electricity produced by biomass, has been distributed amongst power plants using biomass as main fuel and power plants with co-firing option.

For the disaggregation of wind, the Worldwide Wind Farms Database (see *Table 2*) is the source of the exact location and technical characteristics of wind installations, both on- and off-shore.

3.3.2 Energy demand

The disaggregation methodology for the three sectors considered is described in the following paragraphs. As stressed Chapter 2, results will be presented for the road transport sector only, and not for residential and ICS.

3.3.2.1 Energy demand: road transport sector

The energy demand projected by the JRC-EU-TIMES model has been grouped in fourteen categories, based on the vehicle type and fuel. The detailed correspondences are given in *Table 8* (car vehicles), *Table 9* (bus vehicles), *Table 10* (duty vehicles) and *Table 11* (motorcycles).

Table 8. Correspondences between the JRC-EU-TIMES vehicle/fuel combinations and the output categories of the disaggregation, for car vehicles

EREBILAND	JRC-EU-TIMES	EREBILAND	JRC-EU-TIMES
Car - Diesel	TCARDST100	**Car – Natural gas (LPG)**	TCARGAS100
	TCARMDST101		TCARMGAS101
	TCARMDST111		TCARMGAS111
	TCARMDST121		TCARMGAS121
	TCARMDST131		TCARMGAS131
	TCARMDST141		TCARMGAS141
	TCARMDST151		TCARMGAS151
	TCARMDST161		TCARMGAS161
	TCARMDST171		TCARMGAS171
	TCARMDST181		TCARMGAS181
	TCARMDST191		TCARMGAS191
Car - Gasoline	TCARGSL100		TCARLPG100
	TCARMGSL101		TCARMLPG101
	TCARMGSL111		TCARMLPG111
	TCARMGSL121		TCARMLPG121
	TCARMGSL131		TCARMLPG131
	TCARMGSL141		TCARMLPG141
	TCARMGSL151		TCARMLPG151
	TCARMGSL161		TCARMLPG161
	TCARMGSL171		TCARMLPG171
	TCARMGSL181		TCARMLPG181
	TCARMGSL191		TCARMLPG191
Car – Hybrid, electric, H2	TCar_PIH_LD_20pct	**Car – Hybrid, electric, H2**	TCARMGH2FC110
	TCar_PIH_LD_80pct		TCARMGH2IC110
	TCARMELC110		TCARMLH2IC110

Table 9. Correspondences between the JRC-EU-TIMES vehicle/fuel combinations and the output categories of the disaggregation, for bus vehicles

EREBILAND	JRC-EU-TIMES	EREBILAND	JRC-EU-TIMES
Urban bus – Gas, gasoline	TBUSDST100	**Bus Intercity - diesel**	TBISDST100
	TBUSDST101		TBISDST101
	TBUSGAS100	**Bus Intercity – Biodiesel, gasoline**	TBISBDL101
	TBUSGAS101		TBISGSL100
	TBUSGSL100		TBISGSL101
	TBUSGSL101		

Table 10. Correspondences between the JRC-EU-TIMES vehicle/fuel combinations and the output categories of the disaggregation, for duty vehicles

EREBILAND	JRC-EU-TIMES	EREBILAND	JRC-EU-TIMES
Heavy duty truck - Diesel	TFREHDST100	**Light duty truck - Diesel**	TFRELDST100
	TFREHDST101	**Light duty truck - Gasoline**	TFRELGSL100
Heavy duty truck – Gas, gasoline, LPG	TFREHGAS101		TFRELMGSL101
	TFREHGSL101		
	TFRELMLPG101		

Table 11. Correspondences between the JRC-EU-TIMES vehicle/fuel combinations and the output categories of the disaggregation, for motorcycles

EREBILAND	JRC-EU-TIMES
Moto - Gasoline	TMOTGSL100
	TMOTGSL101

Similarly to the electricity generation sector, the disaggregation of national energy consumption figures for transport is based on a disaggregation index.

The disaggregation is generated at the highest possible spatial resolution (grid level, 100m) and the results have been then re-aggregated at the NUTS2 level. Results are expressed in [PJ].

Two different disaggregation methodologies have been developed:

- the first methodology applies to long-distance travelling: heavy truck – diesel; heavy truck – gas, gasoline; bus intercity – biodiesel, gasoline; bus intercity – diesel;
- The second methodology applies to short-medium distance travelling: all car vehicles categories, light duty trucks and urban buses.

The first type of disaggregation is based on road network data (Open Street Map), highway traffic data (United Nations Economic Commission for Europe - UNECE) and TREMOVE model output.

The road networks have been derived from Open Street Map, distinguishing the following categories - motorways, national roads and regional/local roads. Land-use information as derived from the LUISA platform has then been used to classify national and regional/local roads in urban and non-urban types.

In order to distribute energy demand over the road network, information about traffic would be needed. At present, no such kind of information seems to be available at European scale in a harmonized and consistent format for urban/non-urban, national and local roads. Therefore, population density has been used as surrogate for road traffic. In other words, it is assumed that the average population density in a buffer area around each grid point of the road network is an approximation of the potential usage (i.e. traffic) of that segment of road.

For highways, it was instead possible to use real traffic data, expressed as Average Annual Daily Traffic (AADT).

AADT is considered as one of the most important raw traffic dataset, as it provides essential inputs for traffic model developments and calibration exercises that can be used for the planning of new road construction, determination of roadway geometry, congestion management, pavement design and many others. AADT is generally available for most of the European road networks. The data is collected by traffic control centres, refined and disseminated to users by traffic information centres in most of the EU countries.

The AADT database from UNECE covers different years, 2010 being the last available one. Its update is not yet complete, therefore it was decided to use data for 2005, applying previous versions of the database from2000 and 1995 in order to fill the information gaps.

Information is missing for the entire Greek motorway network (69 records) and hence, it was necessary to assign equal weight to all network.

In order to be consistent with the other road networks (national and regional) and also due to the very fine scale that has been used, the Open Street map (OSM) E-roads network (i.e. highways) appear to be much more spatially detailed and thus, more appropriate for the intended scope.

UNECE AADT traffic values were assigned to the OSM highways network based on Euclidean distance from between the two datasets. Then the value of traffic for the network is modified according to the relative presence of roads segments in the 100*100m2 pixel.

The TREMOVE model is used to divide the total input of energy demand at the national scale (from JRC-EU-TIMES) between urban, not-urban and highway road networks.

Of particular interest is the 'fuel consumption and emissions' module from the TREMOVE model. This module is used to calculate "fuel consumption and emissions, based on the structure of the vehicle stock, the number of kilometres driven by each vehicle type and the driving conditions".

Among other parameters, this module also estimates the energy use, expressed in PJ. This parameter is hence derived for each of the fourteen considered macro-categories of transport processes and used as a weight in order to share the amount of energy demand between urban roads, non-urban roads and highways (E-roads).

The considered year of TREMOVE simulation is 2020.

The original database is modified for Malta and Cyprus, in order to divide the emissions between urban and non-urban types, since no road on those two countries is classified as E-road, according to UNECE.

The second methodology is based on a newly developed accessibility indicator *(*a detailed description of the indicator can be found in *"Indicators of urban form and sustainable urban transport - Introducing simulation-based indicators for the LUISA platform". Chris Jacobs-Crisioni, Mert Kompil, Claudia Baranzelli, Carlo Lavalle. JRC Technical report, In Publication*). This indicator has been defined with the purpose of having a straightforward measure (proxy) of the level of energy consumption due to transport of residential areas.

The disaggregation index is based on the spatial distribution (grid level, 100m) of number of passenger kilometres produced by roads (two examples are reported in *Figure 9*). Passenger kilometres are produced as flow multiplied by length of link. The underlying assumption it that 1 average car on a 1000 km link uses as much energy as a 1000 average cars on a 1 km link.

The key question answered by this indicator is: *if every inhabitant makes the same amount of trips to destinations only within 30 minutes, what Euclidean distance would the inhabitants travel on average*? The underlying assumption is that longer travelled Euclidean distances are associated with higher energy consumption and reduced opportunities for energy efficient transport modes such as walking and cycling. We estimate that the threshold of 30 minutes already provides a feasible limit which can be associated with short-distance trips such as commuting, shopping and social visits. A recent JRC survey has indeed shown that working day trips in most surveyed European countries are shorter than 30 minutes [32], and we therefore expect that this restriction does not severely affect the validity of the findings.

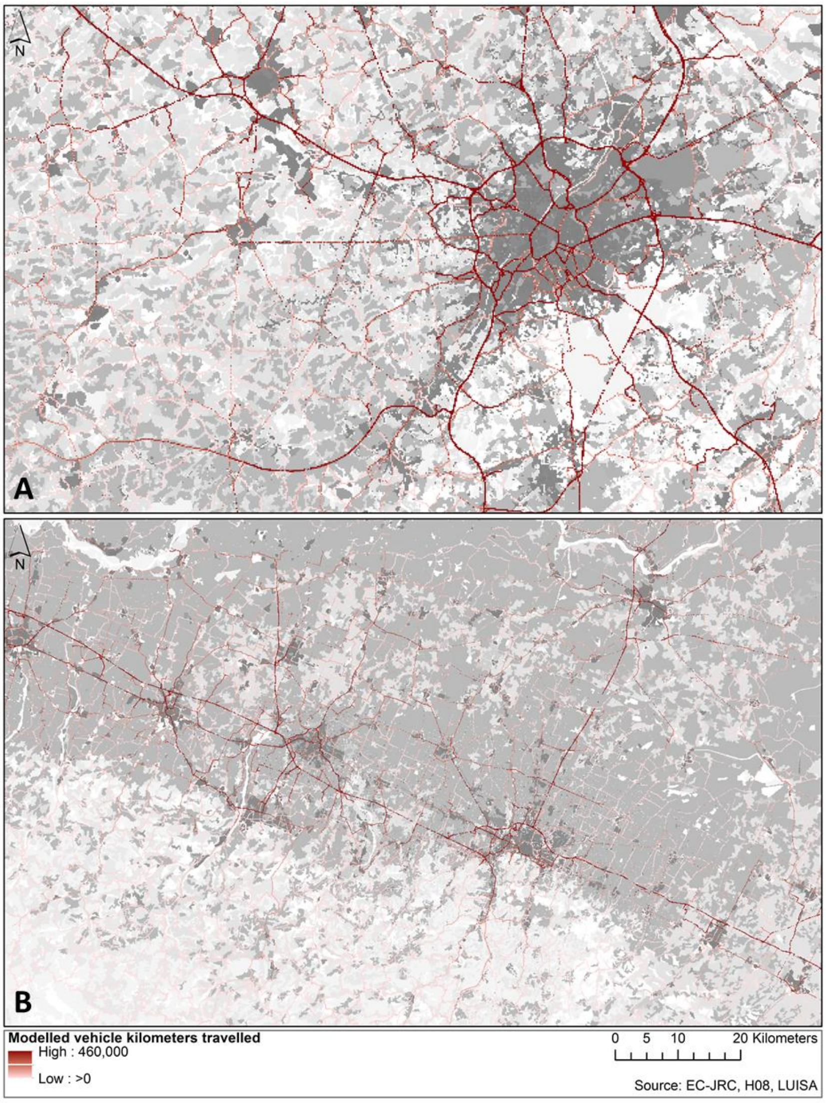

Figure 9. Indicator of vehicle kilometres travelled nearby the cities of Brussels - Belgium (frame A) and Bologna – Italy (frame B), for the year 2010

3.3.2.2 Energy demand: residential sector

Two methodologies are envisaged for the disaggregation of energy consumed by the residential sector.

The first methodology is solely based on population density (available at grid level) and households' characteristics (i.e. number of components, available at regional level). A simple relation is drawn between consumption levels and these two factors, and it is then used as proxies for the disaggregation procedure.

The second, more sophisticated, methodology is based on an extensive collection of data at local (neighbourhood, municipal or NUTS3) level of factors related to:

- Use of the building (residential, industrial, commercial, mixed or other);
- Building/dwelling characteristics (e.g. dimensions, age, typology, household structure);
- Structural details (e.g. employed construction materials, renewal rate, certifications, etc.)
- Energy-related technological details (including for the production of energy)
- Geographical and climatic location.

This methodology is based on the use of statistical regression techniques to estimate the influence of the above mentioned variables (predictors) on energy consumption in residential buildings at the local level (municipality). Similar statistical models can be fitted for municipalities that show similar population density patterns, urbanisation trends and climatic characteristics.

It is envisaged to implement this second methodology within a dedicated case study (II year of the EREBILAND project).

3.3.2.2 Energy demand: ICS sector

A straightforward approach is proposed for the disaggregation of aggregated energy consumption figures for industry/commerce/service. Main proxy is the regional variation of sector Gross value Added (GVA).

Additional input data that might be used include: production statistics for aggregations of NACE categories; and location and detailed production statistics of some industrial categories, such as polluting industries.

4. Results

In this section, results are presented for the years 2015, 2020 and 2030, for the electricity production and transport sectors.

4.1 Electricity production

Results are reported at regional level. Electricity generated is reported in [PJ], annual value.

4.1.1 Electricity generated by biomass

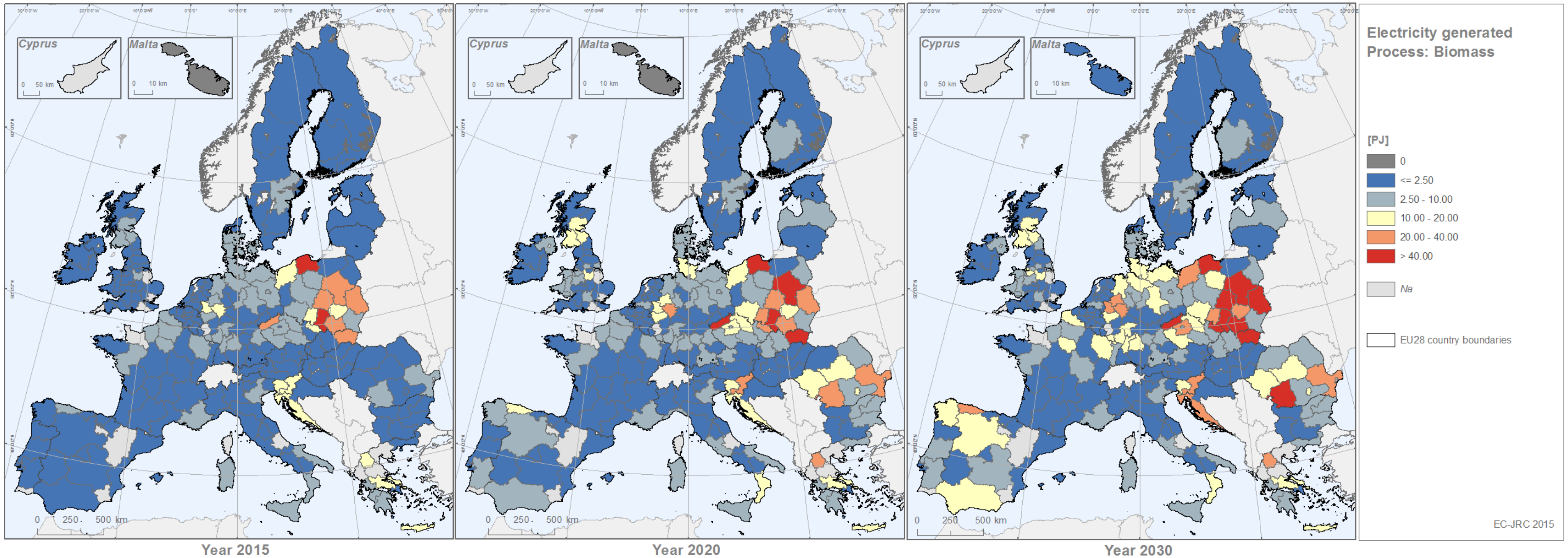

Figure 10. Electricity generated from biomass, for the years 2015, 2020 and 2030

Almost all European regions, from 2015 to 2030 experience an increase in the amount of electricity generated from biomass. A slightly negative trend (up to 13% decrease) can be found only in all the Danish NUTS2 and Luxemburg. Few regions in the UK, Germany, Portugal, France, Spain, Italy, Greece and Cyprus, don't produce any electricity from this source. Among the remaining regions, the amount of electricity that is produced in some NUTS2 in Bulgaria, Spain, the Netherlands, Romania and the UK, increases by a factor of at least 5.

4.1.2 Electricity generated by biogas

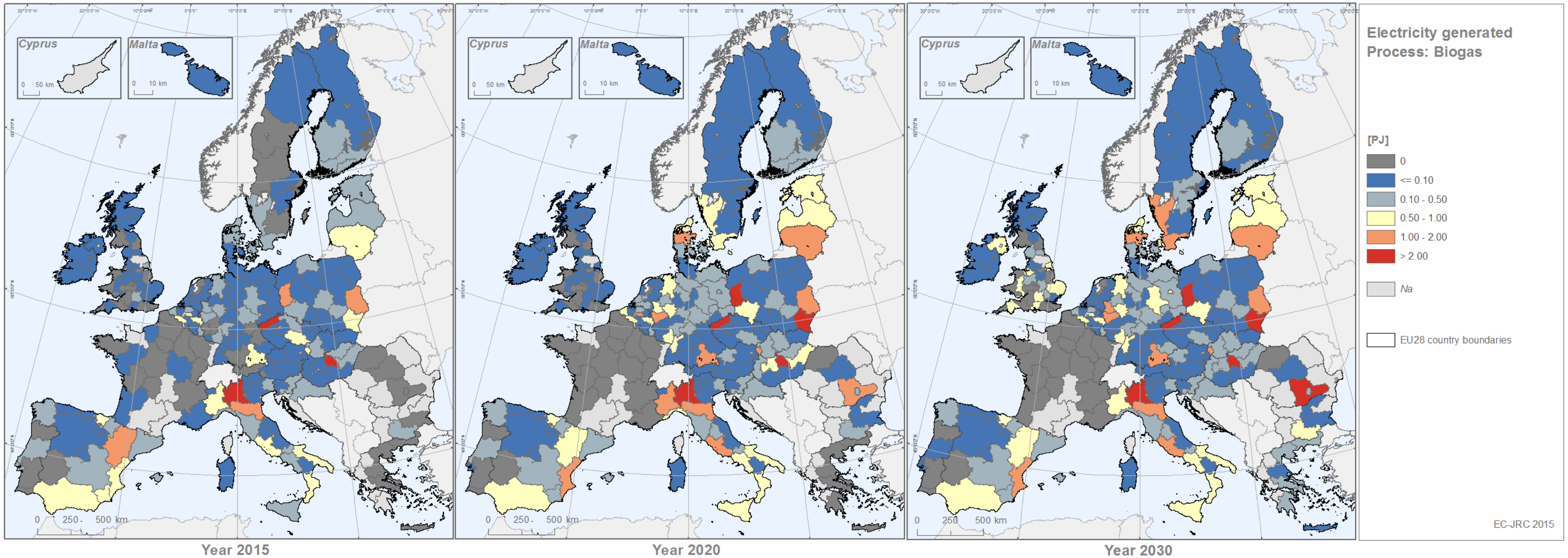

Figure 11. Electricity generated from biogas, for the years 2015, 2020 and 2030

Throughout Europe, eighty six regions don’t experience any significant change, from 2015 to 2030, in the amount of electricity produced from biogas. A decreasing trend can be found in regions belonging to Czech Republic, Spain, Finland, Hungary, Ireland, Italy (only one region), the Netherlands, Portugal and Slovenia. The sharpest decrease (close or above 50%) can be found in both Irish NUTS2, the Southern Great Plain region in Hungary, the central regions in Portugal and Western Slovenia. Conversely, electricity from biogas increases by a factor of at least 8 in the majority of regions in the UK, Germany, Austria and Hungary.

4.1.3 Electricity generated by coal (lignite)

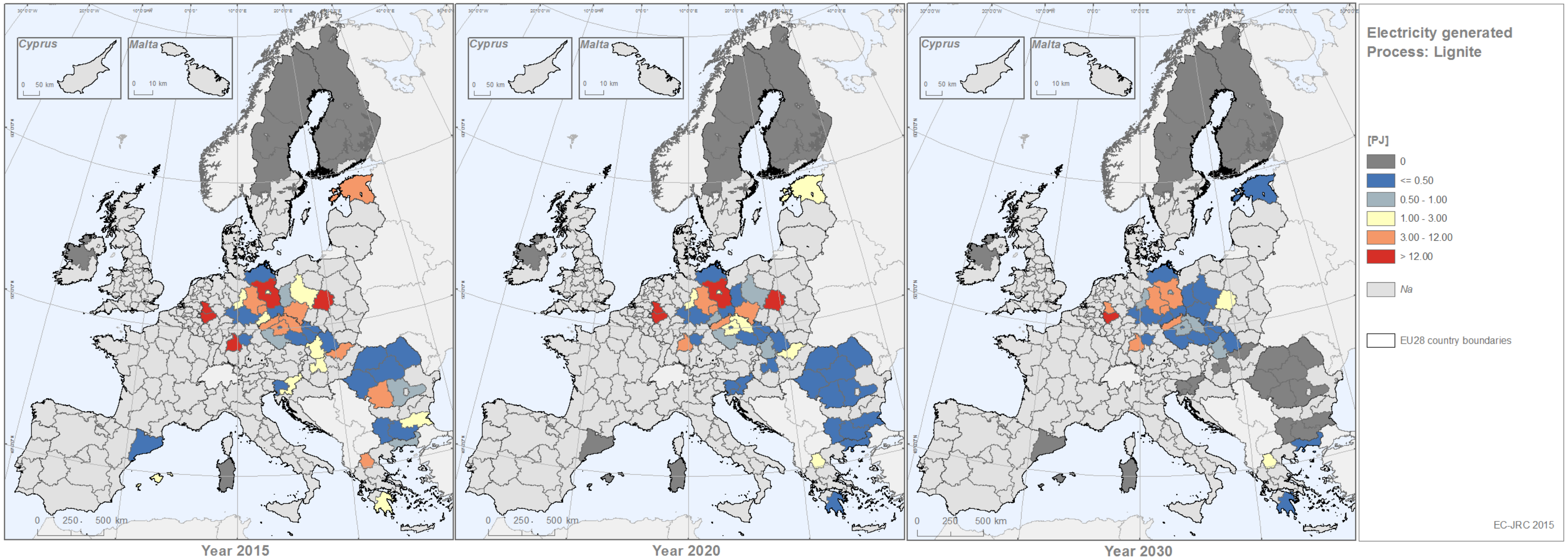

Figure 12. Electricity generated from lignite, for the years 2015, 2020 and 2030

In all regions across Europe, the amount of electricity generated from lignite decreases. In some NUTS2, originally using lignite, this type of fuel is forecasted to be phased out: this happens in Spain, Bulgaria, Hungary, Romania and Slovenia.

4.1.4 Electricity generated by coal (hard coal)

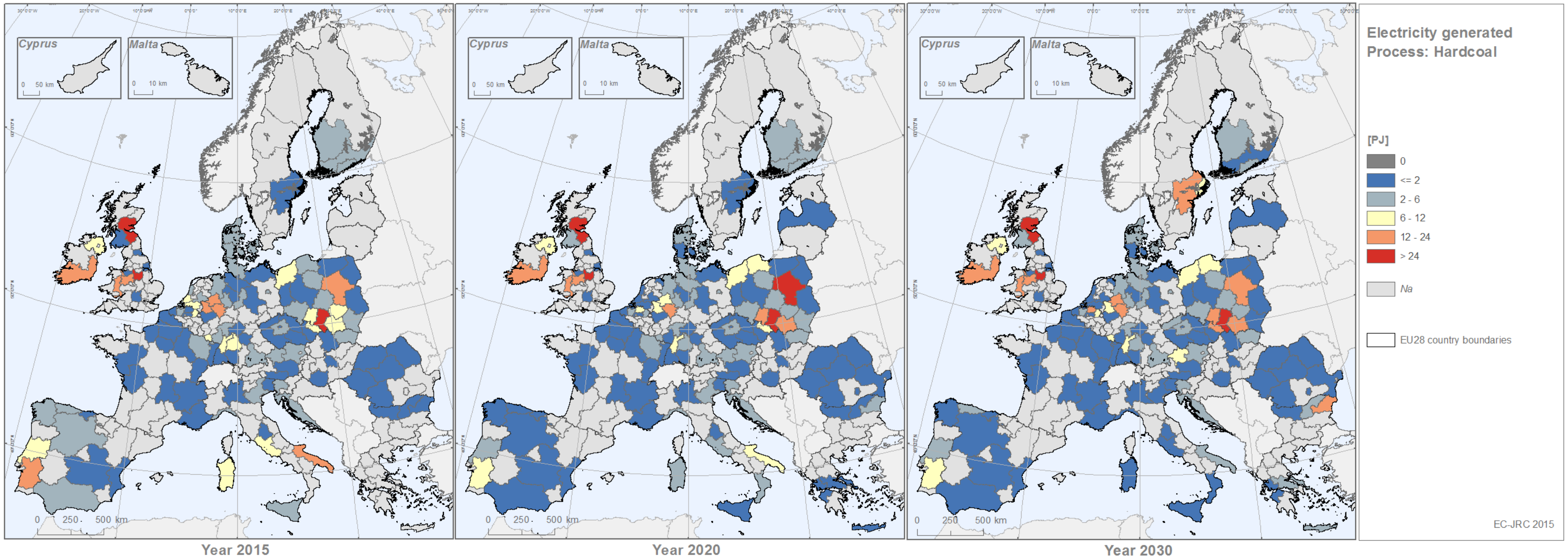

Figure 13. Electricity generated from hard coal, for the years 2015, 2020 and 2030

Trends in the amount of electricity generated from hard coal experience a much less degree of variation, compared to renewables or even gas. Extreme increases (of a factor of at least 8) can be found only in four Bulgarian regions, two regions in Germany, Slovenia and in South Western Scotland. Of the regions currently (2015) using hard coal to generate electricity, eighty eight are foreseen to reduce this production. The sharpest decreases (above 70%) take place in Spain, Italy and the Netherlands.

4.1.5 Electricity generated by gas

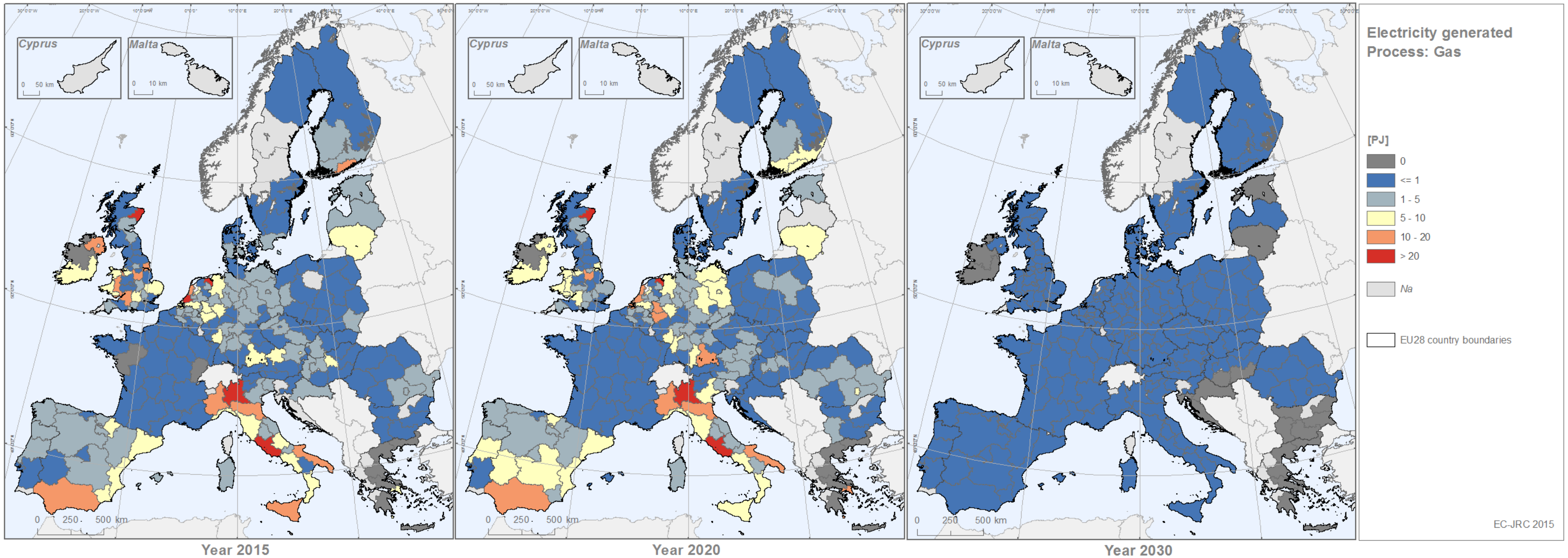

Figure 14. Electricity generated from gas, for the years 2015, 2020 and 2030

The amount of electricity generated from gas generally decreases throughout Europe from 2015 to 2030. Only exceptions are two regions in Poland (Zachodniopomorskie and Opolskie), Carinthia in Austria, Extremadura in Spain and two NUTS 2 in France (Brittany and Auvergne). The mildest decrease (less than 70%) takes place in few regions in Slovakia, Poland, Sweden, France and Germany. In Lorraine (France) the decrease is just of 4%.

4.1.6 Electricity generated by geothermal

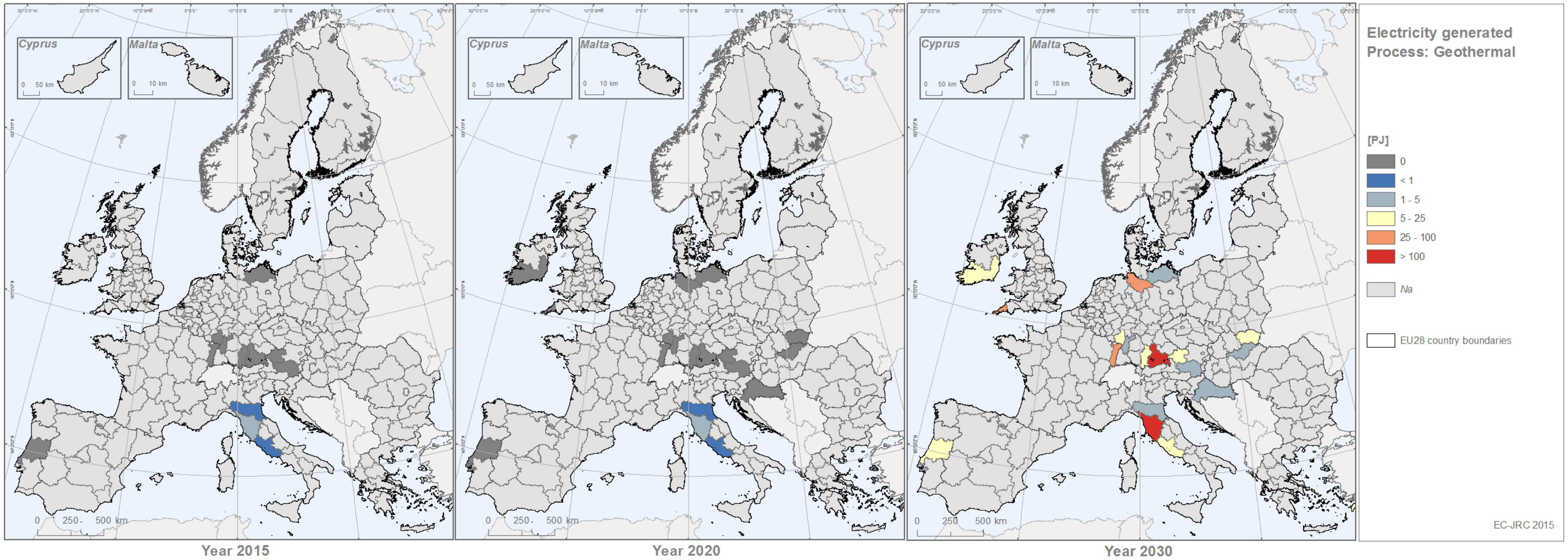

Figure 15. Electricity generated from geothermal, for the years 2015, 2020 and 2030

Geothermal is the least diffuse source used to generate electricity in Europe. In 2030, only twenty one regions between Austria, Germany, France, Croatia, Hungary, Ireland, Italy, Portugal, Slovakia and the UK, are forecasted to generate electricity from geothermal.

4.1.7 Electricity generated by hydroelectric

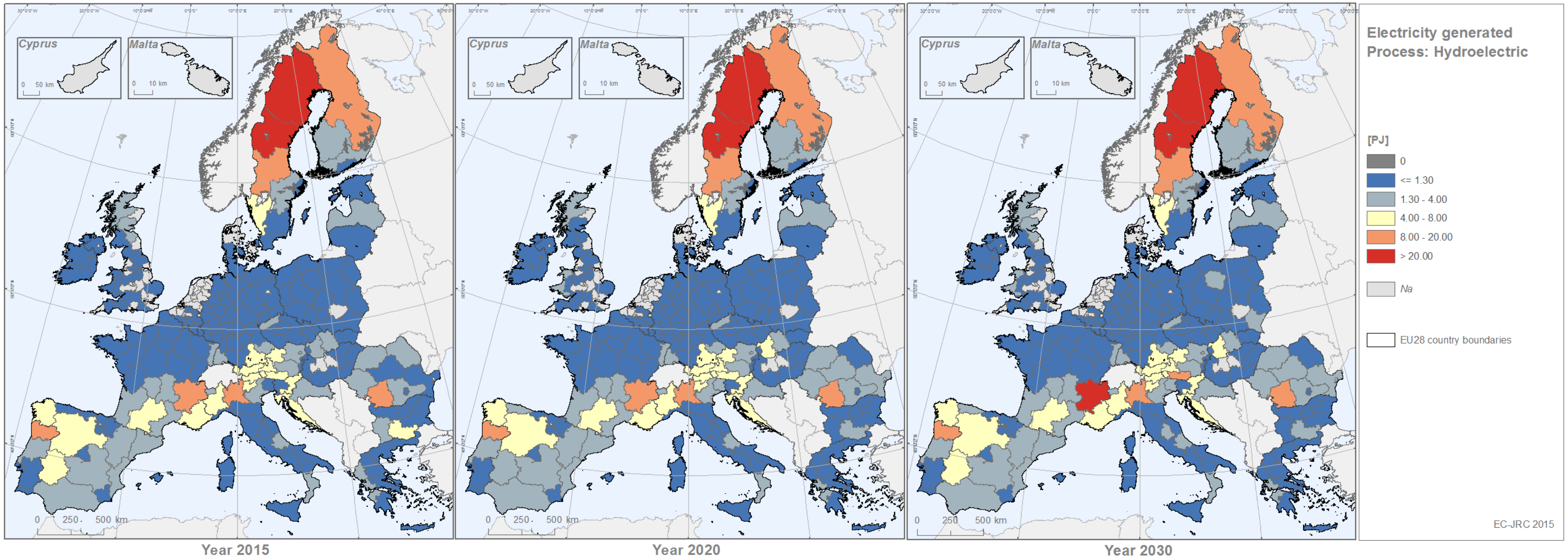

Figure 16. Electricity generated from hydroelectric, for the years 2015, 2020 and 2030

The amount of electricity generated from hydroelectric is in general forecasted to increase in Europe from 2015 to 2030. Exceptions are a few regions in Bulgaria, Czech Republic, Germany, Spain, Greece, Hungary, Portugal, Romania, Sweden and most NUTS2 in the UK. The decreases are in general of small entity. Decreases around or greater than 10% can be found in Bulgaria, Germany, Greece, Romania and the UK.

4.1.8 Electricity generated by nuclear

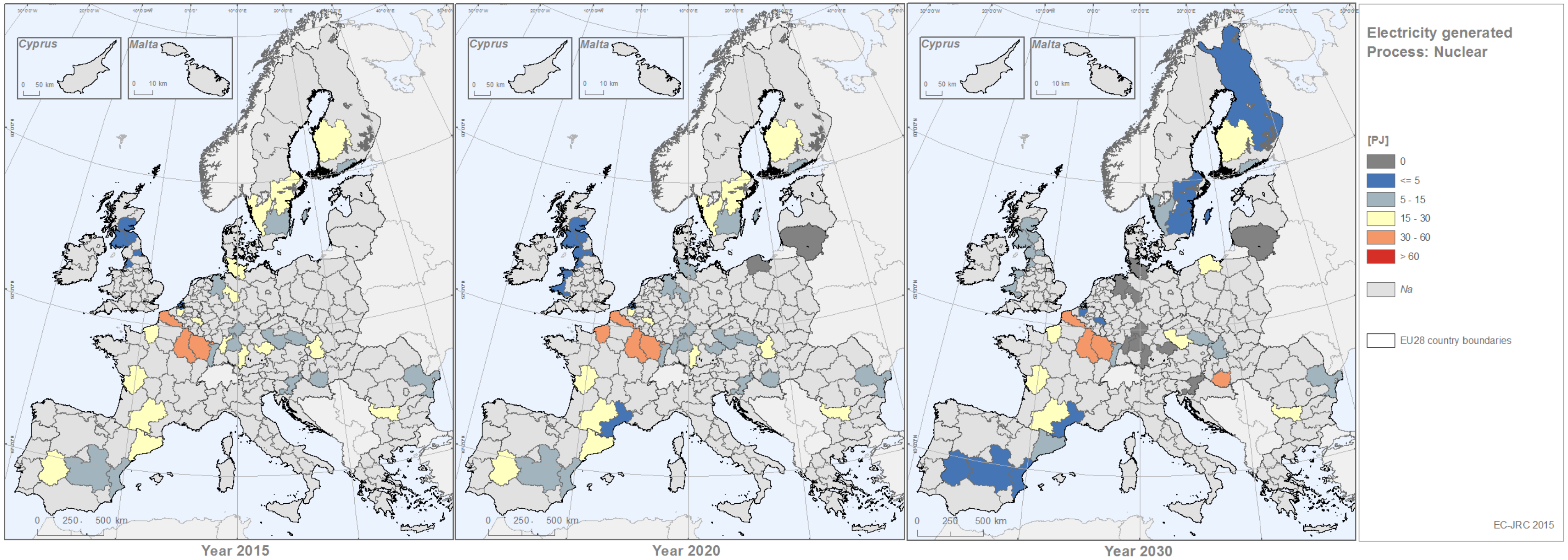

Figure 17. Electricity generated from nuclear, for the years 2015, 2020 and 2030

Electricity generated from nuclear source is forecasted to decrease in the majority of the regions with active nuclear power plants in 2015. Only exceptions are Jihozápad in Czech Republic, Upper Normandy in France and Zeeland in the Netherlands. Considerable increase of electricity produced from nuclear takes place in four regions in the UK.

4.1.9 Electricity generated by oil

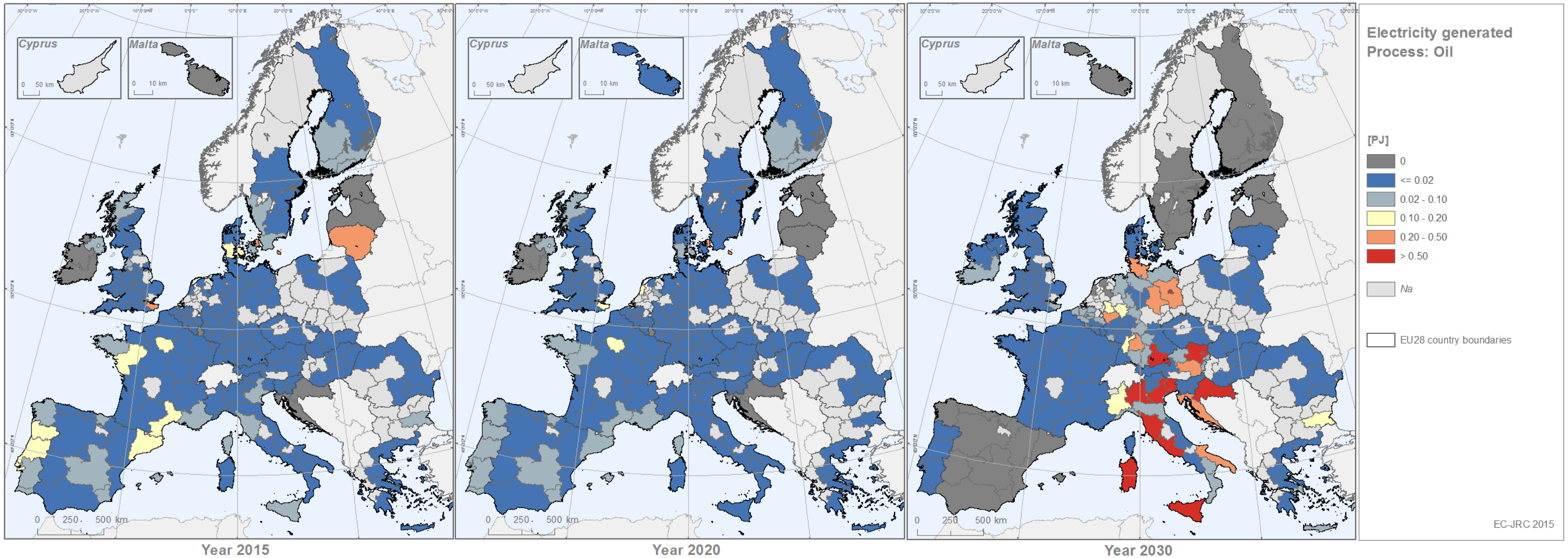

Figure 18. Electricity generated from oil, for the years 2015, 2020 and 2030

The majority of the regions generating electricity from oil in 2015, experience a decrease in 2030. Notable exceptions are a few regions in Austria, Belgium, Germany, Greece, Hungary, Italy, Poland and Slovenia. In these NUTS2, the absolute amount of electricity generated from oil in 2030 is relatively low (on average 90 GJ), but compared to the production levels in 2015, the increase can go up to 4 orders of magnitudes.

4.1.10 Electricity generated by solar

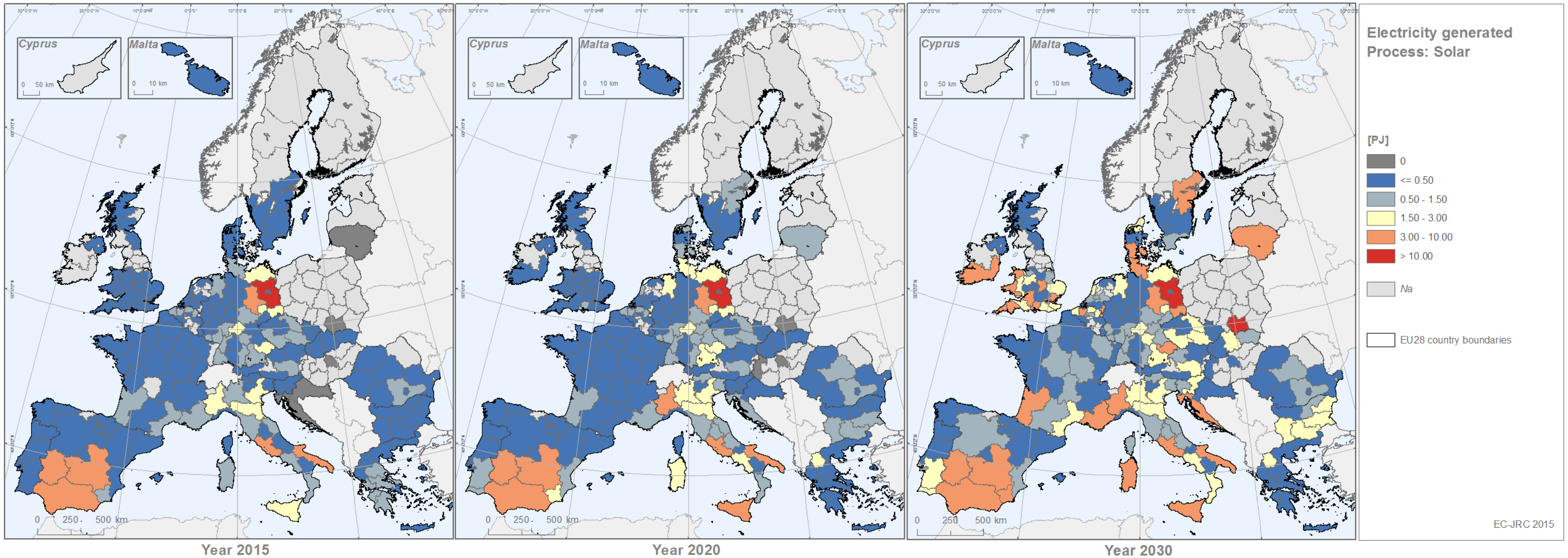

Figure 19. Electricity generated from solar, for the years 2015, 2020 and 2030

Electricity produced from solar is forecasted to increase in almost three quarters of European regions. The biggest increases (above 5 times the 2015 generation levels) can be found in a few NUTS2 in Bulgaria, Denmark, France, Greece, Portugal, Sweden, Slovakia, the UK and one region in Italy. The only regions where electricity from solar is forecasted to decrease are located in Greece and Romania.

4.1.11 Electricity generated by on-shore wind

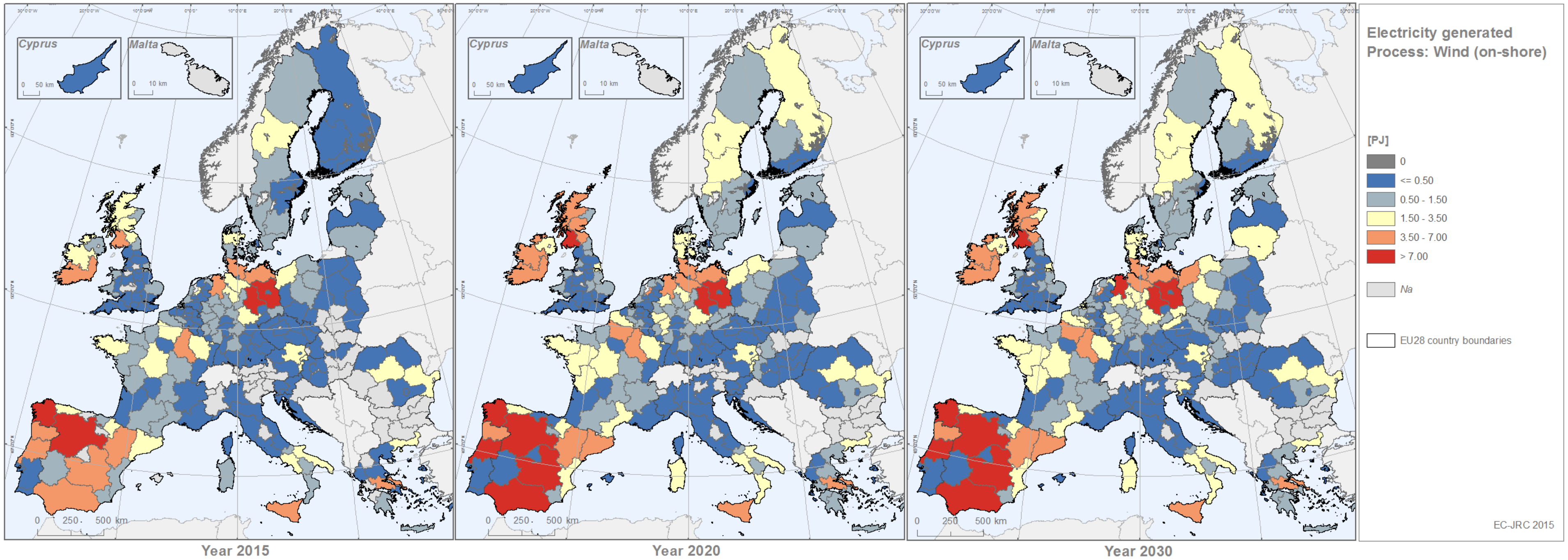

Figure 20. Electricity generated from on-shore wind, for the years 2015, 2020 and 2030

In the large majority of European regions, electricity generated from on-shore wind installations is forecasted to increase. The largest increases (above 5 times the 2015 generation levels) can be found in few regions in Czech Republic, Finland, Lubuskie in Poland, the north-est NUTS2 in Romania, Western Slovakia and Slovenia. For all the other regions experiencing an increase in on-shore wind electricity, the average increase is almost 67%. Few NUTS2 in Denmark, Spain, Hungary, Italy and Sweden from 2015 to 2030 decrease the generation of on-shore wind electricity by, on average, 14%.

4.1.12 Electricity generated by off-shore wind

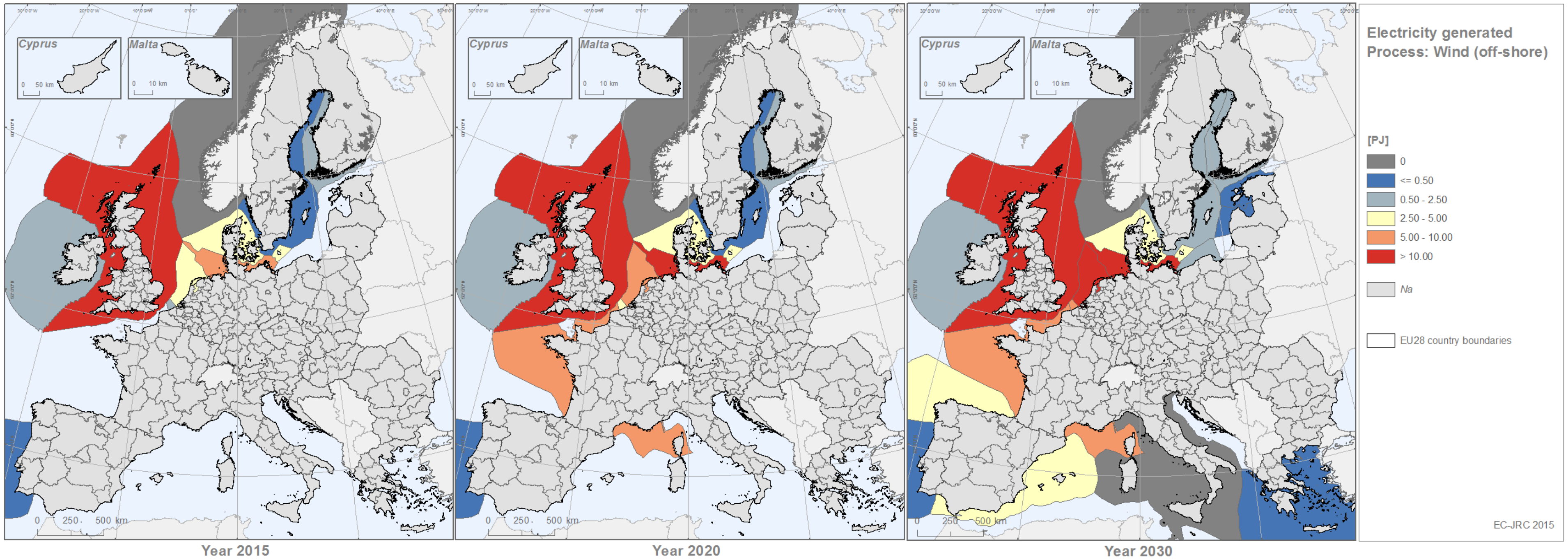

Figure 21. Electricity generated from off-shore wind, for the years 2015, 2020 and 2030

Electricity produced from off-shore wind installations is forecasted to increase in all countries with active plants in 2015. Estonia, France, Latvia, Poland and Spain go from having no active plants in 2015 to positive off-shore wind electricity generation in 2030.

4.2 Energy demand: road transport sector

Results for the years 2015, 2020 and 2030 are reported in the following sections. Values are expressed in either [bp/km] or [Mp/km] for passenger transport; and in [t/km] for freight transportation.

One of the three categories identified for buses (Bus Intercity – Biodiesel, gasoline) is not reported, as the JRC-EU-TIMES model output for this process is zero for all the considered years.

4.2.1 Energy demand supplied for the process car - diesel

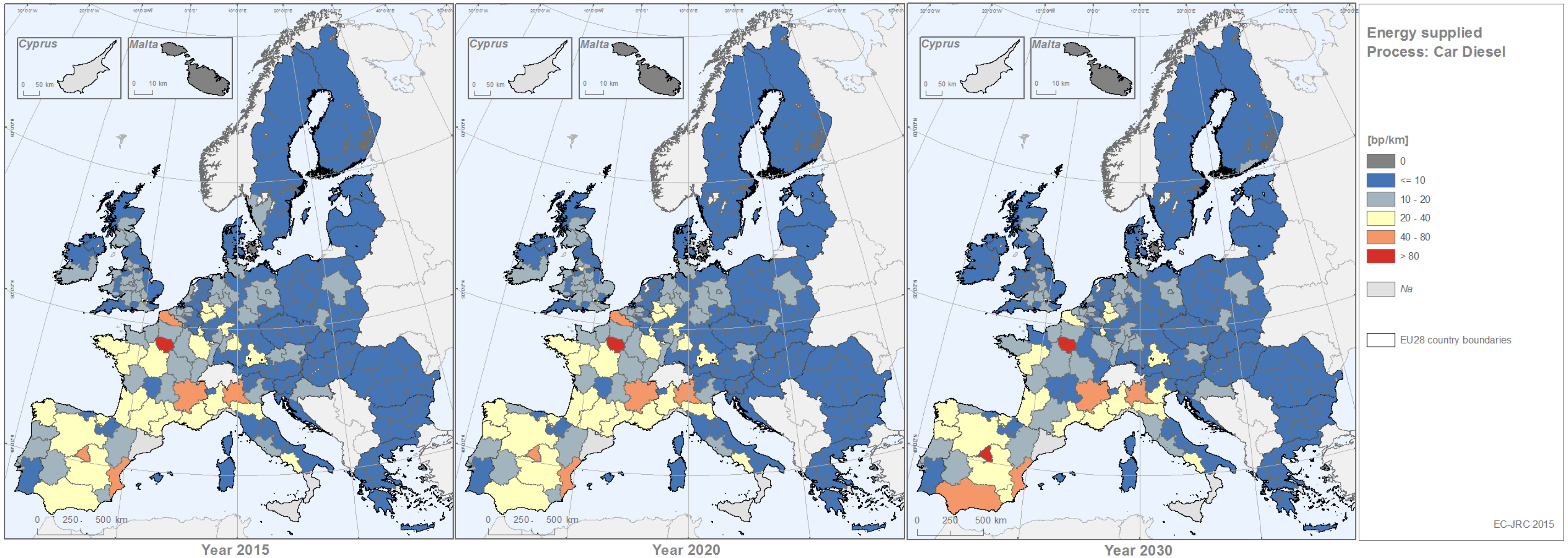

Figure 22. Energy demand supplied for the process car – diesel, in the years 2015, 2020 and 2030

In more than two thirds of European regions, the energy supplied to the process car – diesel decreases from 2015 to 2030, with an average decrease of almost 20%. The NUTS2 where the negative trend is sharper are located in Greece, Croatia (Jadranska Hrvatska) and Poland (Podlaskie), with the highest decrease of 97% in Ionia Nisia (Greece). In the regions where the energy supplied to this process increases, the average change is higher than 11%, with increases up to 66% in București-Ilfov (Romania).

4.2.2 Energy demand supplied for the process car – gas, LPG

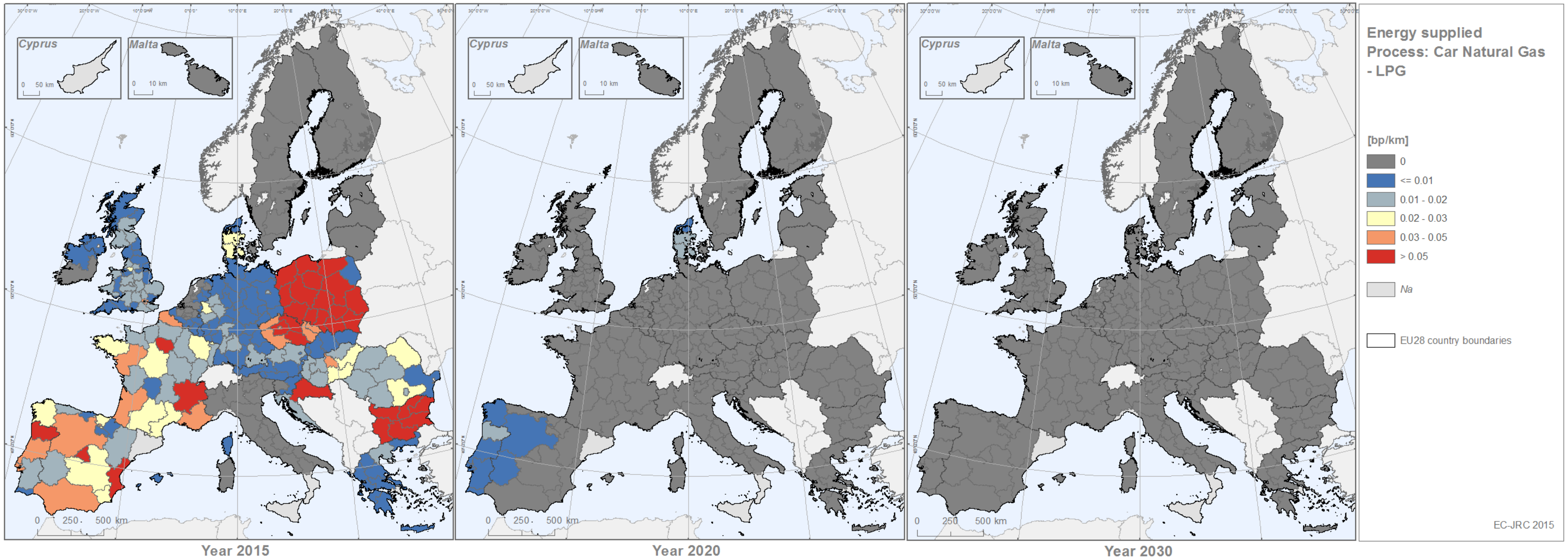

Figure 23. Energy demand supplied for the process car – gas, LPG, in the years 2015, 2020 and 2030

The energy supplied to the process car – gas, LPG is forecasted to decrease throughout all European regions. The decrease is more gradual in few regions in Denmark, Portugal, Greece, Spain and Italy.

4.2.3 Energy demand supplied for the process car - gasoline

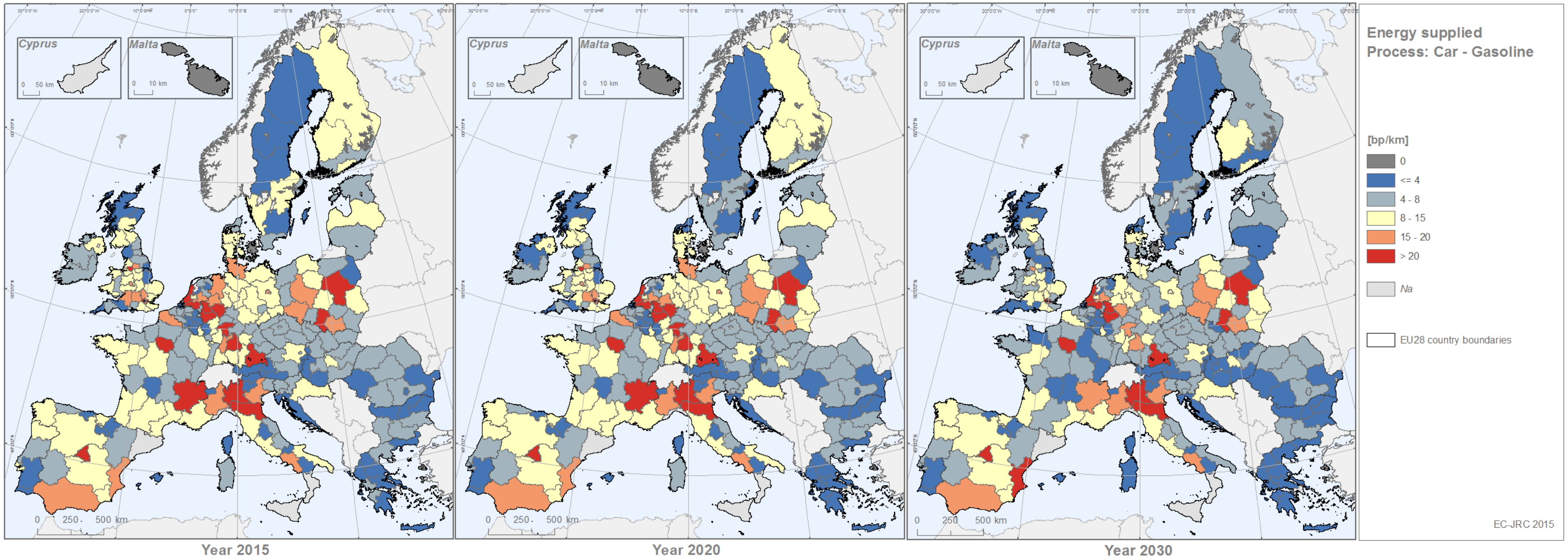

Figure 24. Energy demand supplied for the process car - gasoline, in the years 2015, 2020 and 2030

Energy supplied to the process car – gasoline is forecasted to decrease in more than 80% of the European regions, with an average decrease of 27%. Slight increases (6% on average) are forecasted to take place in a few regions in Belgium, Bulgaria, Czech Republic, Estonia, Spain, Italy, Luxemburg, the Netherlands, Poland and Romania.

4.2.4 Energy demand supplied for the process heavy duty truck - diesel

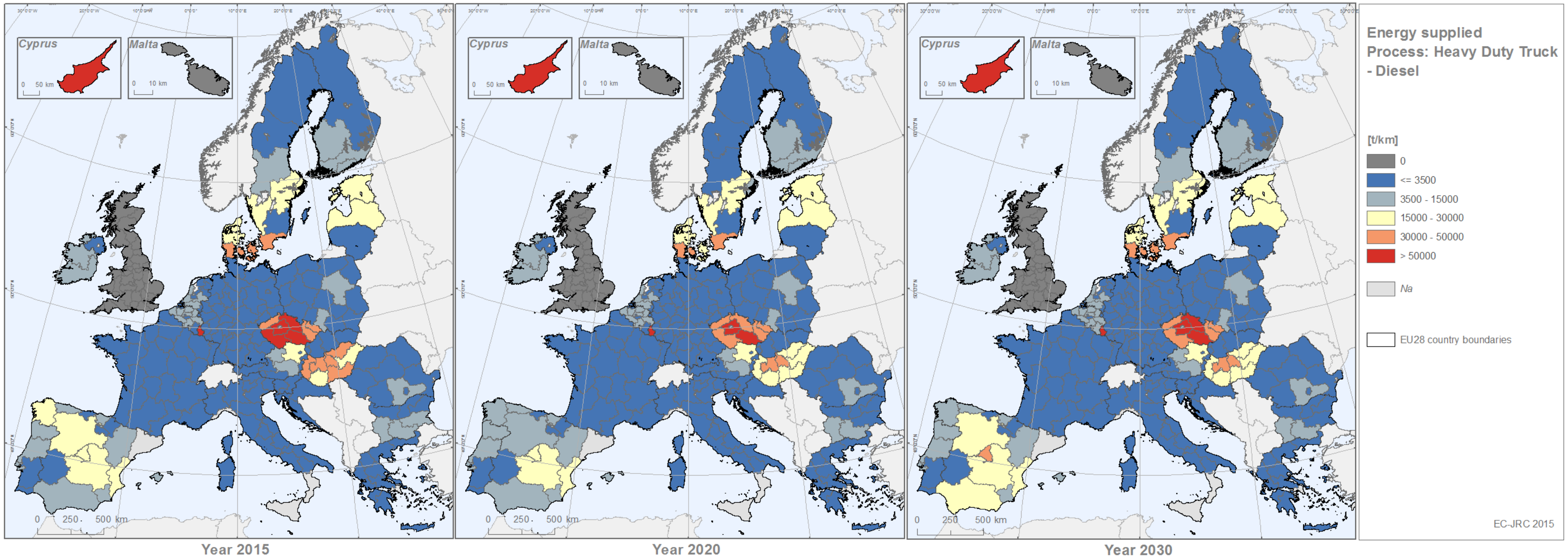

Figure 25. Energy demand supplied for the process heavy duty truck - diesel, in the years 2015, 2020 and 2030

The energy supplied to the process heavy duty truck – diesel is forecasted to progressively decrease from 2015 to 2030 in 66% of the European regions, with an average decrease of more than 8%. The biggest decreases (above 20%) take place in Finland (regions of Åland, West Finland, Etelä-Suomi and Pohjois- ja Itä-Suomi), Spain (Galicia), Croatia (Jadranska Hrvatska) and Greece (Ionia Nisia). In the regions where the energy supplied to this process increases, the average change is 8% and the highest increases (above 20%) take place in Greece (Central Macedonia and Crete), Belgium (Luxembourg region, Walloon Brabant, Namur and Brussels-Capital Region) and Portugal (Algarve).

4.2.5 Energy demand supplied for the process light duty truck - diesel

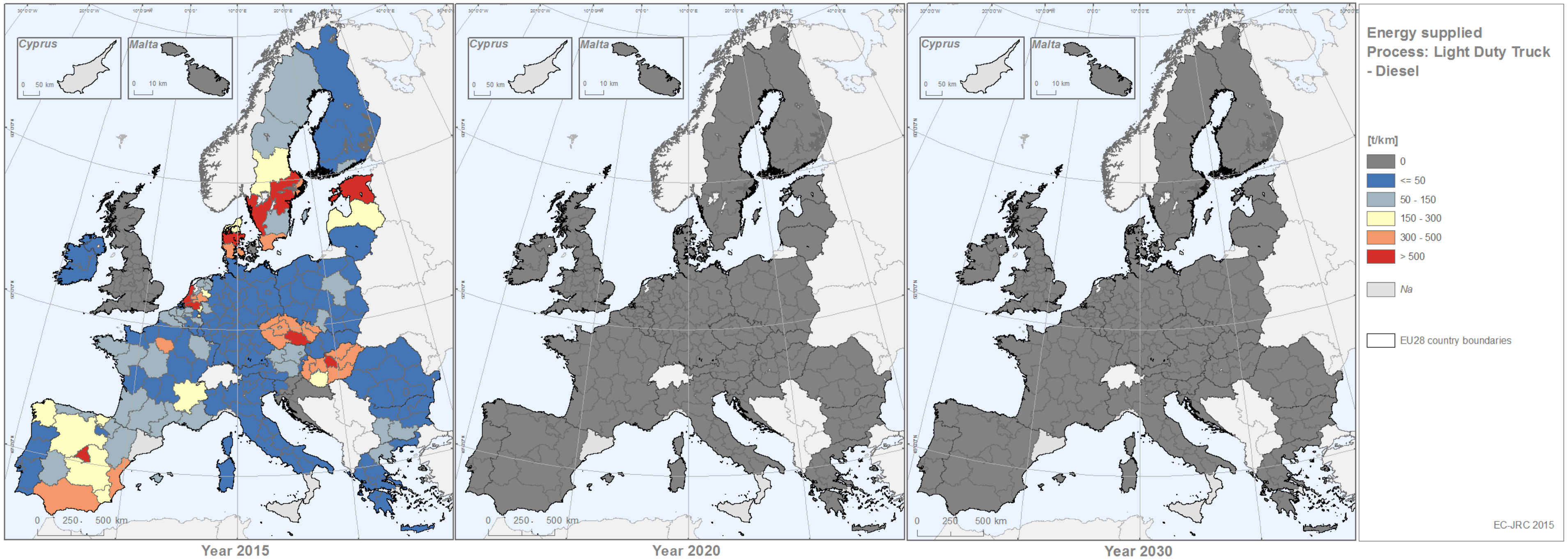

Figure 26. Energy demand supplied for the process light duty truck - diesel, in the years 2015, 2020 and 2030

The energy supplied to the process light duty truck – diesel is forecasted to steeply decrease throughout European regions.

4.2.6 Energy demand supplied for the process light duty truck - gasoline

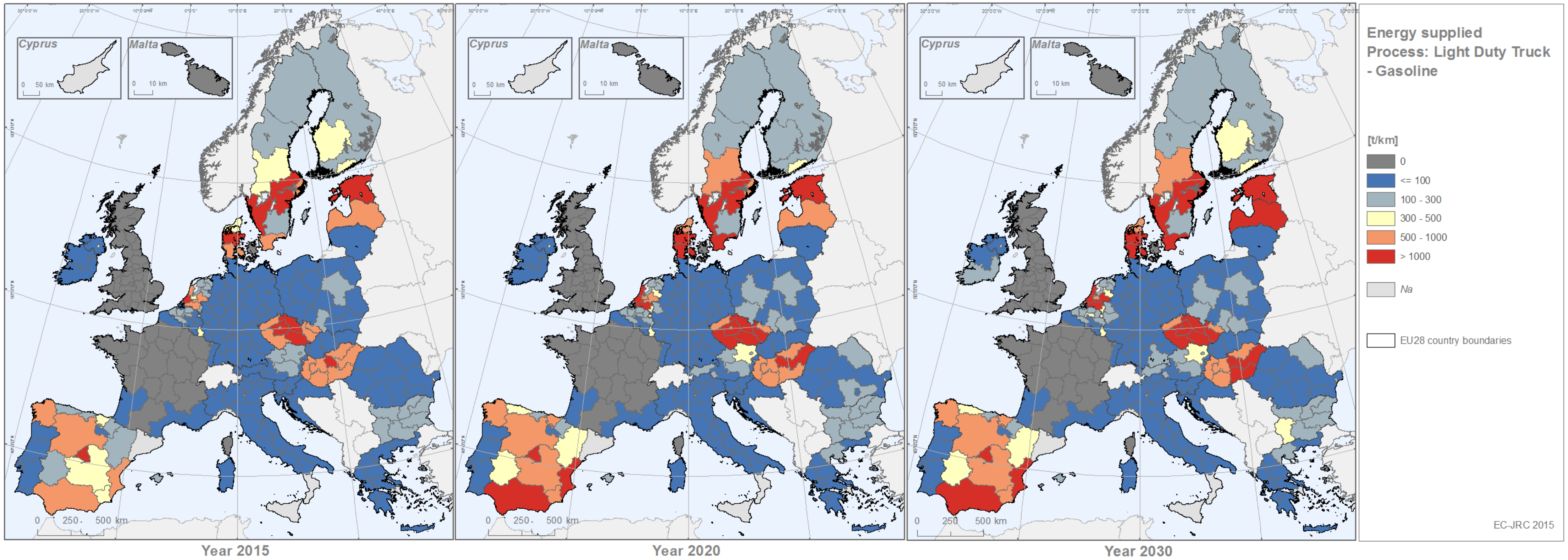

Figure 27. Energy demand supplied for the process light duty truck - gasoline, in the years 2015, 2020 and 2030

The energy supplied to the process light duty truck – gasoline is forecasted to increase in more than 90% of European regions, with an average increase of more than 40% from 2015 to 2030. The highest increases (above 70%) take place in eleven regions in Germany, Walloon Brabant in Belgium, Flevoland in the Netherlands, Lower Austria and Eastern Macedonia and Thrace. Among these regions, only Lower Austria, Flevoland and Köln (Germany) reach levels above 100 t/km in 2030. Energy supplied to the process light duty truck – gasoline declines only in sixteen NUTS2 (average decrease of 43%), with the sharpest decline (above 70%) in Provence-Alpes-Côte d'Azur (France) and the Ionian Islands (Greece).

4.2.7 Energy demand supplied for the process inter-city bus - diesel

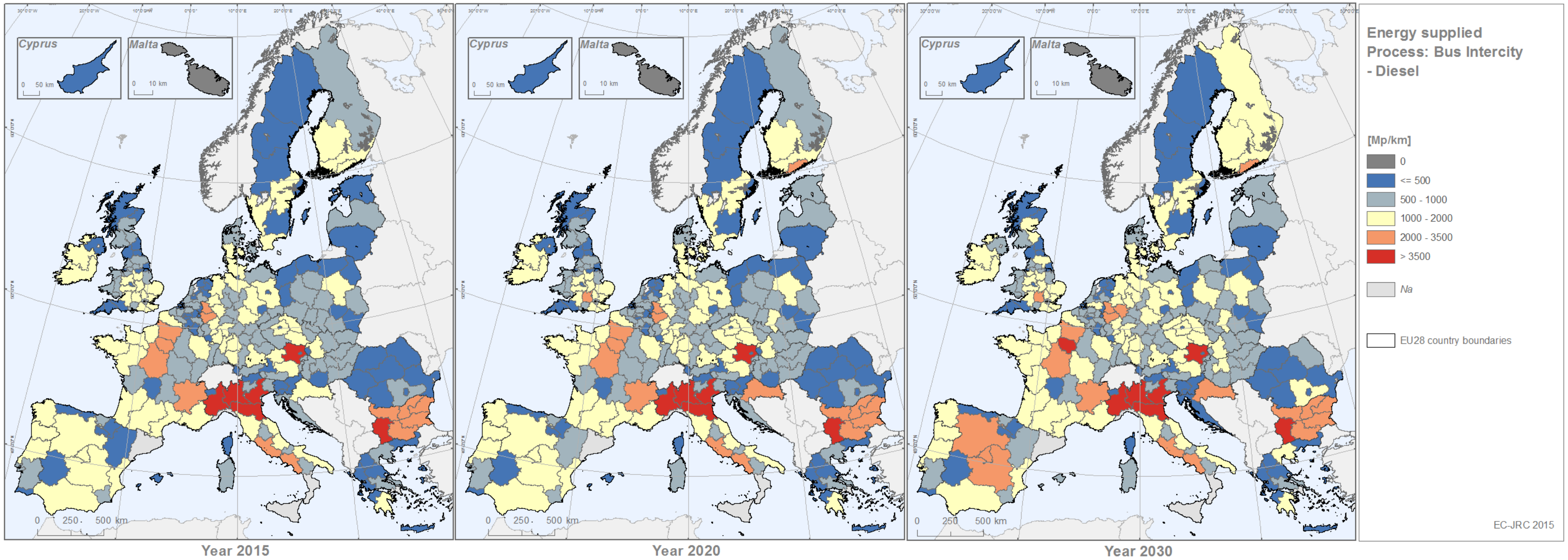

Figure 28. Energy demand supplied for the process inter-city bus - diesel, in the years 2015, 2020 and 2030

The energy supplied to inter-city buses running on diesel is forecasted to increase from 2015 to 2030 in the large majority of European regions, with an average increase of more than 19%. The only regions where the energy supplied to this process is going to decline from 2015 to 2030, are located in Poland (Lubelskie, Świętokrzyskie, Podlaskie, Zachodniopomorskie and Warmińsko-Mazurskie), Greece (the Ionian Islands and the Kyklades), Bulgaria (Severoiztochen), Finland (Åland), Spain (Galicia) and Croatia (Jadranska Hrvatska).

4.2.8 Energy demand supplied for the process urban bus – gas, diesel, gasoline

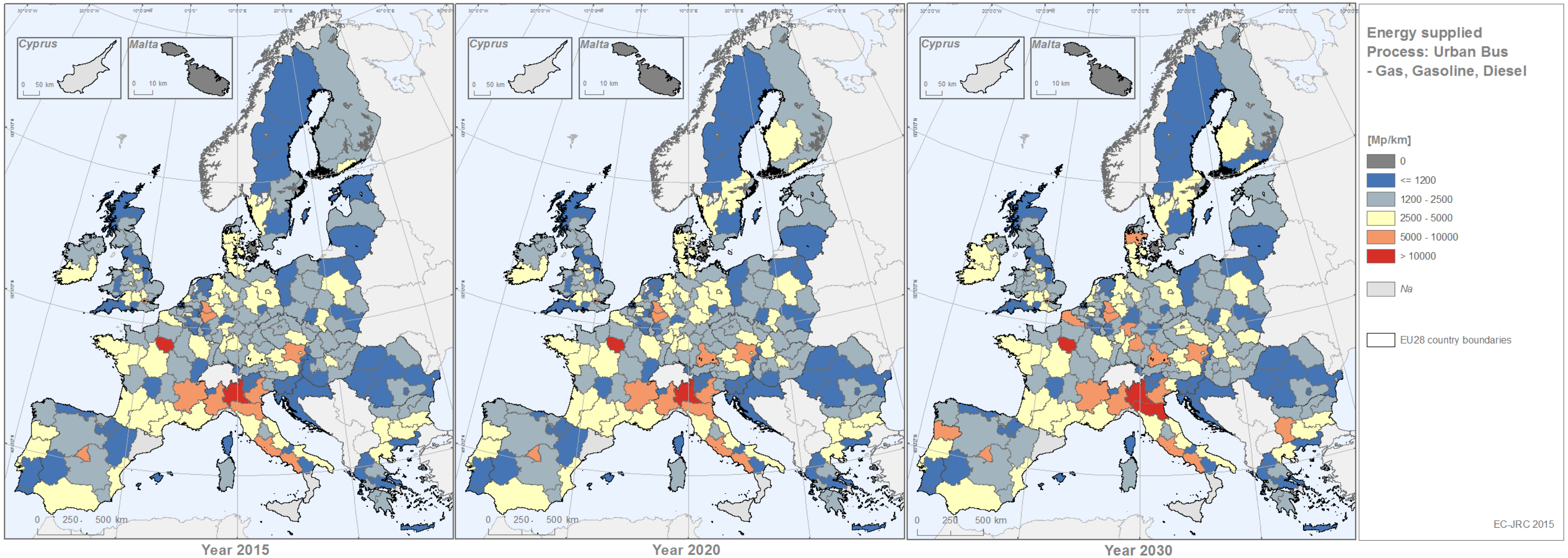

Figure 29. Energy demand supplied for the process urban bus – gas, diesel, gasoline, in the years 2015, 2020 and 2030

The energy supplied to urban buses (gas, diesel and gasoline) is going to moderately increase from 2015 to 2030 in almost 90% regions throughout EU-28, with an average growth of 15%. On the contrary, the trend is negative in few regions located in Austria, Germany, Spain, Finland, Greece, Croatia, Poland and the UK, with the sharpest decreases (above 30%) in Etelä-Suomi (Finland), the Ionian Islands and Central Greece (Greece), Jadranska Hrvatska (Croatia) and Podlaskie (Poland).

4.2.9 Energy demand supplied for the process motorcycles - gasoline

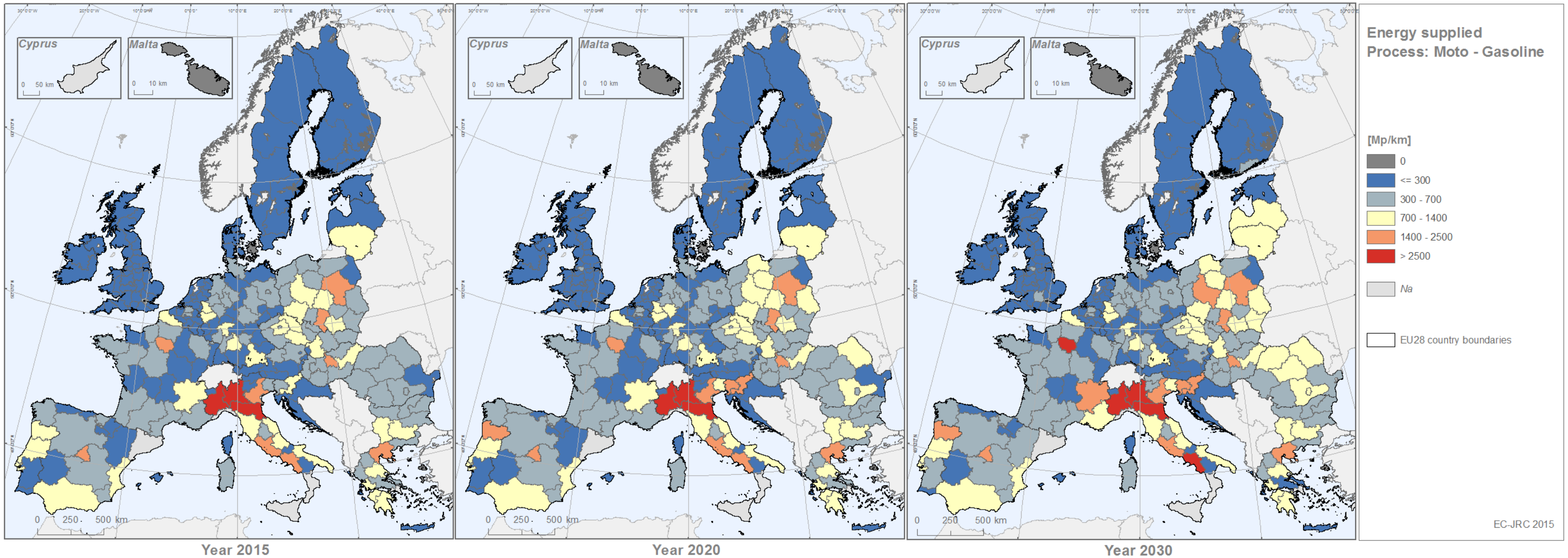

Figure 30. Energy demand supplied for the process motorcycles - gasoline, in the years 2015, 2020 and 2030

Energy supplied to motorcycles (gasoline) is forecasted to increase in more than 80% of European NUTS2, with an average growth of 16%. High increases (above 60%) can be found in Ireland, Romania and Latvia. Regions characterised by a decline in the energy supplied to this process experience relatively modest changes from 2015 to 2030, with an average decline of almost 12%; sharper declines can be found in very few regions in Greece and Jadranska Hrvatska in Croatia.

4.2.10 Energy demand supplied for the process car – hybrid, electric, hydrogen

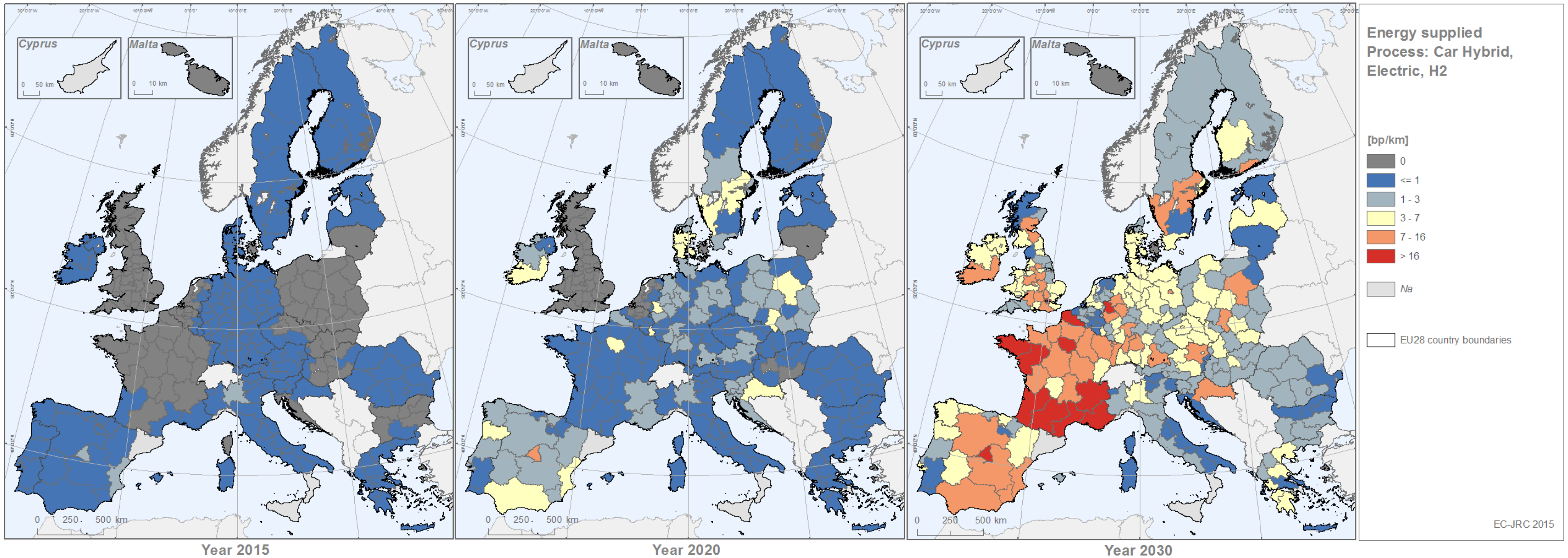

Figure 31. Energy demand supplied for the process car – hybrid, electric, hydrogen, in the years 2015, 2020 and 2030

Energy supplied to cars (hybrid, electric and hydrogen) is forecasted to increase throughout Europe, in general with sharp increases.

4.2.11 Energy demand supplied for the process heavy duty truck – gas and light duty truck - LPG

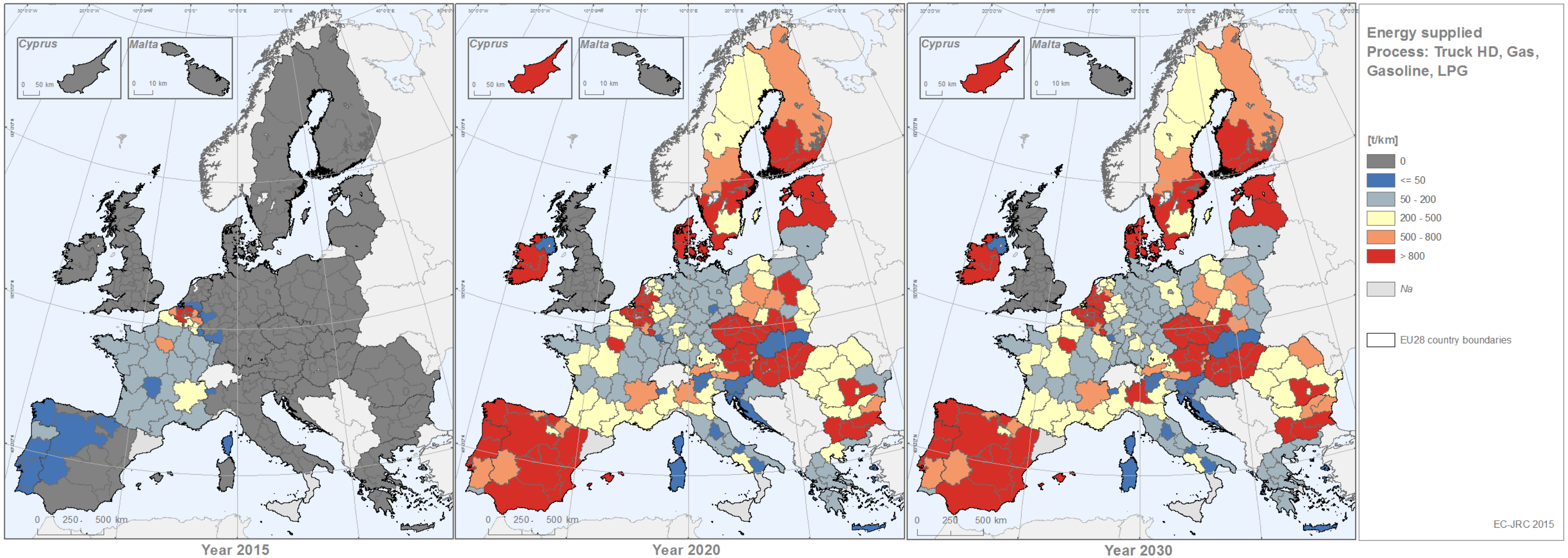

Figure 32. Energy demand supplied for the process heavy duty truck – gas and light duty truck - LPG, in the years 2015, 2020 and 2030

Energy supplied to this process (heavy duty truck – gas and light duty truck - LPG) is forecasted to increase in all European regions from 2015 to 2020. In most NUTS2 this trend is kept or even accelerates between 2020 and 2030. The only regions where the trend is reversed (lower energy supplied in 2030 compared to 2020) are located in Poland, Greece, Finland (only Åland) and Croatia (only Jadranska Hrvatska).

4.3 Strategy for the validation of the results

Validation activities are planned to be carried out during the second year of the EREBILAND project.

Input data have been already cross-checked with information available. Nevertheless, further comparisons shall be carried out using data collected from national sources. As example, data on electricity production and infrastructure, available for Denmark, Ireland and the United Kingdom.

The results of the disaggregation exercise for the electricity production sector, for the year 2015, are going to be cross-checked with regional statistics when national sources provide the information.

5. Conclusions

This report presents the methods, findings and products elaborated during the first year of operation of the Exploratory Project EREBILAND.

Digital maps have been produced for the following:

- Electricity Production from coal, gas, oil, biogas, geothermal, hydroelectric, biomass, solar, wind on-shore, wind off-shore;
- Energy demand for the Transport Sector (by type and fuel)
- Energy demand for residential sector is being produced in the frame of the Territorial Impact Assessment for the revision of the Energy Performance of Building Directive and are not reported here
- Solar potential, as published in Perpina et al,2015[1]

Relevant work on bio-energy is reported elsewhere (ref. Baranzelli et al, 2014[2]).

In line with its Work-Programme, EREBILAND will cover the next steps of work:

a. In-depth analysis of residential and industrial/commercial sectors energy demand, with data collection from :
   - Census data (from municipal to building level, depending on the country)
   - Ancillary country data (census tract/building level)
   - Energy-related data (in collaboration with F07)
   - Materials' use in buildings (by typology, climate and future scenario)
   - Other data (e.g. Covenant of Mayors)

b. Evaluation of the technical coefficients for energy (i.e. energy efficiency coefficients) to be used as 'cost factors' or 'determinants of growth' in regional/territorial modelling.

The digital products will be gradually disseminated in the frame of the pilot Knowledge Centre for Territorial Policies.

[1] Perpiña Castillo C, Batista E Silva F, Lavalle C. An assessment of the regional potential for solar power generation in EU-28. ENERGY POLICY 88; 2016. p. 86-99. JRC96579

[2] Baranzelli C, Perpiña Castillo C, Lavalle C, Pilli R, Fiorese G. Evaluation of the land demands for the production of food, feed and energy in the updated Reference Configuration 2014 of the LUISA modelling platform. Methodological framework and preliminary considerations. EUR 27018. Luxembourg (Luxembourg): Publications Office of the European Union; 2014. JRC94076

References

[1] European Commission, "COM(2015) 80 final. Energy Union Package - COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK. A Framework Strategy for a Res." Brussels, p. 17, 2015.

[2] European Commission, "COM(2015) 80 final. ENERGY UNION PACKAGE - ANNEX ROADMAP FOR THE ENERGY UNION to the COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVES." Brussels, 2015.

[3] European Commission, "COM(2015) 572 final. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK State of the Energy Union 2015." Brussels, 2015.

[4] European Commission, "COM(2015) 572 final. ANNEX 1 - UPDATED ROADMAP FOR THE ENERGY UNION to the COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK." Brussels, 2015.

[5] European Commission, "COM(2015) 572 final. ANNEX 2 - GUIDANCE TO MEMBER STATES ON NATIONAL ENERGY AND CLIMATE PLANS AS PART OF THE ENERGY UNION GOVERNANCE to the COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITT." Brussels, 2015.

[6] European Commission, "COM(2011) 571 final COMMUNICATION: Roadmap to a Resource Efficient Europe." Brussels, p. 32, 2011.

[7] European Comission, "COUNCIL DIRECTIVE 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora," *Oj L 206*, vol. L 269, no. September 2000. pp. 1–15, 1992.

[8] EuropeanCommission, "Directive 2009/147/EC of the European Parliament and of the Council on the conservation of wild birds," *Official Journal of the European Union*, vol. L 20. pp. 7–25, 2010.

[9] European Parliament, "Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009," *Official Journal of the European Union*, vol. 140, no. 16. pp. 16–62, 2009.

[10] European Commission, "EU Energy, Transport and GHG Emissions Trends to 2050. Reference Scenario 2013.," European Union, 2014.

[11] C. Baranzelli, C. Jacobs-crisioni, F. Batista, C. P. Castillo, A. Barbosa, J. A. Torres, and C. Lavalle, "The Reference scenario in the LUISA platform – Updated configuration 2014 Towards a Common Baseline Scenario for EC Impact Assessment procedures," 2014.

[12] M. Hilferink and P. Rietveld, "Land Use Scanner: An integrated GIS based model for long term projections of land use in urban and rural areas," *J. Geogr. Syst.*, vol. 1, no. 2, pp. 155–177, 1999.

[13] E. Dekkers, J.E.C., Koomen, "Land-use simulation for water management: application of the Land Use Scanner model in two large-scale scenario-studies," in *Modelling land-use change; progress and applications*, H. J. S. E. Koomen, J. Stillwell, A. Bakema, Ed. Dordrecht: Springer, 2007.

[14] P. H. Verburg and K. P. Overmars, "Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model," *Landsc. Ecol.*, vol. 24, no. 9, pp. 1167–1181, 2009.

[15] C. Lavalle, C. Baranzelli, F. B. E Silva, S. Mubareka, C. R. Gomes, E. Koomen, and M. Hilferink, "A high resolution land use/cover modelling framework for Europe: Introducing the EU-ClueScanner100 model," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 6782 LNCS, no. PART 1, pp. 60–75, 2011.

[16] C. Lavalle, S. Mubareka, C. P. Castillo, C. Jacobs-crisioni, C. Baranzelli, F. Batista, I. Vandecasteele, and C. Lavalle, "CONFIGURATION OF A REFERENCE SCENARIO FOR THE LAND USE MODELLING PLATFORM," 2013.

[17] S. Simoes, W. Nijs, P. Ruiz, A. Sgobbi, D. Radu, P. Bolat, C. Thiel, S. Peteves, and L. P. O. of the E. Union, "The JRC-EU-TIMES model. Assessing the long-term role of the SET Plan Energy technologies.," Institute for Energy and Transport of the Joint Research Centre - European Commission, 2013.

[18] A. Brandsma, P. Monfort, and A. Rillaers, "RHOMOLO : A Dynamic Spatial General Equilibrium Model for Assessing the Impact of Cohesion Policy $," 2013.

[19] D. Persyn, W. Torfs, and A. Kancs, "Modelling regional labour market dynamics : Participation , employment and migration decisions in a spatial CGE model for the EU," vol. 29, no. april, pp. 77–90, 2014.

[20] S. Boeters and L. Savard, "The Labor Market in Computable General Equilibrium Models," vol. 1, Elsevier, 2013, pp. 1645–1718.

[21] F. Di Comite and D. Kancs, "Modelling Agglomeration and Dispersion in RHOMOLO," 2014.

[22] IEA Bioenergy Task 32, "DB Task 32." [Online]. Available: http://www.ieabcc.nl/database/cofiring.php. [Accessed: 16-Dec-2015].

[23] UNECE, "Traffic Census 2010," 2010. [Online]. Available: http://www.unece.org/trans/main/wp6/e-roads_census_2010.html. [Accessed: 16-Dec-2015].

[24] OpenStreetMap, "OpenStreetMap." [Online]. Available: http://www.openstreetmap.org/#map=14/45.8886/12.2838. [Accessed: 16-Dec-2015].

[25] OpenStreetMap Wiki contributors, "Nominatim." [Online]. Available: http://wiki.openstreetmap.org/w/index.php?title=Nominatim&oldid=1224309. [Accessed: 16-Dec-2015].

[26] Google Developers, "GoogleV3." [Online]. Available: https://developers.google.com/maps/documentation/geocoding/intro. [Accessed: 16-Dec-2015].

[27] R. Saidur, E. A. Abdelaziz, A. Demirbas, M. S. Hossain, and S. Mekhilef, "A review on biomass as a fuel for boilers," *Renew. Sustain. Energy Rev.*, vol. 15, no. 5, pp. 2262–2289, 2011.

[28] A. H. Truong, "Feasibility and sustainability of co-firing biomass in coal power plants in Vietnam," 2015.

[29] A. Lüschen and R. Madlener, "Economics of Biomass Co-Firing in New Hard Coal Power Plants in Germany Andreas Lüschen and Reinhard Madlener December 2010 Revised July 2012 Institute for Future Energy Consumer Needs and Behavior (FCN) Faculty of Business and Economics / E . ON ERC," 2012.

[30] S. De and M. Assadi, "Impact of cofiring biomass with coal in power plants – A techno-economic assessment," *Biomass and Bioenergy*, vol. 33, no. 2, pp. 283–

293, 2009.

[31] K. J. van Loo Sjaak, Ed., *Handbook of Biomass Combustion and Co-firing*, Twente Uni. Twente, 2002.

[32] C. Pasaoglu, G., Fiorello, D., Martino, A., Scarcella, G., Alemanno, A., Zubaryeva, A., Thiel, "Driving and parking patterns of European car drivers -- - a mobility survey .," 2012.

[33] W. Britz, M. Adenäuer, P. Witzke, J. Helming, T. Jansson, and A. Gocht, "CAPRI model documentation 2014," 2014.

[34] F. Batista e Silva, E. Koomen, V. Diogo, and C. Lavalle, "Estimating Demand for Industrial and Commercial Land Use Given Economic Forecasts," *PLoS One*, vol. 9, no. 3, p. e91991, 2014.

[35] J. et al Carlsson, "Etri 2014," 2014.

[36] P. Bolat and C. Thiel, "Hydrogen supply chain architecture for bottom-up energy systems models. Part 2: Techno-economic inputs for hydrogen production pathways," *Int. J. Hydrogen Energy*, vol. 39, no. 17, pp. 8898–8925, 2014.

[37] A. Sgobbi, W. Nijs, R. De Miglio, A. Chiodi, M. Gargiulo, and C. Thiel, "How far away is hydrogen? Its role in the medium and long-term decarbonisation of the European energy system," *Int. J. Hydrogen Energy*.

[38] S. Quoilin, W. Nijs, I. Gonzales Hidalgo, A. Zucker, and C. Thiel, "Evaluation of simplified flexibility evaluation tools using a unit commitment model," in *12th International Conference on the European Energy Market (EEM)*, 2015, pp. 1–5.

[39] RES2020 Project Consortium and CRES, "The Pan European TIMES model for RES2020. Model description and definitions of Scenarios. Intelligent Energy Europe Project no: EIE/06/170/SI2.442662," 2009.

[40] Y. Scholz, "Renewable energy based electricity supply at low costs - Development of the REMix model and application for Europe," Universität Stuttgart, 2012.

[41] T. J. Hammons, "Tidal Power in the UK and Worldwide to Reduce Greenhouse Gas Emissions," *Int. J. Eng. Bus. Manag.*, vol. 3, no. 2, pp. 16–28, 2011.

[42] D. Magagna, A. MacGillivray, H. Jeffrey, C. Hanmer, A. Raventos, A. Badcock-Broe, and E. Tzimas, "Wave and Tidal Energy Strategic Technology Agenda," SI Ocean, 2014.

[43] S. P. Neill and M. R. Hashemi, "Wave power variability over the northwest European shelf areas," *Appl. Energy*, vol. 106, pp. 31–46, 2013.

[44] A. Brandsma, D. Kancs, P. Monfort, and A. Rillaers, "RHOMOLO: A dynamic spatial general equilibrium model for assessing the impact of cohesion policy," *Pap. Reg. Sci.*, vol. 94, no. November 2014, pp. S197–S221, 2014.

[45] A. Brandsma and D. Kancs, "RHOMOLO: A Dynamic General Equilibrium Modelling Approach to the Evaluation of theEuropean Union's R&D Policies," *ERSA Conf. Pap.*, no. February, pp. 1–18, 2015.

[46] E. Chamberlin, *The Theory of Monopolistic Competition*. Cambridge, MA: Harvard University Press, 1890.

[47] F. Baldwin, R., Forslid, R., Martin, P., Ottaviano, G. and Robert-Nicoud, *Economic Geography and Public Policy*. Princeton University Press, 2011.

[48] J. E. Dixit, A., Stiglitz, "Monopolistic competition and optimum product diversity." The American Economic Review, 1977.

[49] J. Mercenier, "Nonuniqueness of solutions in applied general equilibrium models with scale economies and imperfect competition," *Econ. Theory*, vol. 6, no. 1, pp. 161–177, 1995.

[50] D. G. Blanchflower and A. J. Oswald, "The Wage Curve," Nov. 1989.

[51] A. Brandsma, D. Kanks, and D. Persyn, "Modelling Migration and Regional Labour Markets: An Application of New Economic Geography Model RHOMOLO," *Leuven Univ. Discuss. Pap. 36*, vol. 29, no. 2, pp. 1–28, 2014.

[52] D. Leahy and J. P. Neary, "Absorptive capacity, R&D spillovers, and public policy," *Int. J. Ind. Organ.*, vol. 25, no. 5, pp. 1089–1108, 2007.

[53] A. Marshall, "Principles of economics, (London, McMillan)," 1920.

[54] R. R. Nelson, "The simple economics of basic scientific research," *J. Polit. Econ.*, vol. 67, pp. 297–306, 1959.

[55] L. H. Goulder and S. H. Schneider, "Induced technological change and the attractiveness of CO2 abatement policies," *Resour. Energy Econ.*, vol. 21, pp. 211–253, 1999.

[56] X. Diao, T. Roe, and E. Yeldan, "Strategic policies and growth: An applied model of R and D-driven endogenous growth," *J. Dev. Econ.*, vol. 60, no. 2, pp. 343–380, 1999.

[57] P. Romer, "Endogenous technological change," 1990.

[58] G. M. Grossman and E. Helpman, *Innovation and growth in the global economy*. MIT press, 1993.

[59] P. Aghion, P. Howitt, S. Econometrica, N. Mar, O. Blanchard, P. Bolton, L. Corriveau, M. Dewatripont, D. Eckaus, E. Helpman, R. Henderson, L. Phaneuf, W. Scarth, and N. Stokey, "A Model of Growth Through Creative Destruction Published by : Econometric Society of the literature on endogenous growth pioneered by Romer (1986) and Lucas (1988) has been to endogenize the underlying source of sustained growth in per-capita income ," vol. 60, no. 2, pp. 323–351, 2016.

[60] P. Martin and C. A. Rogers, "Industrial location and public infrastructure," *J. Int. Econ.*, vol. 39, no. 3, pp. 335–351, 1995.

[61] P. R. Krugman, *Geography and trade*. MIT press, 1991.

[62] A. J. Venables, "Equilibrium locations of vertically linked industries," *Int. Econ. Rev. (Philadelphia).*, pp. 341–359, 1996.

[63] J. Varga and J. in't Veld, "A model-based analysis of the impact of Cohesion Policy expenditure 2000--06: Simulations with the QUEST III endogenous R&D model," *Econ. Model.*, vol. 28, no. 1, pp. 647–663, 2011.

List of abbreviations and definitions

AADT	Average Annual Daily Traffic
BEV	Battery Electric Vehicles
Boe	Barrels of Oil Equivalent
bp/km	Billions of passengers kilometre
CAP	Common Agricultural Policy of the European Union
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Use and Storage
CGE	Computable General Equilibrium
CiSi	Copper indium di-selenide
CSP	Concentrated Solar Power
EGS	Enhanced geothermal system
ENCR	(Dedicated) Energy Crops
EU28	European Union (28 countries)
GDP	Gross Domestic Product
GHG	Green House Gases
GVA	Gross Value Added
ha	Hectares
HFC	Hydrogen Fuel Cell
ICS	Industry, Commerce and Services
kha	Thousands of hectares
LCF	Land Cover/use Flows
LU	Land-use
LUISA	Land Use-based Integrated Sustainability Assessment modelling platform
Mp/km	Millions of passengers kilometre
MS	Member State
NUTS	Nomenclature of Territorial Units for Statistics
ORC	Organic Rankine Cycle
OSM	Open Street Map
PHEV	Plug-in Hybrid Electric Vehicles
PV	Photo-Voltaic
SCGE	Spatial Computable General Equilibrium
t/km	Tonnes kilometre

List of figures

Figure 1. Final energy consumption by sector in EU-28 (frame A) and Poland (frame B), in 2013. Data source: EU Commission, DG ENER 9

Figure 2. Electricity production in Poland, according to reported national statistics. Data source: Central Statistical Office of Poland 10

Figure 3. Conceptual scheme of the EREBILAND project. Direct linkages are represented by solid lines; indirect linkages are represented by dotted lines 12

Figure 4. Thematic coverage of the project 13

Figure 5. EREBILAND modelling workflow 14

Figure 6: Structure of the reference energy system in the JRC-EU-TIMES model 18

Figure 7: Simplified structure of the JRC-EU-TIMES model 19

Figure 8. Workflow for the disaggregation of electricity production. The boxes representing the models involved (JRC-EU-TIMES and LUISA) are shaded in grey 27

Figure 9. Indicator of vehicle kilometres travelled nearby the cities of Brussels - Belgium (frame A) and Bologna – Italy (frame B), for the year 2010 35

Figure 10. Electricity generated from biomass, for the years 2015, 2020 and 2030 38

Figure 11. Electricity generated from biogas, for the years 2015, 2020 and 2030 39

Figure 12. Electricity generated from lignite, for the years 2015, 2020 and 2030 40

Figure 13. Electricity generated from hard coal, for the years 2015, 2020 and 2030 41

Figure 14. Electricity generated from gas, for the years 2015, 2020 and 2030 42

Figure 15. Electricity generated from geothermal, for the years 2015, 2020 and 2030 43

Figure 16. Electricity generated from hydroelectric, for the years 2015, 2020 and 203044

Figure 17. Electricity generated from nuclear, for the years 2015, 2020 and 2030 45

Figure 18. Electricity generated from oil, for the years 2015, 2020 and 2030 46

Figure 19. Electricity generated from solar, for the years 2015, 2020 and 2030 47

Figure 20. Electricity generated from on-shore wind, for the years 2015, 2020 and 2030 48

Figure 21. Electricity generated from off-shore wind, for the years 2015, 2020 and 2030 49

Figure 22. Energy demand supplied for the process car – diesel, in the years 2015, 2020 and 2030 51

Figure 23. Energy demand supplied for the process car – gas, LPG, in the years 2015, 2020 and 2030 52

Figure 24. Energy demand supplied for the process car - gasoline, in the years 2015, 2020 and 2030 53

Figure 25. Energy demand supplied for the process heavy duty truck - diesel, in the years 2015, 2020 and 2030 54

Figure 26. Energy demand supplied for the process light duty truck - diesel, in the years 2015, 2020 and 2030 55

Figure 27. Energy demand supplied for the process light duty truck - gasoline, in the years 2015, 2020 and 2030 56

Figure 28. Energy demand supplied for the process inter-city bus - diesel, in the years 2015, 2020 and 2030 57

Figure 29. Energy demand supplied for the process urban bus – gas, diesel, gasoline, in the years 2015, 2020 and 2030 58

Figure 30. Energy demand supplied for the process motorcycles - gasoline, in the years 2015, 2020 and 2030 59

Figure 31. Energy demand supplied for the process car – hybrid, electric, hydrogen, in the years 2015, 2020 and 2030 60

Figure 32. Energy demand supplied for the process heavy duty truck – gas and light duty truck - LPG, in the years 2015, 2020 and 2030 61

Figure A-1. Structure of the reference energy system in the JRC-EU-TIMES model 76

Figure A-2. Simplified structure of the JRC-EU-TIMES model 77

Figure A-3. Evolution of sector demands, expressed as index with respect to 2005 78

Figure A-4. Demand and variable renewable electricity production within a time slice in the JRC-EU-TIMES model 79

List of tables

Table 1. Main LUISA characteristics ... 17

Table 2. EREBILAND knowledge base ... 22

Table 3. Number of producing units/plants in WEPP ... 24

Table 4. Number of producing units/plants in WEPP, per country ... 24

Table 5. Correspondences between the output categories of the disaggregation and the electricity generation classification originally provided by the JRC-EU-TIMES model ... 27

Table 6. Fuel categories correspondences between the output categories of the disaggregation and the WEPP data ... 28

Table 7. Correspondences between the output categories of the disaggregation and the load hours categories originally provided by the JRC-EU-TIMES model ... 29

Table 8. Correspondences between the JRC-EU-TIMES vehicle/fuel combinations and the output categories of the disaggregation, for car vehicles ... 32

Table 9. Correspondences between the JRC-EU-TIMES vehicle/fuel combinations and the output categories of the disaggregation, for bus vehicles ... 32

Table 10. Correspondences between the JRC-EU-TIMES vehicle/fuel combinations and the output categories of the disaggregation, for duty vehicles ... 33

Table 11. Correspondences between the JRC-EU-TIMES vehicle/fuel combinations and the output categories of the disaggregation, for motorcycles ... 33

Table A-1. Main LUISA characteristics ... 74

Table A-2. Import prices of fossil fuels considered in JRC-EU-TIMES, for different years (2010, 2020, 2030, 2040 and 2050) ... 80

Table A-3. Overview of the technical renewable energy potentials considered in JRC-EU-TIMES for the EU28 ... 80

Appendix A

This Appendix contains detailed descriptions of the main modelling tools used in EREBILAND.

A.1 LUISA platform

Scenario-based modelling can be used to investigate multiple possible evolutions of a given territory (city, region, country or even the entire world) in the future. Models can be used to simulate the impacts of a policy measure (e.g. an investment in an economic sector, definition of zoning plans, construction of a road or installation of a technological infrastructure) or of wider trends, such as those related to climate or demography.

The Land-Use-based Integrated Sustainability Assessment (LUISA) Modelling Platform was developed by the Directorate General Joint Research Centre (DG JRC) of the European Commission (EC). It is based upon the new concept of 'Land Functions' and contributes to the evaluation of impacts of policies and socio-economic trends on European cities and regions.

Land functions are instrumental to better understand territorial processes and highlight the impacts of policy options. A land function can be physical (e.g. related to hydrology or topography), ecological (e.g. related to landscape or phenology), social (e.g. related to housing or recreation), economic (e.g. related to employment, production or infrastructure) or political (e.g. consequence of policy decisions). One parcel of land is generally perceived to fulfil many functions. Land functions are temporally dynamic. They depend on the characteristics of land parcels and are constrained and driven by natural, socio-economic, and technological processes.

A rich knowledge base is needed to satisfy the European-wide coverage and multi-thematic nature of territorial processes. LUISA integrates geographically referenced information from diverse sources and ensures consistency of data nomenclature, quality and resolution. This allows for cross-country / region / city comparisons. Spatial and thematic resolutions can be adjusted in order to resolve local features and provide continental patterns.

The LUISA platform was specifically designed to assess territorial impacts of European policies by providing a vision of possible future options and quantitative comparisons amongst policy options. The platform accommodates multi-policy scenarios, so that several interacting and complementary dimensions of the EU are represented.

At the core of LUISA is a computationally dynamic spatial model that simulates discrete land-use changes based on biophysical and socio-economic drivers. The main macro assumptions, which underpin the land-use model, are provided by several external models that cover demography, economy, agriculture, forestry and hydrology. LUISA is also consistent with given energy and climate scenarios, which are modelled further upstream. The model was initially based on the Land Use Scanner and CLUE models ([12] [13] [14], but in its current form LUISA is the result of a continuous development effort by the JRC [15]. The model is written in GeoDMS - an open source, high-level programming language. The model projects future land-use changes at fine spatial resolution of 1 hectare (100 × 100 metres), where the most relevant land-use types are represented (see Section 2.4). LUISA is usually run for all EU Member States. It can also be used for more detailed case studies or expanded to cover pan-European territory. For an overview of LUISA's main characteristics we refer to *Table 1*.

The goal of LUISA is not to provide forecasts. Its main objective and hence, asset, is the capability of simulating comparable scenarios. As a starting point, the 'baseline' scenario captures the policies already in place, assuming the most likely socio-economic trends and 'business-as-usual' dynamics (typically as observed in the recent past). The baseline serves as a benchmark to compare other scenarios, where future conditions and/or policies are assumed to change. This approach to impact assessments provides sound and consistent input to the decision-making process. Two elements are crucial for the assessments with the LUISA integrated modelling framework: 1) The definition of the coherent multi-sector baseline scenario to be used as benchmark for evaluating the alternative options; 2) A consistent and comprehensive database of socio-economic, environmental and infrastructural information.

The baseline scenario provides the basis for comparing policy options and should ideally include the full scope of relevant policies at European level. A comprehensive baseline integrated in a modelling platform such as LUISA serves to capture the aggregated impact of the drivers and policies that it covers. Sensitivity analysis can be helpful to identify linkages, feedbacks, mutual benefits and trade-offs amongst policies. The definition of the baseline should be the result of consensus amongst the stakeholders and experts involved. Ideally, the baseline's assumptions should be shared and used by different models in integrated impact assessments. Since 2013, LUISA has been configured and updated to be in line with the EC's 'Reference scenario' [16], which has been used as a baseline in subsequent impact assessments. Various aspects of the model, such as sector forecasts and land suitability definitions are updated whenever pertinent.

The second element refers to the wealth of data that are needed to satisfy the European-wide coverage and the multi-thematic nature of territorial impact assessments. The principal input datasets required by LUISA must comply with the following characteristics:

- EU-wide (ideally pan-European) coverage;
- Geographically referenced to bring information together and infer relationships from diverse sources;
- Consistency of data nomenclature, quality and resolution to allow cross-country / region comparison;
- Adjustable spatial and thematic resolutions to resolve local features and provide continental patterns.

LUISA has three main modules: a 'demand module', a 'land-use allocation module' and an 'indicator module'. The demand and land-use allocation modules are explained in the following sections.

The main output of the allocation module is land-use maps. Potential accessibility and population distribution maps are also endogenously computed by the model as a result of the simulation, and are themselves important factors for the final projected land-use maps. From these outputs, and in conjunction with other modelling tools which have been coupled with LUISA, a number of relevant indicators can be computed in the indicator module. The indicators capture policy-relevant information from the model's outputs for specific land-use functions, for example water retention or accessibility. When computed for various scenarios, geographical differences in indicators can be identified and impacts can be related to certain driving factors, which were assumed in the definition of the scenarios.

The next sections describe LUISA's land-use classification, demand and land allocation modules. The indicators available in the LUISA platform are not reviewed systematically in this chapter, but few of them will be elaborated upon in the project descriptions in Section 3.

Table A-1. Main LUISA characteristics

Spatial extent	All EU countries
Spatial resolution	100 metres
Thematic resolution	8 main land-use classes (+ agricultural breakdown + 'abandoned' land uses)
Temporal resolution	Yearly
Time span	2006-2050
Primary outputs	Land-use maps, land-use changes, potential accessibility, population distribution map
Secondary outputs	Spatially explicit thematic indicators

A.1.1 The demand module

The demand module captures the top-down (or macro) drivers of land-use change that limit the regional quantities of the modelled LU types. The demands for different land-use categories are modelled by specialized upstream models. For example: regional land demands for agricultural commodities are taken from the CAPRI model [33], which simulates the consequences of the EU Common Agricultural Policy; demographic projections from Eurostat are used to derive future demand for additional residential areas in each region; and land demand for industrial and commercial areas is driven primarily by the growth of different economic sectors. LUISA is linked to several thematic models, and it inherits the scenario configurations and assumptions of those models. Special care is taken for integrating the input data from multiple source models, in order to ensure that inputs are mutually consistent in terms of scenario assumptions.

In the case of urban, industrial and commercial areas, the link between macro driving forces and land demand is modelled within LUISA's demand module. Urban land-use demands are obtained from combining the demand for residences and tourist accommodations.

The demand for residential urban areas is a function of the number of households and a land-use intensity parameter that indicates the number of households per hectare of residential urban land. The number of households is a function of the regional population and an average household size that is assumed to converge across European regions. The land-use intensity parameter can be either extrapolated from observed past trends in a business-as-usual approach, or adapted to respond to specific urban policies.

The demand for touristic land-use is a function of the number of hotel beds in a region and another land-use intensity parameter for the number of beds in tourist accommodations per hectare of touristic urban land. The number of beds is a function of the projected number of tourist arrivals, which are in turn obtained from the United Nations World Tourism Organization.

Finally, the demand for industrial, commercial and services (ICS) land-use is a function of the economic growth in these three sectors and, again, a specific land-use intensity parameter that indicates gross value added per hectare of ICS land [34]. Here, the land-use intensity parameter responds to GDP per capita because it has been found that economic LU intensity depends foremost on that factor.

A.1.2 The land allocation module

The land-use allocation module is based on the principle that land-use classes compete for the most suitable locations based on the available land and the demand for various land-use classes. The allocation of land uses (LUs) is governed by a land-use optimization approach, in which discrete LU transitions per grid cell occur in each time-step. The suitability of locations for various LU types is based on a combination of static rules and statistically inferred transition probabilities. These probabilities are derived from the following factors:

- terrain factors such as slope, orientation and elevation;
- socio-economic factors such as potential accessibility, accessibility to towns and distance to roads; and
- neighbourhood interactions between LU.

The association between these factors and each LU type is derived from statistical regressions of past LU observations. Spatial planning, regulatory constraints (e.g. protected areas) and exogenous incentives influencing specific LU conversions can also be taken into account in the model. Furthermore, two matrices govern the occurrence of LU transitions.

A 'transition cost matrix' informs the model on the likelihood of pair-wise transitions. This transition cost matrix is obtained from observed LU transitions recorded in the CLC time-series (1990-2006); for example indicating that in general a LU transition from agriculture to urban is more likely than from forest to urban.

An 'allow matrix' defines which land-use transitions are permitted and how much time it takes for them to occur.

Both matrices can be used either as calibration or scenario parameters, and contribute to the overall suitability of grid cells for each LU type.

The LU allocation is done independently for each NUTS2 region. Spill-over effects between regions are not yet dealt with in an integrated manner. This represents a limitation of the model. Small NUTS2 regions where manually merged with adjacent NUTS2 in regions such as Berlin, Prague, Brussels and Vienna where several metropolitan areas are connected together via urbanisation.

A.2 Energy modelling: JRC-EU-TIMES

The JRC-EU-TIMES model is a linear optimization bottom-up technology-rich model [1, 2] owned and run by the JRC-IET. It is an improved version of previous, pan-EU energy system models developed in several EU-funded projects, such as NEEDS, RES2020, REALISEGRID and REACCESS. It models, at the country scale, the energy systems of the EU-28, Switzerland, Iceland and Norway for the period of 2005 to 2050.

The JRC-EU-TIMES explicitly considers two energy supply sectors – primary energy supply and electricity generation. Five energy demand sectors are covered: industry, residential, commercial, agriculture and transport. *Figure 6* illustrates the reference energy system of JRC-EU-TIMES.

The objective of the TIMES model is to satisfy demands for energy, materials and services while minimising (via linear programming) the discounted net present value of energy system costs. The costs of energy systems are subject to several constraints, such as: supply limits for primary resources; technical limitations governing the creation, operation, and abandonment of each technology; balance constraints for all energy forms and emissions, and timing of investment payments and other cash flows. TIMES addresses these constrains by simultaneously allocating equipment investments and operations, primary energy supplies and energy trades.

JRC-EU-TIMES was validated by external and internal experts in December 2013. Since then, its techno-economic parameters for selected technologies and renewable energy potentials assumptions have been updated, based on new available information.

JRC-EU-TIMES is appropriate for assessing the role of energy technologies and their innovation for meeting Europe's energy and climate change related policy objectives. Examples of questions that can be addressed with this model include:

- What are the critical drivers for the deployment of the different low-carbon technologies across EU in the sectors addressed by the model?
- What cost reductions and/or performance improvements are needed to make emerging innovative energy technologies competitive?
- Which energy technology portfolio allows meeting EU and national RES targets and what are the associated costs to the energy system?
- What is the role of bioenergy in supporting support decarbonisation of the energy system?

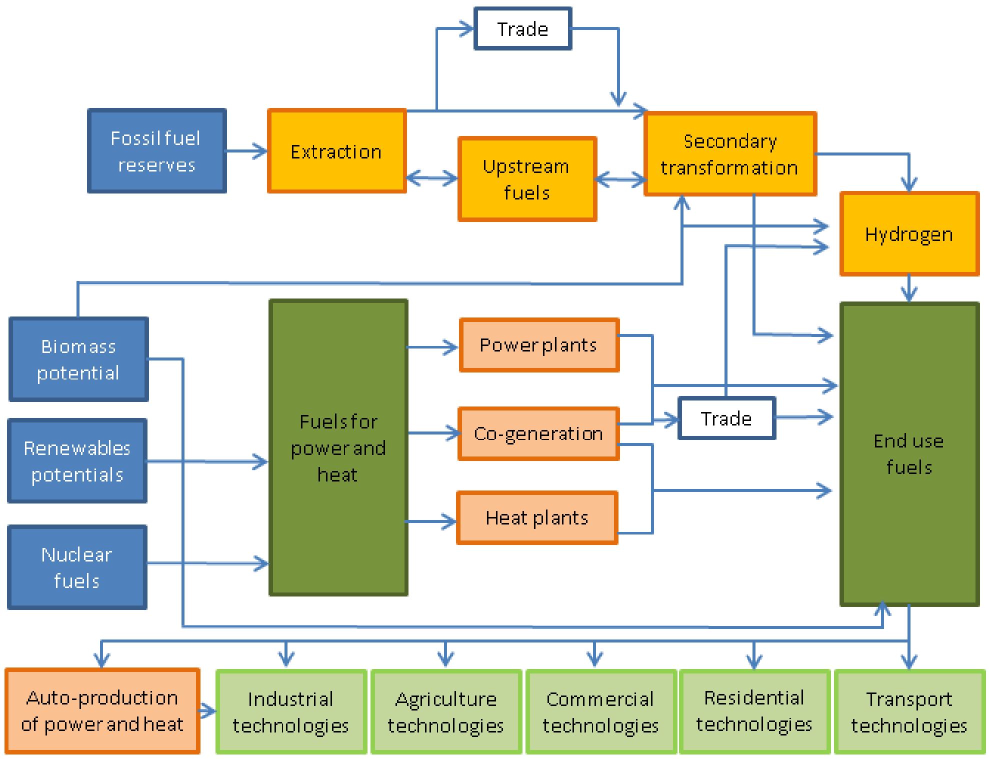

Figure A-1. Structure of the reference energy system in the JRC-EU-TIMES model

Figure 7 summarises the key characteristics of the JRC-EU-TIMES model. Its main drivers and exogenous inputs are:

- the end-use energy services and materials demand;
- characteristics of the existing and future energy related technologies, such as efficiency, stock, availability, investment costs, operation and maintenance costs, and discount rate;
- present and future sources of primary energy supply and their potentials;
- policy constraints and assumptions. An extensive description of the model, including inputs and output values, can be found in [17].

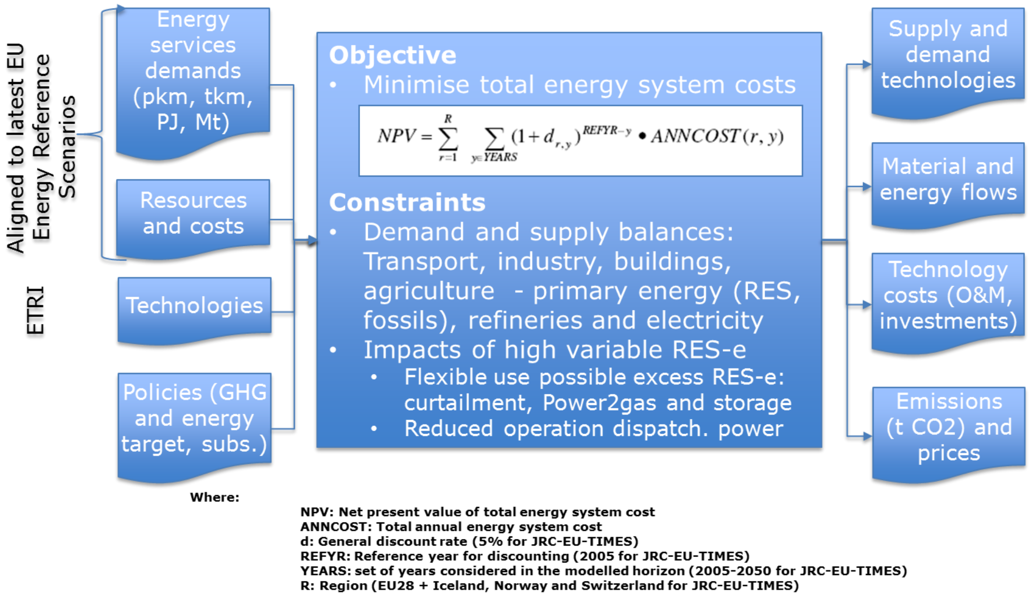

Figure A-2. Simplified structure of the JRC-EU-TIMES model

A.2.1 End-use energy services and materials demand

The projections of materials and energy demand for each country are differentiated by economic sector and end-use energy service. They use historical 2005 data as a starting point. The underlying macroeconomic projections, as well as sector specific assumptions regarding, for instance, renovation rates of buildings, have been updated in line with [10]. The evolution of sector demands over time is shown in **Error! Reference source not found.**.

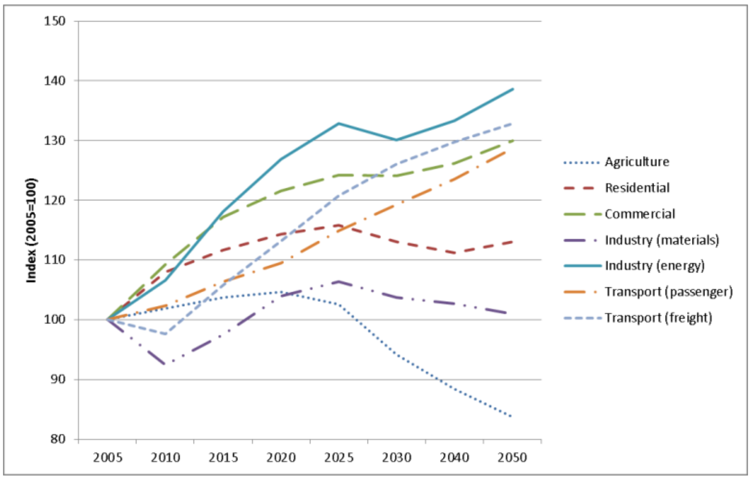

Figure A-3. Evolution of sector demands, expressed as index with respect to 2005

A.2.2 Characteristics of current and future energy related technologies

Country and sector-specific energy balances are derived from energy consumption data from Eurostat, determining the energy technology profiles for supply and demand in the base year. The techno-economic parameters for new energy supply technologies beyond the base year are updated, following ETRI [35].

The JRC-EU-TIMES model has a high level of technological detail, with the explicit representation of more than three hundred technologies in the supply and demand sectors. The detailed specification can be found in [17].

Compared to [17], a higher level of technological detail has been included for solar PV and concentrated solar power (CSP), as well as ocean energy, geothermal and biomass with carbon capture and storage (CCS) in the electricity sector.

On the demand side, the representation of energy efficiency in buildings is improved, with the explicit modelling of insulation options that lead to a reduction in energy consumption for heating and cooling in residential and commercial buildings.

Car technologies have been disaggregated further, with more than fifty car powertrain variants, including several improvement levels for conventional cars, alternative-fuel cars, battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV) for short and long range, and hydrogen fuel cell (HFC) cars. The techno-economic assumptions for the transport sector are based on [36]. EU Member States specific differences in the vehicle fleet composition are implicitly considered in the model through the base year data. The modelling of hydrogen is also further refined, by updating the techno-economic parameters of hydrogen production (centralised and decentralised), storage (tank and underground), and hydrogen delivery, encompassing hydrogen conditioning, and end-use technologies for transportation and stationary applications (residential, commercial and industrial). Moreover, the possibility of electricity and hydrogen co-generation via Very High Temperature nuclear reactor is also explicitly included. The changes to the hydrogen sector are described in [37].

Each year is divided in twelve time-slices that represent an average of day, night and peak demand for the four seasons of the year. To address flexibility issues, each time-slice of the power sector is further split into two sub-periods. In twelve out of the twenty-four sub-periods, there is a possible excess generation of electricity, endogenously calculated for each country based on the installed power of PV, wind and wave technologies as well as on demand profiles. This allows modelling the competition amongst curtailment and different transformation and storage options in case of excessive variable renewable electricity production.

The approach in JRC-EU-TIMES is based on three additional constraints linked to the ability of the power fleet to satisfy energy demand in the absence of variable renewable electricity, and on the modelling of the competition amongst curtailment and different storage options to accommodate excessive production from variable sources of renewable electricity.

The variability of renewables and the associated flexibility constraints are integrated based on the analysis of their duration curve within a time slice as in [38]. The constraint on allowed excess variable renewable electricity is based on a statistical analysis of various profiles and penetration levels. In this approach, the excess electricity can be stored, curtailed or transformed into another energy carrier (**Error! Reference source not ound.**).

The analysis of these different demand and variable renewable electricity profiles shows that the coefficients are fairly constant. The constraint on possible excess variable renewable electricity is in this model version expressed in each time slice by following linear function:

$$0.85 \times VARESe - 0.4 \times FED = Stored + Curtailed + 0.15 \times EHC + 0.25ESW + P2G + P2O$$

[-]

(5)

Where:

VARRESe: the sum of all variable electricity production

FED: Final Electricity Demand (electricity consumption from electrolysers or the charging cycle of a battery are excluded from here)

EHC: Electricity for heating and cooling of buildings

ESW: Electricity for hot sanitary water

P2G: Power to Gas (Electricity for hydrogen production)

P2O: Power to Oil (with CCUS – Carbon, Capture, Use and Storage)

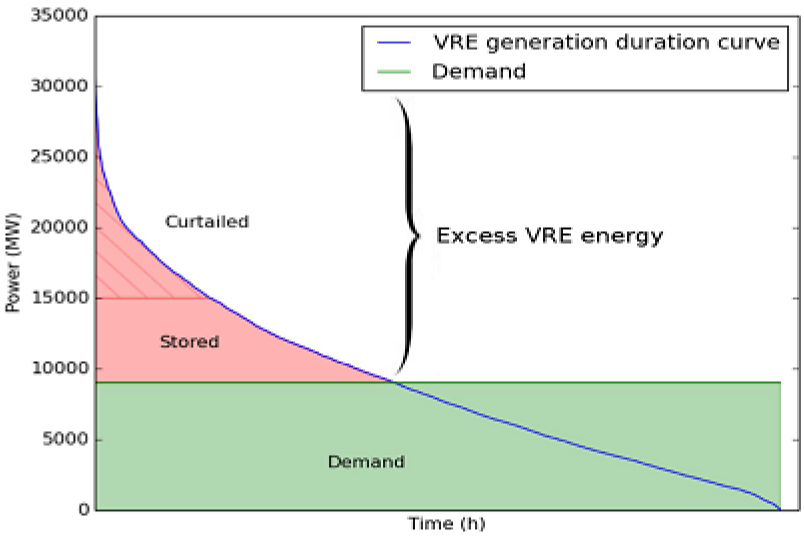

Figure A-4. Demand and variable renewable electricity production within a time slice in the JRC-EU-TIMES model

A.2.3 Present and future sources of primary energy supply and their potentials

The assumptions on fossil fuel import costs have also been updated with more recent data, as shown in ***Error! Reference source not found.***.

Table A-2. Import prices of fossil fuels considered in JRC-EU-TIMES, for different years (2010, 2020, 2030, 2040 and 2050)

2010 USD per boe	2010	2020	2030	2040	2050
Oil	79.5	84.7	106.7	117.9	123.4
Gas	50.2	54.8	64.6	71.3	73.9
Coal	21.2	16.2	23.3	25.8	27.4

Source: Energy Trends Reference Scenario 2015, unpublished

The assumptions regarding the potential for several renewable energy sources have been updated, based on more recent data, studies and country-level analysis, as well as modelling features. The maximum technical potential assumed for each source of renewable energy are summarised in ***Error! Reference source not found.***.

Table A-3. Overview of the technical renewable energy potentials considered in JRC-EU-TIMES for the EU28

RES	Methods	Main data sources	Assumed maximum possible technical potential capacity / activity for EU28
Wind onshore	Maximum activity and capacity restriction disaggregated for different types of wind onshore technologies, considering different wind speed categories	[39] until 2020 followed by expert-based own assumptions	271 GW in 2020 and 381 GW in 2050
Wind offshore	Maximum capacity restriction disaggregated for different types of wind offshore technologies, considering different wind speed categories	[39] until 2020 followed by expert-based own assumptions	75 GW in 2020 and 143 GW in 2050

PV	Maximum land surface available for different types of PV (mainly thin film and CiSi)	Adaptation from JRC-IET based on [39]	115 GW and 1970 TWh in 2020 2010 GW in 2050
CSP	Maximum capacity restriction disaggregated	Adaptation from JRC-IET based on [39] for 2020, then [40]	9 GW in 2020 526 GW in 2050
Geothermal electricity	Maximum activity restriction, disaggregated for different types of geothermal technologies	[39] until 2020 followed by expert-based own assumptions	Geothermal dry-steam and flash power plants: 20 TWh in 2020 and 31 TWh in 2050 Geothermal ORC plants: 17 TWh in 2020 and 707 TWh in 2050 Geothermal EGS: 1.5 TWh in 2020 and 8798 TWh in 2050
Ocean	Maximum activity restriction in TWh, disaggregated for tidal and wave energy	[39] until 2020 followed by JRC-IET own assumptions	Near-shore wave production: 782 TWh in 2020 and 1064 TWh in 20050 Off-shore wave production: 3127 TWh in 2020 and 4254 TWh in 2050 Tidal energy: 385 TWh in 2030 and 390 TWh in 2050
Hydro	Maximum capacity restriction, disaggregated for run-of-river and lake plants	[39]	22 GW in 2020 and 40 GW in 2050 for run-of-river. 197 GW in 2020 and 2050 for lake. 449 TWh generated in 2020 and 462 TWh in 2050
Bioenergy	Maximum amount that can be sustainably harvested, disaggregated by different biomass feedstocks	JRC own calculations	Agriculture biomass (crops and residues): 5495 PJ in 2020 and 6452 in 2050 Forest biomass (roundwood and residues): 5000 PJ in 2020 and 4856 in 2050 Waste (solid urban waste and sludge): 716 PJ in 2020 and 975 in 2050

The potentials for tidal and wave are derived from [41] and[42], modified based on JRC's own assumptions for the long-term.

The availability of ocean energy is further disaggregated into tidal (stream and range) and wave energy, with the latter further subdivided into near-shore and off-shore energy. There can be complex interactions between the installation of off-shore wave energy technologies and the availability of ocean energy near-shore. We mimic this in a simplified form, by assuming exogenous shares of the ocean wave maximum potentials are available for either near-shore or off-shore wave energy installations. While this is a crude assumption, the maximum potential for wave energy in particular is not a constraining factor to the deployment of this technology. We also better reflect the seasonality in the availability of wave energy, based on [43].

A.3 Economic modelling: RHOMOLO

RHOMOLO is a dynamic spatial general equilibrium model of the European Commission. It is developed and used by Directorate-General Joint Research Centre (DG JRC) to undertake the ex-ante impact assessment of EU policies and structural reforms. Recently, the RHOMOLO model has been used together with the Directorate-General for Regional and Urban Policy for impact assessment of Cohesion Policy, and with the European Investment Bank for impact assessment of EU investment support policies.

RHOMOLO provides sector-, region- and time-specific model-based support to EU policy makers on structural reforms, growth, innovation, human capital and infrastructure policies. The current version of RHOMOLO covers 270 NUTS2 regions of the EU28 MS and each regional economy is disaggregated into NACE Rev. 1.1 industrial sectors [44], [45].

The structure of the model departs from standard computable general equilibrium models in several dimensions. First, it generalises the modelling of market interactions by introducing imperfect competition in labour and product markets. Second, it exploits the advantages of a full asymmetric bilateral trade cost matrix for all EU regions to capture a rich set of spatial market interactions and regional features. Third, it acknowledges the importance of space also for non-market interactions through an inter-regional knowledge spill-over mechanism originating from research and development activities within a country.

RHOMOLO is built following the same micro-founded general equilibrium approach as the QUEST model of Directorate-General for Economic and Financial Affairs (DG ECFIN), and is often used in combination with it.

A.3.1 The underlying general equilibrium framework

In the tradition of Computable General Equilibrium (CGE) models, RHOMOLO relies on an equilibrium framework à la Arrow-Debreu where supply and demand depend on the system of prices. Policies are introduced as shocks to the existing equilibrium of prices, which drive the system towards a new equilibrium by clearing all the markets after the shocks. Therefore, CGE models have the advantage of providing a rigorous view of the interactions between all the markets in an economy.

Given the regional focus of RHOMOLO, a particular attention is devoted to the explicit modelling of spatial linkages, interactions and spill-overs between regional units of analysis. For this reason, models such as RHOMOLO are referred to as Spatial Computable General Equilibrium (SCGE) models. A richer market structure has been adopted to describe pricing behaviour, as RHOMOLO deviates from the standard large-group monopolistic competition à la Chamberlin [46]. Given the potential presence of large firms in small regional markets, the assumption of atomistic firms of negligible size has been relaxed in favour of a more general small-group monopolistic competition framework [47].

Each region is inhabited by households, whose preferences are captured by a representative consumer who consumes with a love for variety [48]. Households derive income from labour (in the form of wages), capital (profits and rents) and transfers (from national and regional governments). The income of households is split between savings, consumption and taxes.

Firms in each region produce goods that are consumed by households, government or firms (in the same sector or in others) as an input in their production process. Transport costs for trade between and within regions are assumed to be of the iceberg type and are sector- and region-pair-specific. This implies a 5 x 267 x 267 asymmetric trade cost matrix derived from the European Commission's transport model TRANSTOOLS.

The industrial sectors of economic activity in each region differ with respect to the scope for product differentiation between varieties. Firms in constant-returns-to-scale sectors produce undifferentiated commodities and price at marginal costs. Firms in the differentiated good sector produce one particular variety of a good, under increasing returns to scale. These firms can price-discriminate their export markets and, given the small-group monopolistic competition structure, can set different levels of mark-ups in different destination markets. The number of firms in each sector-region is empirically estimated through the national Herfindahl indices, assuming that all the firms within one region share the same technology. Given their higher weight in the price index, firms with higher market shares are able to extract higher mark-ups from consumers than their competitors, and, since market shares vary by destination market, also mark-ups vary by destination market.

A.3.2 Product market imperfections

The different sectors of the economy are split into two categories: homogeneous-good-producing perfectly competitive sectors and imperfectly competitive sectors supplying the differentiated goods.

Perfectly competitive sectors are characterised by undifferentiated products produced under constant returns to scale technology. Consumers can distinguish the different origins of the product, so that the standard Armington assumption is respected, but they cannot distinguish individual providers of the good, which means that firms compete under perfect competition and the resulting price equals the marginal costs of production. This means that the production of such goods does not yield any operating profits to the producers, whose number is irrelevant to the model given their constant-returns-to-scale technology.

As for the imperfectly competitive sectors, they are instead populated by a finite (though possibly high) number of firms producing differentiated products, whose specific characteristics are visible to consumers. Consumers, who are able to distinguish both the geographic origin of the product and the characteristics associated with each individual producer, enjoy product variety in consumption. Consumers' perception of heterogeneity between variety pairs is captured by the elasticity of substitution parameter, which is the same for all variety-pairs, so that all varieties enter consumer preferences symmetrically.

Regional markets are assumed to be segmented, which implies that firms can optimally choose a different price in every regional market served. Under standard monopolistic competition assumptions, in models where preferences are described in terms of constant elasticity utility functions à la Dixit-Stiglitz [48], the elasticity of substitution would suffice in determining the mark-ups and pricing of each firm in every destination market. Firms apply the same Free On Board (FOB) export prices to all destination markets, including a constant mark-up that depends only on the elasticity of substitution, and difference in observed Cost, Insurance and Freight (CIF) import prices depend only on differences in iceberg transport costs, abstracting from taxes and subsidies.

However, one critical assumption of the monopolistic competition framework is that firms in the market are sufficiently small to treat market aggregates as exogenous in their pricing behaviour. RHOMOLO adopts a more general description of market structure and allows firms to behave strategically. Following [49], market power increases with firms' market share. Besides resulting in a more realistic description of firm behaviour, one key reason to depart from a large-group monopolistic competition framework in favour of a small-group monopolistic competition structure is rooted in the regional focus of the RHOMOLO model, which implies that, in determining their equilibrium prices or quantities, firms take into account their impact on the price index, which grows with their market share.

A.3.3 Labour market imperfections

Unemployment in RHOMOLO is modelled through a wage curve. In [50] the wage curve is described as 'empirical law' that negatively relates individual real wages to the local unemployment rate (controlling for a set of interpersonal productivity characteristics, such as education, sex, age, etc.). From a theoretical perspective, the wage curve can be understood as a reduced-form representation of various complete structural models of imperfect labour markets, such as union wage bargaining models, efficiency wage models, or matching models. The existence of a wage curve has been documented extensively in the literature [50]. A wage curve implies that wages are set above the market clearing level, resulting in unemployment. Two different types of wage curves are considered in RHOMOLO, a static one linking current unemployment to the wage level and a dynamic extension, which accounts for the impact of past wages and changes in inflation and unemployment.

In the context of RHOMOLO, an important advantage of modelling labour markets via a wage curve is the combination of operational applicability and sound micro-foundations, which make it an ideal choice for a high-dimensionality model with heterogeneous skills in each region. In addition, it is the standard approach followed in CGE models to model unemployment (see, for example, [20]).

Additional channels of labour market adjustment, such as labour migration, participation, human capital accumulation, etc. are elaborated in a specific labour market module (see [19], [51]). The labour market module is activated in those RHOMOLO simulations, where significant impact on labour markets can be expected.

A.3.4 R&D and innovation

RHOMOLO models R&D and innovation as one separate sector of the economy selling innovation services. Innovation is produced by a national R&D sector populated by firms employing high-skill workers hired from the regional labour markets of the country, remunerating them at the same nation-wide wage. The national R&D sector sells R&D services as an intermediate input to firms in all the sectors of regional economies of the same country.

One of the key issues modellers are faced with, when dealing with R&D, is the issue of how to deal with spill-overs. As noted by [52], any innovative activity has an information component that is almost completely non-appropriable and costless to acquire, an idea dating back to [53] and [54]. The implementation of this idea in general equilibrium models, though, is more recent, splitting research activities into appropriable and non-appropriable knowledge, as for example in [55] in the context of climate studies, or [56] based on a theory of endogenous growth, or [57]–[59] based on the extension of product varieties.

In RHOMOLO, there are spatial technology spill-overs in the sense that the national R&D sector affects the total factor productivity of regional economies within each country, which results in inter-regional knowledge spill-overs from the stock of national accumulated knowledge. Therefore, the production (and purchase) of R&D services is associated with a positive externality. This positive externality, derived from the accumulation of a knowledge stock in the country, benefits all regions (possibly to a different extent) through sector-region specific knowledge spill-over elasticities.

A.3.5 New Economic Geography features of the model

The structure of the RHOMOLO model engenders different endogenous agglomeration and dispersion patterns of firms, by making the number of firms in each region endogenous (see [21]). Three effects drive the mechanics of endogenous agglomeration and dispersion of economic agents: the market access effect, the price index effect and the market crowding effect.

The market access effect captures the fact that firms in central regions are closer to a large number of consumers (in the sense of lower iceberg transport costs) than firms in peripheral regions. The price index effect captures the impact of having the possibility of sourcing cheaper intermediate inputs because of the proximity of suppliers and the resulting price moderation because of competition. Finally, the market crowding effect captures the idea that, because of higher competition on input and output markets, firms can extract smaller mark-ups from their customers in central regions. Whereas the first two forces drive the system of regional economies towards agglomeration by increasing the number of firms in core regions and decreasing it in the periphery, the third force causes dispersion by reducing the margins of profitability in the core regions.

RHOMOLO contains three endogenous location mechanisms that bring the agglomeration and dispersion of firms and workers about: the mobility of capital, the mobility of labour, and vertical linkages.

Following the mobile capital framework of [60], we assume that capital is mobile between regions in the form of new investments, and that the mobile capital repatriates all of its earnings to the households in its region of origin. Following the mobile labour framework of [61], we assume that workers are spatially mobile; workers not only produce in the region where they settle (as the mobile capital does), but they also spend their income there (which is not the case with capital owners); workers' migration is governed by differences in the expected income, and differences in the costs of living between regions (the mobility of capital is driven solely by equalisation in the nominal rates of return, see [51]). Following the vertical linkage framework of [62], we assume that, in addition to the primary factors, firms use intermediate inputs in the production process; similarly to final goods consumers, firms value the variety of intermediate inputs; trade of intermediate inputs is costly.

In addition to these effects, which are common to theoretical New Economic Geography models with symmetric varieties, spatial CGE models, such as RHOMOLO, add some stability in location patterns by calibrating consumer preferences over the different varieties in the base year. Through calibration, the regional patterns of intermediate and final consumption, observed in a given moment of time, are translated into variety-specific preference parameters. These parameters ensure the given level of demand for varieties produced in each region, including peripheral ones. Therefore, it would be impossible to obtain extreme spatial configurations in terms of agglomeration or dispersion, because firms in the regions with very low number of firms would enjoy very high operating profits due to the high level of consumer marginal provided by their relative scarce variety and thus would attract more firms in the region.

A.3.6 Solving the model: dynamics and inter-temporal issues

In contrast to the QUEST model [63], which is a fully dynamic model with inter-temporal optimisation of economic agents, RHOMOLO is solved following a recursively dynamic approach. The regional disaggregation of RHOMOLO implies that the dynamics have to be kept relatively simple. The optimisation consists of a sequence of short-run equilibria that are related to each other through the accumulation of physical and human capital stocks. Thus, the optimisation problems in RHOMOLO are inherently static, because the different periods are linked to each other through the accumulation of stocks in the economy. In each period the households make decisions about consumption, savings and labour supply in order to maximise their utility subject to budget constraint.

A.3.7 Disaggregating energy sectors in RHOMOLO

In the current version of RHOMOLO, energy sectors are part of a more aggregated group of industrial sectors labelled 'Manufacturing'. Hence, it is not possible to run policy simulations related to energy, such as improvements in energy efficiency. However, a number of cohesion policy measures are directly targeted at energy production and use. Some example are:

- (005) Electricity (storage and transmission)
- (006) Electricity (TEN-E storage and transmission)
- (007) Natural gas
- (008) Natural gas (TEN-E)
- (009) Renewable energy: wind
- (010) Renewable energy: solar
- (011) Renewable energy: biomass
- (012) Other renewable energy (including hydroelectric, geothermal and marine energy) and renewable energy integration (including storage, power to gas and renewable hydrogen infrastructure)
- (013) Energy efficiency renovation of public infrastructure, demonstration projects and supporting measures
- (014) Energy efficiency renovation of existing housing stock, demonstration projects and supporting measures
- (015) Intelligent Energy Distribution Systems at medium and low voltage levels (including smart grids and ICT systems)
- (016) High efficiency co-generation and district heating

In the current version of RHOMOLO it would not be possible to assess impacts of such cohesion policy investments in energy infrastructure. Therefore, within the EREBILAND project, sector breakdown of industrial activities will be disaggregated into several energy sectors in the RHOMOLO model. It is envisaged to disaggregate the following energy-based activities from the current aggregated group of industrial sectors labelled 'Manufacturing':

- (4) Mining of coal and lignite; extraction of peat;
- (5) Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction excluding surveying;
- (6) Electricity, gas, steam and hot water supply.

A.3.8 Simulating cohesion policy investments in energy infrastructure

Having these three energy-based activities as separate industrial sectors in RHOMOLO (see paragraph above), it would be possible to use RHOMOLO together with JRC-EU-TIMES to assess socio-economic impacts of the cohesion policy investments in energy infrastructure at regional level.

One possible scenario could be first to assess how cohesion policy investments in energy affect energy supply and use of different industrial sectors and final demand of households and government using the JRC-EU-TIMES model. Second, these simulated changes in the input-output coefficients and final demand could be fed into the RHOMOLO model, where the socio-economic impacts on GDP, employment, investment, trade, etc. could be assessed at the regional and sector level. Also other types of energy policy simulations will be possible with the extended RHOMOLO model.

LB-NA-27697-EN-N

JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation

Publications Office

doi:10.2788/357099

ISBN 978-92-79-54577-1