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The LUISA Territorial Reference Scenario 2017

A technical description

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Foreword

Location matters. It matters for health, for the environment, for the economy. Naturally, location matters for policy. It matters because many things change, when one changes location: climate, culture, architecture, educational opportunities, the labour market. Location matters in small countries, and it certainly matters in an area as large as the European Union. It should come as no surprise then that the context for European policies is very different, in different parts of the EU territory. Understanding those different contexts better would be a great help for better policy making.

The LUISA modelling platform is set up to assist in the understanding of the territorial characteristics and territorial trends throughout Europe. It is used regularly to assist in European Commission (EC) policy making processes, and has repeatedly been recognized by EC policy makers as an useful instrument. At the heart of the LUISA modelling platform is the so-called Territorial Reference Scenario. That scenario projects the most likely changes in the spatial distribution of activities across the European territory, given business-as-usual location choice preferences, official EU projections, and EU policies that are in act and have territorial relevance. Policy impacts are then quantified by comparing the results of a policy model variant with the results of the Territorial Reference Scenario.

Given the importance of the Territorial Reference Scenario for the modelling platform, it must come as no surprise that a lot of effort is put into making it as comprehensive and accurate as possible. Thus, in 2017, substantial changes have been made to the modelling framework, which form major steps towards a fully integrated platform for mapping and modelling bottom-up changes in settlement patterns in the EU. The result of that development process is the LUISA Territorial Reference Scenario 2017. This report describes, comprehensively, all the aspects in which that Territorial Reference Scenario has been changed.

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Abstract

This report describes all the changes done to the LUISA modelling approach in the development of the LUISA Territorial Reference Scenario 2017. Key changes are updates to the base year (now 2012), and updates to the macro and meso-level sectoral projections on demography, economy and agriculture that partially drive the model. Furthermore, the Territorial Reference Scenario 2017 is the first to benefit from a new approach for modelling interactions between land function and land cover, a Net Present Value approach for modelling land-use changes, an overhaul of the way land abandonment is modelled, and the inclusion of a new dynamic sub-model for regional residential density change. Many model inputs have been added or modified. Lastly, new quality checks and many usability changes ensure model consistency and make operating the model easier.

1 Introduction

LUISA is a pan-European territorial modelling platform developed for the ex-ante evaluation of regional and local impacts of European policies and trends. LUISA allocates (in space and time) the demand and supply of resources, the location choices of human activities, and infrastructure and its effects on location choice. Biophysical suitability, policy targets and regulatory constraints, economic criteria and manifold other factors are dynamically considered in LUISA for the allocation of population, economic activities and resources. The projected territorial patterns cover all EU Member States and several Western Balkan countries[1] at a detailed geographical resolution (100m2), typically until 2050.

LUISA is configured to project a territorial reference (also called "baseline" or "trend") scenario, assuming official socio-economic trends, business as usual preferences and the effect of established European policies with direct and/or indirect territorial impacts. Variations to that reference scenario can then be used to estimate impacts of specific policies or alternative macro-assumptions. In 2017, considerable effort has been put in an update of the LUISA reference scenario. The JRC and DG REGIO set up the LUISA Territorial Reference Scenario 2017 primarily for the production of thematic information for the Seventh Cohesion Report, and to be used in the frame of the ex-ante impact assessment of the cohesion policy post-2020. Other EC Services are also involved in various manners. In this report, the key elements of the LUISA Territorial Reference Scenario 2017 are explained, after a brief overall description of the LUISA platform.

1.1 The LUISA territorial modelling platform

The LUISA territorial modelling platform coherently links specialised macroeconomic, demographic and geospatial models with thematic spatial databases. As a truly integrative tool, LUISA incorporates historical trends, current state and future projections in order to capture complex interactions between human activities and their determinants. The final aim is to translate socio-economic trends and policy scenarios into processes of territorial development. The LUISA platform can be divided into three main elements: a comprehensive territorial knowledge base, advanced analytical and modelling modules, and production and visualization of territorial indicators. These elements are briefly described in the sections below.

1.1.1 A comprehensive territorial knowledge base

The framework is based upon a coherent structure of data layers at the finest possible granularity, including:

— Statistics on economic and demographic trends (long time series, historical and projected);

— Infrastructure (e.g. for transport, energy, primary and secondary services);

— Human and industrial settlements (e.g. from satellite and cartographic sources);

— Building and dwelling characteristics, tourism, meteorological data, etc.;

— Micro-data on corporate investments in research and innovation

Since the introduction of the LUISA Territorial Reference Scenario 2017, the core element for the territorial knowledge base is the LUISA Base Map 2012, derived from the combination of the most up-to-date and detailed information from multiple geographical data sources. Improvements of the LUISA base map are continuously on-going to provide further breakdowns of infrastructure and activities (transport and energy infrastructure, commercial and industrial areas, social facilities, touristic accommodation, etc.). Another key element of the knowledge base is the gridded layer of population, generated in LUISA by downscaling

(1) Serbia, Bosnia and Herzegovina, and Montenegro.

population reported by the Eurostat's GEOSTAT 1km grid 2011, using methods described by Batista e Silva et al. (Filipe Batista e Silva, Gallego, et al. 2013).

Table 1. Policy initiatives with a direct spatial impact incorporated in LUISA

Theme	Policy	Year	Implementation in LUISA Territorial Reference Scenario 2017
Energy	Renewable Energy Directive (Directive 2009/28/EC)	2009	Restriction of biofuel production from land with: high biodiversity value, such as primary forest, highly biodiverse grassland and nationally designated areas; or high carbon stocks, such as wetlands, continuously forested areas or peatlands
Agriculture	Common Agricultural Policy (CAP) reform (Regulation No 1305/2013)	2013	Direct Payments, Cross Compliance and Rural Development programs specified at the Member State level, such as: good Agricultural and Environmental Conditions (GAEC) measures; areas with Natural Constraints (ANC)/Less Favoured Areas (LFA) compensations, according to the areas under Art. 16 (Natura 2000), Art. 18 (Mountainous areas) and Art. 20 (Areas affected by Specific Handicaps) of Council Regulation (EC) 1257/1999. Since the re-designation of new ANC areas following the CAP 2014-2020 reform is at the moment still ongoing at the Member State level, we will keep the ANC/LFA area designation implemented in the previous reference scenario; green payments, specifically those for the maintenance of permanent grassland; and sustainable forestry measures, such as encouraging afforestation of agricultural land in marginal lands at risk for abandonment
Transport	Trans-European Transport Network (TEN-T) revision	2011	Updates of approved changes in the transportation network
	Regional Structural funds	2007	Funding allocated as network improvements by modelling exercise (Jacobs-Crisioni et al. 2016)
Biodiversity	EU Biodiversity strategy to 2020 (COM/2011/0244)	2011	Location-specific rules are established to restrict or enhance certain land uses according to the strategy and the Habitats and Birds Directives

1.1.2 Advanced analytical and modelling modules

Analytical tasks of the LUISA platform are separated into various modules that can be used, either in parallel or in series, to produce indicators and analyse the results of combining various available data layers. The modular structure allows the analysis of spatio-temporal processes at various geographical scales (e.g. countries, regions, cities). Main socio-economic variables are analysed at NUTS 2 and NUTS 3 levels and drive the detailed spatial allocation of population, production systems, services and activities. Linkages with exogenous specialised models and databases are set at the appropriate level.

In particular economy and demography are assumed to be important macro-drivers of territorial development. In the LUISA Territorial Reference Scenario 2017, the macroeconomic and demographic assumptions are aligned with the official projections published in the 2015 Ageing Report (EC 2015) and used in the EU Reference Scenario 2016 (EC 2013). The regional agricultural activities follow the CAPRI 2016 Baseline projections, thus being consistent with the EU Agricultural Outlook 2016-2026 (EC 2016). The LUISA Territorial Reference Scenario 2017 also intrinsically takes into account various policy implications that play out at local levels. A comprehensive list of spatially relevant policy initiatives incorporated in LUISA is given in Table 1.

1.1.3 Production and visualization of territorial indicators

The final output of LUISA represents a set of spatially explicit indicators that can be grouped according to specific themes, defined as 'territorial indicators'. The indicators span over a wide temporal window, typically from 2000 until 2050. They can be represented at various levels (national, regional, urban or other). The data and indicators produced by LUISA are publicly accessible in the Territorial Dashboard https://data.jrc.ec.europa.eu/tc/t-board/. Those indicators – some also derived using additional statistical sources (e.g. Eurostat and statistical sources) – cover the following domains:

Population Dynamics
Economy
Employment
Education
Research & Innovation
Health
Energy
Transport & Accessibility
Environment & Climate
Urban Development
Social Issues
…

1.2 This report

This report details the development of the LUISA Territorial Reference Scenario 2017. In all cases, changes are reported in comparison with the 2014 Baseline scenario (Baranzelli et al. 2014). The changes to the local allocation mechanisms that are reported here are part of a long-time-span project to move LUISA towards the ultimate goal of a deductive model that projects future changes in multiple human activity patterns, and their physical representation, using a land rent approach. The most important changes reported here are given in Table 2. In Section 2, the incorporated regional demographic, economic and agricultural projections are discussed. Section 3 focuses on all changes in modelling approach. Section 4 treats new modelling inputs. Section 5 discussed additional modelling outputs and additional quality checks. Section 6 lists changes done to simplify the technical implementation of the model. Section 7 synthesizes this report and concludes with some final remarks on the development of the LUISA modelling platform.

Table 2. Overview of major changes to the LUISA Territorial Reference Scenario 2017 (from the 2014 Scenario), ordered by section in which those changes are discussed.

2. Projections	**3. Modelling approach**	**4. Inputs**	**5. Outputs and quality**	**6. Implementation**
Demographic and macroeconomic trends	Generalized reciprocal modelling of land functions and cover	New base year data, refinement of base map	Firm checks on population distribution	Multi-version catalogue of administrative boundaries
Agricultural outlook projections including CAP reform	Shift from inductive to deductive utility-based approach in land cover optimisation	Different land-use classification	Feedbacks to regional demand models	Generic methods to aggregate, disaggregate, reaggregate
	Shift from multinomial to binomial logit models for land cover suitability	Various new variables as inputs	Added agricultural abandonment risk maps	Simplified model definitions
	Dynamic demand model for residential land cover			Simplified factor definitions

2 Updated projections

Projected local activity patterns from LUISA are driven by exogenous projected macro-level changes in, amongst others, population, economic activity and agricultural production, as well as by processes of local change that in the model are considered at least partially endogenous. Demographic, macroeconomic and agricultural projections have been updated for the LUISA Territorial Reference Scenario 2017. Those updates are discussed in this section.

2.1 Demographic and macroeconomic trends

Economy and demography are important macro-drivers of territorial development. For example, population dynamics are assumed to be the major driver of the demand for housing, while macro-economic projections are used to estimate the demand for industrial, commercial and service facilities. In the LUISA modelling platform, the demographic and economic assumptions are typically taken from a number of exogenous sector-specific models that are mutually consistent.

In the LUISA Territorial Reference Scenario 2017, macroeconomic and demographic assumptions are aligned with the official projections published in the 2015 Ageing Report (EC 2015), which are also used in the EU Reference Scenario 2016 (EC 2013). The used demographic projections have been produced for all EU member states and are available with regional, gender and age breakdowns (EUROPOP2013). The most detailed version at NUTS 3 level has been implemented in the LUISA Territorial Reference Scenario 2017. In addition, the demand for tourist accommodation areas has been determined according to the number of tourist arrivals projected by the United Nations World Tourism Organization (UNWTO 2014). The total demand for urban areas is obtained by combining the demand for housing and tourist accommodations (for more details, see Baranzelli et al., 2014).

The macroeconomic trends incorporated in the LUISA Territorial Reference Scenario 2017 are primarily based on DG ECFIN projections, which forecast variables such as Gross Domestic Product (GDP), employment, productivity and labour force. ECFIN's projections rely on EUROPOP2013 demographic projections for the period 2015-2060 and are originally released at national (NUTS 0) level. The national level projections are disaggregated to regional NUTS 3 level projections in the LUISA platform. That disaggregation exercise is performed based on the assumption that past regional and sector growth rates will be maintained over time, while keeping sure that the disaggregated variables fit the national totals from the reference projections (Batista e Silva et al. 2016).

Sector breakdown of regional Gross-Value-Added (i.e. GDP excluding taxes and subsidies) is achieved by applying national sector growth rates from the GEM-E3 model (EC 2013). This is then used to compute the demand for industrial, commercial and service facilities areas according to the method proposed by Batista e Silva et al. (2014).

2.2 Agricultural market outlook projections and Common Agricultural Policy (CAP) reform

The demand for agricultural commodities is derived from the most recent agricultural market outlook projections of the CAPRI agro-economic model. CAPRI is a partial equilibrium model that simulates market dynamics of agricultural commodities for impact assessment of the Common Agricultural Policy (CAP) (Britz & Witzke 2008). Notwithstanding the European focus, the model simulates the effects of trade policies globally, and includes seventy-seven countries divided into forty trade blocks, which are incorporated through a global, multi-commodity market module.

Table 3. Core policy assumptions in CAPRI's agricultural market outlook

PILLAR I		
Instrument	CAPRI Base year 2008	Baseline 2030
Direct payments	As defined in 2003 reform and 2008 Health Check (HC); covering SFP or (SAPS)	2013 reform (partially) implemented
Decoupling	Historical/Regional/Hybrid schemes	Basic Payment Scheme
Coupled direct payment options	As defined in 2003 reform (including Article 68/69 and CNDP)	VCS according to the options notified by MS up to 31/08/2015
Redistributive payment	NA	Not implemented
Young Farmer Scheme	Not implemented	Not implemented
Green Payment	NA	Green Payment component granted without restriction (only limitation: no conversion of permanent grassland)*
Capping	Modulation implemented	Implemented according to 2013 reform. Capped budget redistributed over RD measures
Convergence	NA	included
PILLAR II		
Instrument	CAPRI Base year 2008	Baseline
Agri-environmental schemes	Less Favoured Areas (LFA) and Natura 2000 payments	Areas with Natural Constraints (ANC) and Natura 2000
Business Development Grants / investment aid	Not considered	Not considered
Common Market Organization		
Instrument	CAPRI Base year 2008	Baseline
Sugar quotas	Yes	Abolition of the quota system in 2017
Dairy quotas	Yes	Quota system expires in 2015
Tariffs, Tariff Rate Quotas	Yes	Maintained at current level
Export Subsidies	Yes	Not applied in 2030

The EU supply and market modules of CAPRI are calibrated to the European Commission's medium-term prospects for agricultural markets and income (EC 2016), considering the following targets: supply, demand, production, yields and prices. CAPRI is then used to estimate the non-CO_2 greenhouse gas emissions (GHG) for methane and nitrous oxide, and the nitrogen surplus in the EU agricultural sector, as published in DG AGRI's medium-term market outlook (EC 2016). CAPRI is also part of the model suite used to derive the EU energy, transport and GHG trends published in the EU Reference scenario 2016 (EC 2013).

Among other outputs, the CAPRI model produces projections at regional (NUTS 1 and NUTS 2) level for all Member States on yields, production, and land area needed to meet demand for crops. The projected land requirements are used as an input in the LUISA platform. In the LUISA Territorial Reference Scenario 2017, the regional land demand for agricultural activities has been derived from the CAPRI 2016 Baseline projections. By doing so, agricultural expectations are held consistent with the EU Agricultural Outlook 2016-2026 (EC 2016). CAPRI baseline projections incorporate policy, market and macroeconomic assumptions. Regarding policy assumptions, the CAPRI 2016 Baseline integrates agricultural and trade policies approved up to 2015, including the following measures of the latest CAP 2014-2020 reform (see Table 3 for further details on the CAP policy assumptions incorporated in CAPRI and LUISA):

— abolition/expiry of production quotas for milk and sugar;

— tariffs and export subsidies;

— Pillar I of the CAP – direct payment schemes such as the Basic Payment Scheme, Single Area Payment Scheme, Coupled Support and Green Payments;

— the major programmes from Pillar II of the CAP, such as support for areas with natural or other specific constraints, Natura 2000 payments to agriculture, and agri-environment measures;

— Greening measures such as crop diversification.

The CAPRI 2016 Baseline does not take into account any potential WTO agreements in the future, and no assumptions are made concerning bilateral trade agreements that are currently under negotiation. Limits on nitrogen application (as a consequence of the Nitrate Directive) are, however, taken into account.

3 Changes in modelling approach

To obtain projections of local changes in activity distributions, LUISA applies a doubly constrained discrete allocation mechanism. In that mechanism regional demands are allocated, assuming a competitive land market, with the aim of maximizing the utility of the modelled land uses (Lavalle et al. 2011; Hilferink & Rietveld 1999; Koomen et al. 2015). The model is constrained by the projected demands for the various land uses, and by the amount of land available in a region. Additionally, the local allocation mechanism provides projections of local population counts and potential accessibility levels. In the LUISA Territorial Reference Scenario 2017, many elements of the LUISA modelling flow have been changed drastically. This section discusses how: land cover/function relations have been modelled; a clear economic rationale has been incorporated in the land cover modelling; processes of abandonment are now modelled; as well as the model's newly incorporated feedbacks with a sub-model for regional residential land demand.

3.1 A generalized approach to model land functions and land cover reciprocally

Land cover and land function are two intrinsically different concepts that are not easily integrated in a single modelling approach. An in-depth discussion of integration efforts has been given recently by Jacobs-Crisioni et al. (Jacobs-Crisioni et al. 2017). Previous LUISA versions (F Batista e Silva et al. 2013; Baranzelli et al. 2014) have used a method of integration similar to method *B* discussed in that publication. In those versions, population was initially allocated, after which urban and abandoned urban land covers were allocated based on threshold rules. Only after allocation of urban and abandoned urban land cover, all other land covers were allocated. There are two important drawbacks to that approach. First, it is not straightforward to include regional expectations. In previous LUISA iterations, it was found necessary to apply some sort of discrete allocation mechanism to be able to control the amount of urban growth within regions. This, however, implied a chain of two separate discrete allocation mechanisms. Second, urban land-uses were not modelled as participating in the land market where other land uses were assumed to participate. Such an exclusion of urban land uses from the simulated land market prevents the model from fully optimizing the overall utility of land-use patterns.

In the LUISA Territorial Reference Scenario 2017, the linkage between land function and land cover has been changed substantially. It is now based on a reciprocal process where the model first computes activity pressures i.e. the degree to which there is demand for physical capacity to support a certain land function. The model then uses those pressures as a driving factor in the land cover modelling process, where all modelled land covers participate and compete simultaneously in the simulated land rent market. At the next step, the model assumes that land is used for the purpose that brings the greatest utility, taking into account the relative benefits of alternative land uses (Fujita 1989). Finally, land functions are redistributed over the new land cover map. For now, this reciprocal method is only used to distribute residential (i.e. night-time) population and residential land uses. In the future, additional land uses may be modelled using the same template. The new modelling process is shown schematically in Figure 1.

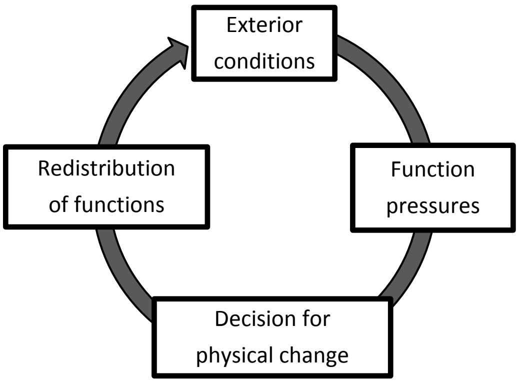

Figure 1. New linkage between land function and land cover

At the heart of this approach is a set of population change equations that govern population pressure and population redistribution. These functions have been empirically fitted for all modelled countries separately, using Global Human Settlement Layer (GHSL) population distribution data produced by JRC (Freire et al. 2016). For the sake of calibration, the original 250m population data has been downscaled to 100m assuming that the population is distributed equally in the underlying cells. A substantial amount of additional variables have been included in the datasets, which the functions have been fitted on. All available observations in each country have been used.

The above mentioned population change equations are used to downscale projected regional population changes, together with a fixed amount of people that is expected to move within their own region. Currently, 3.8% of people are expected to move within their regions each year – a similar value to the average intra-regional mobility according to the 2011 EU census. Those 3.8% are taken homogeneously from each raster cell, and subsequently redistributed along with projected regional population changes. The total allocatable population is defined as:

$$K_{j,t} = \Delta Q_{j,t} + \sum_r^n L_r 0.038 T Q_{r,t-1}, \tag{1}$$

where

— $\Delta Q_{j,t}$ is the projected population change in region *j*;

— L_r is a dummy variable indicating whether grid cell *r* is in region *j;*

— $Q_{r,t-1}$ is the population density in grid cell *r* at the previous simulation time-step

— and *K* receives per modelled year *T*, the sum of 3.8% of the population at the previous time-step for each grid cell within the region.

Except for the period 2012-2015, all LUISA time-steps cover five years, so that in each regular model iteration (3.8% x 5) = 19% of a pixel's population is reallocated.

3.1.1 Population pressure equation

Obtaining population pressure results is based on an iterative procedure that starts with the results of an empirical function:

$$D^I_{r,t} = \beta 0 + \gamma_b B_{b,t-1} Q_{r,t-1} + \delta_b B_{b,t-1} W_{rg} Q_{g,t-1} + \theta_b B_{b,t-1} A_{r,t-1} + \beta 1 X0_r + \cdots + \beta s X s_r + \varepsilon_r, \tag{2}$$

So that a first estimate of population modifier D in pixel *r* at moment *t* depends on:

— Constant value $\beta 0$;

— Dummy variable *B* in which prior population densities are binned through *b*, so that the results of *Q*, *WQ* and *A* are fitted with different estimators depending on previous population densities;

— Average previous population densities $W_{rg}Q_{g,t-1}$ in the immediate (Queen's case) neighbourhood of raster *r,* defined through spatial weight matrix *W.*

— Relative potential accessibility levels *A*. In this iteration of LUISA, potential accessibility levels are defined by dividing absolute potential accessibility levels with the average values in the country of scope. This has the advantage of consistency, necessary because values of *A* have a different scale compared to the values in the data used for model fitting.

— A set of additional variables *X*0 to *Xs*, assumed to be independent to prior population densities

This equation is solved at the start of every model iteration, given initial or current distributions of the modelled variables. Subsequently, this value is converted to include a proxy for local function capacity supply, modelled as $S_{r,t}$.

$$S_{r,t} = \begin{cases} Q_{r,t-1} \; if \; AGE_r > AGECRIT \\ S_{r,t-1} SMOD_j \; if \; AGE_r \leq AGECRIT \end{cases} \tag{3}$$

So that local function capacity supply is modelled depending on:

— Modelled age of the housing stock *AGE* for raster *r*;

— An age criterium AGECRIT; and

— Modelled regional change in housing consumption, $SMOD_j$.

Here, the model only allows substantial changes in function capacity after a fixed amount of time, observed through *AGE* and *AGECRIT*. This is expected to simulate that investments to change the capacity of existing buildings are done periodically, thus causing inertia in function distributions. At the model start, ages are distributed randomly with values between 0 and 10. The minimum age to allow for changes in capacity supply is 10 years. Even without investments, housing supply may change slightly in order to reflect overarching changes in built-up space consumption that are modelled through LUISA's regional urban land consumption model.

The function capacity supply is used to convert previous population modifier estimates through:

$$D^{II}_{r,t} = D^{I}_{r,t} + \left(S_{r,t-1} - Q_{r,t-1}\right) \tag{4}$$

To ensure that only strictly non-negative values occur, thus avoiding technical difficulties in the later downscaling, this is converted so that:

$$D^{III}_{r,t} = \begin{cases} D^{II}_{r,t} if \; D^{II}_{r,t} \geq 0 \\ 0 \; if \; D^{II}_{r,t} < 0 \end{cases} \tag{5}$$

Subsequently, the total allocatable population in a region (*K*) is downscaled using $D^{III}_{r,t}$ through:

$$\Delta Q^{pressure}_{r,t} = K_{j,t} (\sum_{r \in j}^{n} D^{III}_{r,t})^{-1} L_r D^{III}_{r,t}, \tag{6}$$

where $\Delta Q^{pressure}_{r,t}$ is the local population pressure, i.e. a continuous function that describes the attractiveness of locations for allocating changes in population. Population pressure is subsequently used as a driving factor for the allocation of urban land-use changes. The land-use change model is discussed in greater detail in Section 3.2. Here we continue with an explanation of the population distribution routines.

3.1.2 Population distribution equations

After the allocation of discrete land uses, population is redistributed over space. The method to do so is very similar to the way population pressure is computed. However, some compromises have been done to ensure that enough inertia is maintained in the population allocation. The first results of an exercise meant to validate the current approach seem promising. The results of that exercise will be published separately when fit. For the population distribution exercise, Equation (2) has been fitted again on specific subsets of the calibration data, where in particular: 1) land use is classified as urban and travel time to the closest major urban cluster is up to 45 minutes (case $D_{r,t}^{urban}$); 2) land use is classified as urban, but travel time to the closest major urban cluster is longer than 45 minutes (case $D_{r,t}^{urban\,remote}$); and 3) land use is not urban, and there were already people living in the grid cell at hand, thus $Q_{r,t-1} > 0$ (case $D_{r,t}^{non-urban}$). Thus, population changes are only possible if a grid cell is urban, has just become urban, or is not urban and already had population at the modelling start.

A tentative population redistribution is computed by first defining:

$$D_{r,t}^{IV} = D_{r,t}^{urban} + D_{r,t}^{urban\,remote} + D_{r,t}^{non-urban} \tag{7}$$

The three cases of *D* computed are mutually exclusive per raster cell, so that the result for *D* is always zero for at least two of the functions. Subsequently, an extra step is included to ensure that the results of the function are strictly non-negative. This is relevant for the later downscaling of the regional allocatable population pool:

$$D_{r,t}^{V} = \begin{cases} D_{r,t}^{IV} if\ D_{r,t}^{IV} \geq 0 \\ 0\ if\ D_{r,t}^{IV} < 0 \end{cases} \tag{8}$$

After which tentative population distributions are computed as:

$$Q_{r,t}^{proto} = Q_{r,t-1} + K_j (\sum_{r \in j}^{n} D_{r,t}^{V})^{-1} L_r D_{r,t}^{V} \tag{9}$$

After the allocation of discrete land-use changes, $S_{r,t}$ is updated. Subsequently, the effect of existing supply is again accounted for as:

$$D_{r,t}^{V} = Q_{r,t}^{proto} + \left(Q_{r,t}^{proto} - S_{r,t}\right) \tag{10}$$

Finally, continuously-valued population distributions are computed as:

$$Q_{r,t}^{cont} = Q_{r,t-1} + K_j (\sum_{r \in j}^{n} D_{r,t}^{V})^{-1} L_r D_{r,t}^{V} \tag{11}$$

Lastly, values of *Q* are rounded down to discrete numbers and the remainder after rounding is distributed equally to the raster cells with the highest rounded values of *Q*, obtaining a definite value as $Q_{r,t} = f(Q_{r,t}^{cont})$, with *f()* indicating the function to discretely allocate activity levels.

3.2 Revision in modelling physical land-use changes

The way land-use changes are modelled has been changed substantially for the LUISA Territorial Reference Scenario 2017. The approach is now in line with the utility-based modelling framework that is proposed by Koomen et al. (Koomen et al. 2015). This framework has its theoretical foundation in bid-rent theory (Alonso 1964) and assumes that, in a competitive land market, land owners aim at maximising their utility, being land purchased/rented by the bidder offering the highest bid, i.e. the potential land-user able to derive the highest rent from land. Hence, an independent patch of land obtains the land-based activity or cover with the highest utility given: 1) general and location-specific factors that together set the opportunities and constraints for different land-based activities; 2) the regional demand for those particular land-based activities and related services; and 3) the restriction that all demands for these activities have to be met within the regions, which those demands are assigned to.

3.2.1 Computing utility

Land-based activities require investments with a long-term time horizon. Utility is therefore computed as the net present values (NPV) of that land cover at a specific location. NPV is a standard method used in capital budgeting to appraise long-term investments, by measuring discounted time series of expected cash inflows and outflows, while taking into account the time value of money. To be regarded as economically attractive, an investment should have a strictly non-negative NPV. When applied in a spatially-explicit way, NPV is calculated as:

$$NPV_r = -I + \sum_{t=y}^{n} \frac{R_{r,t} - C_t}{(1+d)^{t-y}} \tag{12}$$

In which:

- I are the initial investment costs (in €/ha, e.g. land clearing/demolition costs, building costs, acquiring agricultural machinery);
- $R_{r,t}$ are the annual gross revenues for raster cell *r* in year *t* (in €/ha, obtained from e.g. rental income, revenues from selling crops, subsidies);
- C_t are annual costs (in €/ha, e.g. maintenance costs, field operations in agriculture);
- *n* is the investment time-horizon (in years); and
- *d* is the discount rate.

Annual costs *C*, the time horizon, and discount rates are held fixed in the model regardless of location and modelling time. Initial investment costs do depend on the existing land cover in a specific location, as the existing physical makeup of a location may call for clearing or demolition operations. The investment costs include sunk costs of previous investments through a negative cost, which implies that existing land uses are not converted easily when another land cover yields a higher rational utility.

Revenues *R* are highly dependent on location. They are computed as:

$$R_{r,t} = \%SUIT_{r,t} * \max R_t \tag{13}$$

In which:

- $\%SUIT_{r,t}$ is the local suitability, or more accurately the percentage of maximum revenue to be obtained at a specific raster cell. It is defined as the probability that a particular land cover exists given a set of variable values, and is estimated through binomial logistic regression analyses (see Section 2.2.2);
- $\max R_t$ is the maximum revenues (in €/ha), i.e. the annual revenues that are assumed to be obtained from a particular land-use in case the local suitability is optimal (i.e. $\%SUIT_{r,t}$ = 100).

One important note to add here is that if a particular land cover transition is not allowed, the NPV of the target land cover defaults to an extremely negative value to prevent the forbidden transition from occurring. The rules that govern land transitions are defined within the LUISA framework.

Lastly, we implement the computed NPVs in the allocation algorithm, by employing a logit-type approach derived from discrete-choice theory (McFadden 1978). Discrete-choice theory aims to explain and predict the outcome of decision-making process of economic agents when choosing among mutually exclusive alternatives. The discrete choice model assigns probabilities for the different alternatives according to the utility of those alternatives in relation to the total utility of all alternatives. When applying this model in a spatially-explicit way, the probability of choosing among mutually exclusive land-based activities is computed as follows:

$$P_{r,i} = \frac{e^{\beta * U_{r,i}}}{\sum_{k=1}^{n} e^{\beta * U_{r,k}}}, \tag{14}$$

where:

- $X_{r,i}$ is the probability of alternative *i* being chosen in gridcell *r*,
- $U_{r,i}$ is the utility of alternative *i* in gridcell *r* (i.e. the NPV of that activity in that particular location),
- U_k is the utility of alternative *k,*
- *n* is a finite number of mutually exclusive alternatives for land-based activities, and
- β is a parameter to adjust the model sensitivity (typically 1 as default value).

By coupling together bid rent and discrete choice theories, it is possible to describe the land-market clearing process: a land seller compares alternative bids and sells the land parcel to the actor with the highest bid, thus maximising both revenue of sellers and utility of buyers (Martinez 1992).

In the proposed utility-based modelling approach, we intrinsically assume that urban development will typically outcompete agriculture, while within the agricultural sector intensive horticulture and permanent crop production will tend to outcompete arable farming and livestock production, given that optimal conditions are present for all land uses. Such a hierarchy in land markets has repeatedly been proposed in economic theory (Bakker et al. 2011; Fujita 1989). Heterogeneity in local conditions may, however, imply that these hierarchical relationships do not necessarily apply; for instance, in mountainous areas with poor accessibility and low crop yields, livestock production might be a more economically viable option than urban development or intensive horticulture.

Due to limited data availability, the NPV model has mainly been calibrated with data respective to the Netherlands, a country characterized by a competitive land market, well-defined property rights and high pressure on land. Annex 1 lists the data sources that have been adapted in the calculation of NPV for the different land-uses. We do not presume absolute NPVs for the Netherlands to be representative for the whole EU, as substantial differences surely exist among Member States in terms of, for example, labour costs or rental incomes. In fact, we do not aim at calculating the exact NPV ranges for each land use within a country, but rather to implement a local measure of the relative competitiveness of different land use alternatives. For that purpose, the land market in the Netherlands is deemed a reasonable proxy, so that the model is still able to mimic the assumed land market behaviour, even if not calibrated with data specific to that given country. Local specific conditions such as climate, landscape and accessibility are, nevertheless, taken into account in the computation of NPVs, since benefits are a function of local suitability, which in turn is estimated through country-specific logistic regression analysis (see Section 3.2.2). Furthermore, declining marginal utility of land-use conversion (e.g. due to oversupply of housing or agricultural commodities) is dealt with by imposing regional demands as constraints, according to the agricultural market projections given by the CAPRI model (Britz & Witzke 2008); see also Section 2.

3.2.2 Computing suitability

Suitability is obtained through binomial logistic regressions on observed land-cover patterns, so that data takes the value 1 if the fitted land cover is present in that raster cell, and 0 otherwise. The routines used here to obtain estimators computationally efficiently are tailor-made functions programmed by Bo Andrée (VU University Amsterdam). CORINE land cover data has been used to signal land cover presence. Tests have been done to try and fit suitability functions on CORINE land cover changes, but insufficient amounts of land cover changes are identified in that data source to reliably fit the necessary functions. Thus, except urban land cover, suitability functions for all land cover types were fitted using observations with the value 1 if the cover at hand was present in the grid cell, and 0 otherwise. Urban land cover suitability functions were fitted using land cover changes between 1990 and 2014 observed in a subset of GHSL data, where observations were not already discretely urban at the start. Thus, in the case of urban, a grid cell obtained the value 1 if a grid cell was not urban in 1990 and became discretely urban by 2014, and 0 if the cell was not discretely urban in 2014. Whether a grid cell with a specific amount of built-up cover is urban has been defined iteratively, for each country separately, by searching which threshold value would yield the largest degree of similarity between GHSL 2014 and urban cells as defined in the LUISA Base Map 2012.

3.3 Explicit modelling of agricultural and urban abandonment

Abandoned agricultural, urban and industrial land uses are modelled in LUISA together with their active counterparts. The modelling logic is based on hypothetical expectations of abandonment processes, as comprehensive data on the magnitude and spatial distribution of abandoned land uses in Europe is still unavailable. Substantial improvements have been made to the way agricultural and urban abandonment were modelled in LUISA for the Territorial Reference Scenario 2017.

3.3.1 Agricultural abandonment

Modelling agricultural land abandonment is a new challenge in LUISA. The conceptual approach, taken in the LUISA Territorial Reference Scenario 2017, refers to land that was previously used for crop or pasture but has no more farming functions, which basically means a total cessation of agricultural activities. In terms of modelling, abandonment is a temporary phenomenon that happens because the agricultural system is in transition towards an optimal spatial distribution throughout the simulation period and thus, will either remain as an abandoned class, or can be converted into another land cover in the following time-step, depending on the results of land cover utility optimization.

The most important novelties in the new approach are:

— the dynamic components when modelling agricultural land abandonment, mainly driven by population density and travel time[2] to the nearest town,

— the spatial resolution of the abandonment and risk map outputs (grid level, 100-metres resolution),

— the future projections of the agricultural land abandonment while competing with other land uses (urban, industry, forest, etc.) up to 2050.

— the number and the spatial scale of the variables combined to build a risk map of agricultural abandonment (a dynamic composite indicator). A more detailed description in section 4.2 and Annex 2.

([2]) The other factors, mainly biophysical and economic, remain stable through the simulation period.

This dynamic composite indicator is a crucial and new spatial component incorporated into the land allocation mechanism. It is constructed through the aggregation of a set of factors classified in the following three groups: 1) biophysical land suitability, 2) farm structure and economic agricultural viability, and 3) population and regional context. This aggregation of factor sets has been implemented by using a weighted linear addition method, where biophysical factors have been assigned the highest weights following the assumption that abandonment processes are most likely triggered initially in low-yield remote mountainous regions, and in regions with unfavourable soil and climate conditions for agriculture.

Regional agricultural demands are provided exogenously to LUISA by the CAPRI model[3]. As noted before, the Net Present Value approach now embedded in LUISA only holds for marginal changes in demand and supply; thus requiring regional checks on all economically relevant land covers. Therefore, also expectations on agricultural land abandonment have been imposed in the LUISA Territorial Reference Scenario 2017. Those agricultural land abandonment expectations are computed for three groups of agricultural abandonment related to arable crops, permanent crops and livestock, and are dynamically quantified into ranges of shares of abandoned land for each group in a Member State. The applied ranges of shares are taken as wide ranges around losses of Utilized Agricultural Area that are observed in CORINE Land Cover between 2000 and 2012, further supported by the reference values taken from the modelling exercises presented in Van der Zanden et al. (Van der Zanden et al. 2017).

3.3.2 Urban abandonment

Urban abandonment is now modelled through a number of variables and criteria. As a first step, conversion is only allowed if the grid cell is urban in the previous timestep, *and* meets the criteria specified in the variable 'AbandonableUrban'. That variable currently flags raster cells so that:

$$AbandonableUrban_{r,t} = \begin{cases} 1 \; if \; Q_{r,t-1} < 3 \; and \; Q_{r,t-1} < \frac{1}{4}\left(Q_{r,2012}\right) \; and \; ProbTouristic_{r,2012} = 0 \\ 0 \; else \end{cases} \tag{15}$$

If the abandonable urban criterium is not met, the NPV for abandonable urban land cover obtains an extremely low value, essentially disabling its potential abandonment.

Abandoned urban land is not given in the LUISA base map. This prohibits estimating a percentage revenue function empirically. Instead, urban abandonment suitability is obtained through number of people present in a grid cell, so that:

$$\%R_{r,t}^{aban\;urban} = (1 + Q_{i,t-1})^{-1} \tag{16}$$

This percentage revenue is applied alongside the other revenue factors in the NPV approach.

The changes brought to the computational definition of urban abandonment imply substantial restrictions to the urban abandonment playing field. Due to the nature of the discrete allocation mechanism used in LUISA, such restrictions had to be imposed at the regional level to ensure that the model does not assume abandonment of urban land

(3) CAPRI model produces projections at regional (NUTS 1 and NUTS 2) level for all MSs on the yields, production, and land area to be allocated for specific crops. In the LUISA Territorial Reference Scenario 2017, the regional land demand for agricultural activities will be specified within LUISA according to the CAPRI 2016 Baseline projections, thus being consistent with the EU Agricultural Outlook 2016-2026 (EC, 2016). Agricultural land classes will be simulated as agricultural production systems (arable farming, pastoral systems, mixed crop-livestock production) as an aggregation of CAPRI commodities, with the exception of the energy crops, which are already represented as one unique class in CAPRI.

when that is not available. Thus, expectations of regional levels of urban abandonment have had to be imposed in the model. This is done dynamically through:

$$0 \geq AbandonedUrban_{j,t} \leq \sum_{r \in j}^{n} AbandonableUrban_{r,t-1} \quad (17)$$

The resulting range is imposed as the acceptable amount of urban abandonment in each modelled time-step.

3.4 Dynamic demand model for residential land cover

In earlier LUISA iterations, the demand for residential land cover has been defined a-priori as a function of current land-use densities, trends of residential land consumption per household, and a trend of household size change. Together with the JRC's Composite INdicators group, the previously discussed residential demand model has been given an overhaul for the LUISA Territorial Reference Scenario 2017. To do so, factors that define changes in density of urban land use have been studied. Based on an extensive econometric analysis, the recent (2000-2010) densification of urban land use was found to be generally driven by the following factors:

— Metro / capital regions: A region, which is or belongs to a metropolitan area, boosts population density, especially if it contains the national capital city;

— In rural regions built-up is generally growing faster than population, resulting in population density decline.

— Total population, GDP per capita and employment growth, and accessibility, altogether representing important determinants of regional attractiveness (for people and investments) and encourage population density growth. Consequently, the pressure on land prices is likely to be high, leading to denser types of urban development.

— A large percentage of available land (*%AL*) impacts negatively population density growth and vice-versa. Regions with high *%AL* have no or few physical constraints to development. The pressure on land prices is likely to be low and extensive land developments are relatively inexpensive.

— Regions with already high density levels experience low population density growths due to existing or expected diseconomies of scale and/or technical, legal or economic constraints to further densification.

— Regions with low (or high) population density growth tend to be close to other regions with low (or high) population density growth.

— The evolution of a given region is not only affected by its own characteristics, but also by those of nearby regions, i.e. competition effect. As a result, a region may enjoy population density growth (due to the factors, listed above, e.g. GDP or employment growth) also at the expense of its neighbours.

The study of urban density over time and its drivers is not only interesting from an academic point of view but also relevant for policy support. It provides a snapshot of urban density across EU's regions, which is useful on its own. Furthermore, it shows long-run trends and uncovers underlying urbanization processes which help anticipating future developments to ultimately design more effective policies.

One of the results of this study is a dynamic function based partially on LUISA results from a previous time-step. For example, the average relative potential accessibility of regions, and the percentage of land available for urban expansion in a region are taken into account at each time-step to define changes in the residential densities in a region. Using projected regional population counts, this is subsequently converted into an estimated amount of residential land cover in the region. Subsequently a range of minimum and maximum values is defined based on that estimate. To ensure a modelling solution the following rules are, however, incorporated into those definitions:

- The minimum amount of residential land is the smallest result of either 90% of the expected residential land, or the summed amount of residential land in the region that is allowed according to the model's conversion rules;
- The maximum amount of residential land is the largest result of either the expected residential land, or the current amount of residential land.

The rules put in place here are necessary to accommodate land cover allocation with sometimes very restrictive conversion rules, such as the rules for urban abandonment. Without those rules, LUISA would sometimes halt when specific land-use conversions are enforced through the claims, but a sufficient amount of raster cells where the land-use conversions are allowed is unavailable.

4 Changes in inputs

There have been substantial changes to the inputs for the LUISA Territorial Reference Scenario 2017. Those are new base year values of the endogenous variables, thus reflecting an update in the base year; and various new exogenous variables. These are discussed in the following sections.

4.1 Base year endogenous values

In the update of the reference scenario, the base year has been updated from 2006 to 2012. Most importantly, the recently released 2012 CORINE land cover maps have been used to update the land cover maps imputed in the LUISA approach. Substantial edits have been done to those CORINE land cover maps, resulting in the LUISA Base Map 2012. The approach and workflow used to generate that base map is detailed in this section.

Population distribution maps have been updated as well from 2006 to 2011. To do so, a two-variable (principle and supporting) dasymetric downscaling method has been applied (Filipe Batista e Silva, Gallego, et al. 2013). Here, Geostat 2011 census population data has been downscaled from a 1x1km resolution to a 100x100m resolution using the LUISA base map as principle variable, and GHSL levels of built-up land as secondary variable. To ensure consistency between the 2012 land cover map and the original 2011 population data, 2012 regional population counts are downscaled on top of the 2011 population data using the population distribution methods outlined in Section 3.1.2 and 2012 land-use maps. This is done automatically within the model cycle.

4.1.1 Introducing the LUISA Base Map 2012

The CORINE Land Cover (CLC) map is characterized by a relatively coarse minimum mapping unit (MMU) of 25 hectares for all Land Use / Land Cover (LULC) categories, which is a limiting factor for applications requiring a finer detection of LULC patterns, such as the LUISA model. Another key limitation, particularly, for applications related to urban areas, population and economic activity, concerns the low thematic resolution for artificial LULC classes. The JRC has been engaged in developing and implementing a methodology to address the above-mentioned limitations of CLC, so to release an enhanced European LULC map labelled LUISA Base Map 2012. The following characteristics of the LUISA Base Map 2012 are important to mention:

<u>Spatial resolution</u>: Minimum mapping unit of ~5 hectares (1 ha for artificial surfaces and for all LULC classes in areas covered by the Urban Atlas dataset – European Functional Urban Areas (FUAs) above 50,000 inhabitants). Width of linear features of ~20 m. Cell size = 100 x 100 metres.

<u>Thematic resolution</u>: Same as in CLC 2012, with the following additional LULC classes: 410 - Inland wetlands (a union of 411 - Inland marshes and 412 - Peatbogs); 113 - Urban fabric low density (10-30% built-up); 114 - Urban fabric very low density and isolated (<10% built-up); 143 - Leisure and touristic built-up.

<u>Geographical coverage</u>: EU28 + EFTA + Western Balkans + Turkey, including Islands, Azores, Canary Islands, Madeira, Ceuta, and Melilla and excluding French overseas territories.

<u>Reference year</u>: 2012

<u>File format</u>: Unsigned 8-bit raster file (available as GeoTIFF and File GeoDatabase Raster Dataset)

As its name indicates, the LUISA Base Map 2012 (v1.0) is an enriched version of CLC 2012, with a significantly higher spatial resolution of 1 hectare for artificial LULC categories and at least 5 hectares for non-artificial ones. The methodology is based on the integration of LULC-relevant information from multiple CLC 2012- compatible geodata sources (particularly noteworthy are the Copernicus "High Resolution Layers").

4.1.2 Refining method used to create the LUISA Base Map 2012 base map

The LUISA Base Map 2012 (v1.0) is a composite map whereby information from multiple geodata sources has been integrated with the original CLC 2012 in a sequential order, following certain rules and criteria (see methodology section below). The process of refining CLC maps has been done before (Filipe Batista e Silva, Lavalle, et al. 2013). For the 2012 version, the refinement process has been extended, and new inputs have been added. Input data sources have been harvested from and selected based upon the compliance with following criteria:

— Compatibility with CLC's LULC nomenclature (LULC class definitions);

— Reference year 2012 +/- 2;

— Higher spatial resolution than CLC 2012;

— Pan-European geographical coverage;

— Preferably free, open and documented data.

The input data sources are listed below:

— CLC products: CLC 2012 v 18.5, CLC Changes 2006-2012 and CLC Changes 2000-2006;

— Copernicus high resolution (HR) layers 2012: HR layer Forest type + Tree cover density, HR layer Permanent water bodies, HR layer Wetlands;

— TomTom Multinet 2014: Land Use layer + Built-up layer;

— JRC's European Settlement Map (ESM) (10m version, aggregated to 100 m reference grid);

— Urban Atlas 2012: All available FUAs by January 2017 (655).

— OpenStreetMap (OSM) and TomTom Multinet 2014 as source of road network data.

The methodology consisted of a sequential integration of LULC information from multiple geodata sources into the original CLC 2012 map. At each step of the sequence, specific input data layers were used to recode the grid cells with which they overlaid spatially, following pre-established decision rules. Each step typically deals with the integration of one particular data input from the above mentioned sources. The order of the sequence is determined by the degree of spatial detail and accuracy of the data source at hand (the more detailed and accurate, the later in the sequence), or by other logical considerations (e.g. linear features are added later in the process due to less strict MMU). The entire workflow is shown in Table 4. The classes that have been added or refined are marked in Table 5.

Table 4. Workflow followed to produce the LUISA Base Map 2012

Step	Input data source	Description of procedure	Affected LULC classes
1	CLC change maps	Selected CLC change patches that were not included into CLC2012 map due to generalization rules are added.	All
2	Copernicus High resolution layers	A threshold of 50% is applied to the continuous pixel values (i.e. the respective class must cover the majority of pixel to be considered). A MMU of 5 contiguous pixels is applied.	31X, 41, 51X
3	TomTom Multinet 2014 – Land Use layer	Land use information from TomTom are added. A look-up table is used to establish the relationship between the TomTom and CLC nomenclatures. Vector polygons are rasterized using Maximum Combined Area criterion. Applied MMU = 1 pixel, i.e. individual pixels are included.	121, 122, 123, 124, 141, 142
4	European Settlement Map	First, a 100 m raster coincident with EEA reference grid is derived from the original 10 m version. Pixels overlapping non-residential artificial classes are excluded, as are the pixels under minimum building density threshold (empirically derived value of 5%). Applied MMU = 1 pixel, i.e. individual pixels are included.	11X
5	Urban Atlas 2012	Vector polygons are rasterized using Maximum Combined Area criterion; a decision matrix (original CLC class vs. urban atlas class) is used to establish the final classification of overlapping pixels. Applied MMU = 1 pixel, i.e. individual pixels are included.	All
6	European Settlement Map	The general 11X class 'urban fabric' is differentiated into 4 classes according to the underlying building density (based on ESM data) – 111 - dense, 112 - medium density, 113 - low density, 114 - very low density or scattered built-up.	11X
7	HR layer Permanent water bodies + OSM and TomTom Multinet 2014 – Road networks	Linear features such as rivers and mains roads are included. The inclusion of linear features obeys to less restrictive thresholds of within-pixel cover so to preserve as much as possible the spatial contiguity of these features (in view of their distinct function and importance in structuring and fragmenting the territory). However, within artificial areas, linear features are included only when the percentage covered is larger than that of building cover.	122, 51X
8	European Settlement Map	Built-up areas in the class 142 - Sport and leisure facilities are extracted as a separate class 143 - Leisure and touristic built-up.	142, 143
9	TomTom Multinet 2014 – Built-up layer	Areas pertaining to Local Administrative Units (LAU2) for which the amount of built-up is significantly lower than expected (given an empirical relationship between size of the population and urban fabric surface) are refined by adding built-up areas from the TomTom built-up layer. Added built-up areas are coded as 114 - very low density or isolated built-up.	114

4.2 Land-use classification

In LUISA, currently five main groups of land-use classes are modelled: urban, industry/commerce, agriculture, forest and natural vegetation. Most land-use classes are defined as they were in the Reference Scenario 2014 (Baranzelli et al. 2014). The only exception concerns agriculture. In previous model versions, agricultural classes were modelled based on their physical characteristics. In the LUISA Territorial Reference Scenario 2017, the classification has been changed considerably. It now indicates specific agricultural production systems and their associated crops, rather than their physical characteristics. The identified production systems are arable crops, mixed crop/livestock, livestock production, vineyards, fruit production, olive production, rice production and bioenergy crops[4]. The advantage of separating the various systems is that heterogeneity in their revenue equations can be better incorporated in the modelling approach. Table 5 lists the original LUISA Base Map 2012 classification and how those various classes were modelled in LUISA.

Table 5. Base map classification and LUISA modelling classification

Code	Base map label	LUISA model type
111 [a]	Urban fabric dense (>50% built-up)	Urban
112 [a]	Urban fabric medium density (30-50% built-up)	
113 [a]	Urban fabric low density (10-30% built-up)	
114 [a]	Urban fabric very low density and isolated (<10% built-up)	
143 [a]	Leisure and touristic built-up	
121	Industrial or commercial units	Industrial
211	Non-irrigated arable land	Arable crops
212	Permanently irrigated land	
241	Annual crops associated with permanent crops	Mixed crop livestock
242	Complex cultivation patterns	
243	Land principally occupied by agriculture	
231	Pastures	Livestock production
244	Agro-forestry areas	
311, 312, 313	Broad-leaved, coniferous, mixed forest	Forests Mature
324	Transitional woodland-shrub	Transitional woodland shrub
334	Burnt areas	
221	Vineyards	Vineyards
222	Fruit trees and berry plantations	Fruit production
223	Olive groves	Olive production
322	Moors and heathland	SHVA
323	Sclerophyllous vegetation	
321	Natural grasslands	Natural grassland
213	Rice fields	Rice production
122, 123, 124	Surface transport infrastructure, ports, airports	Not modelled
131, 132, 133	Mineral extraction, dump, construction sites	
141, 142	Green urban areas, sport and leisure facilities	
331, 332, 333, 335	Beaches, bare rocks, sparsely vegetated, glaciers or eternal snow	
410 [a], 421, 422	Water / land interchange	
511, 512, 521, 522, 523	Water surfaces	

([a]) indicates new or refined elements introduced in the LUISA Base Map 2012 process.

([4]) In LUISA, agricultural land can be either for: 1) production of food, feed and fiber (arable, mixed crop, permanent crops and livestock); or 2) production of energy (bioenergy crops). For the spatial modelling of dedicated energy crops, elements such as land demand, availability and suitability have been defined, as well as a policy-based categorization for sustainable cultivation. These elements drive the spatial allocation of the crops in LUISA's discrete allocation procedures, which simulate competition with all other land-uses (Perpiña Castillo et al. 2015; Perpiña Castillo et al. 2016).

4.3 Zoning for urban and population expectations

In previous LUISA releases (Baranzelli et al. 2014), urban land-use demand and population expectations were fed into the model as restrictions in a modified NUTS 2 level administrative boundary set. Where those NUTS 2 zones were too small (e.g. in Prague, London), NUTS 2 zones were aggregated into NUTS 1 zones. In the LUISA Territorial Reference Scenario 2017, urban land-use demand and population expectations are given as restrictions to the model using the latest release of NUTS 3 boundaries. This has the advantage of being completely consistent with the regional population change projections as computed by Eurostat in the context of the EC's Ageing Report (EC 2015).

For any LUISA reference scenario, the ultimate goal is to be completely consistent with a-priori given expectations. This sometimes leads to very high pressure in central urban areas and much lower pressure in neighbouring regions. In later exercises, the possibility to include interregional population spillovers may be investigated.

4.4 Exogenous variables

A number of exogenous variables have been added to the LUISA Territorial Reference Scenario 2017. Those are listed here below.

4.4.1 Fixed effects

The variables used in LUISA do not fully cover the whole range of factors that presumably govern the local attractiveness of a location for residents and investors. A previous study has found that, when controlling for existing population densities and potential accessibility, substantial temporally constant heterogeneity in municipal population density changes is unaccounted for (Jacobs-Crisioni & Koomen 2017). That heterogeneity is picked up through municipal fixed effects. For the LUISA platform, those fixed effects have been downscaled to the 100x100m level using inverse distance weighting interpolation, and used as a factor in the population pressure, distribution, and urban percentage revenue computations.

4.4.2 Relative potential accessibility

Potential accessibility is an important factor in the population and percentage revenue functions. However, calibration of absolute accessibility results is typically complicated, since the scaling in externally computed accessibility measures is not always consistent with the measures used in LUISA, due to differences in inputs. This is tackled by deriving relative accessibility levels, so that potential accessibility in the LUISA Territorial Reference Scenario 2017 is computed as $RA_{r,t} = \frac{A_{r,t}}{1} / \frac{1}{n} \sum_{r \in country} A_{r,2012}$. Thus, potential accessibility is in all cases related to average national accessibility levels in base year 2012. Linking it to averages from that base year ensures that improvements in accessibility levels are taken into account.

4.4.3 Yield maps

New agricultural crop yield maps have been introduced in the LUISA framework. Those maps indicate the degree to which an economically relevant harvest can be obtained from growing specific agricultural crops. Factors that potentially affect crop yields are soil conditions, water availability, and climatic conditions. Due to expected climate changes, those yields will likely change in the future. Maps that indicate crop yields have been generated by crop growth models run under the BioMa framework (Fumagalli & Ferrari 2016) on a relatively coarse geographical resolution for both the current state and assuming various scenarios of climate change foreseen by IPCC's Representative Concentration Pathways. For the presented reference scenario, current and future crop yields have been spatially interpolated to the 100x100m resolution. They have been used in the calibration of land-cover revenues, and are used as inputs in the LUISA Territorial Reference Scenario 2017. The various future scenarios have been combined by computing mean yield effects from changing crop yields in a variety of climate change scenarios.

4.4.4 Proximity to restaurants, touristic attractions and tourist lodging

Cities are increasingly considered as places for leisure. This may affect population distributions and percentage revenue equations. In the LUISA Territorial Reference Scenario 2017, currently present restaurants, tourist attractions and tourist lodging are used as factors in relevant equations. A reasonably comprehensive data source has been used to gather the relevant data. For now, only static presence is taken into account. In the future, these activities may be modelled dynamically alongside residential activity.

5 Changes in quality control and outputs

Substantial improvements have been done to the outputs of the model, both in terms of modelling flow and quality control. The most important changes are listed in this section.

5.1 Feedbacks to regional demand models

With the latest update, dynamic regional expectation models have been introduced for a number of land cover classes. These classes are urban, abandoned urban, and abandoned agricultural land cover. In all cases, regional expectations are based on prior population and land-use allocation results. The method to compute regional expectations for the abandoned land-use classes have already been discussed in previous Sections, leaving only urban demand to be explained here.

Urban demand is based on the amount of people in a region at moment *t*, and the expected density of people per residential pixel. Changes in residential density at the regional level have been identified by empirically estimated equations, as described in Section 3.4. Regional residential density and the percentage of land available for urban expansion are crucial variables in that equation. The percentage of available land is computed as:

$$\%AL_{j,t} = 1 - (BU_{j,t-1} / [AV_{j,t-1} - Natura_j - nda_j]) \tag{18}$$

So that the percentage of available land depends on:

— The sum of built-up land (*BU*);

— The amount of land available to local allocation (*AV*);

— Area of land in the region that is classified as Natura 2000 protected area (*Natura*) ;

— Area of land in the region classified as nationally designated protected area (*nda*).

Together with a number of additional variables, the result of *%AL* has a substantial impact on the modelled residential densities.

5.2 Agricultural abandonment risk maps

With the update of the reference scenario, much more attention has been dedicated to processes of agricultural abandonment. Maps of abandonment risk, remoteness and low population densities are crucial indicators for those processes. To facilitate easy reporting on agricultural abandonment, those factors are now stored as modelling outputs alongside the already existing LUISA outputs.

In particular, factors related to biophysical land suitability (first group), agri-economy and farm structure (second group) and geographic and demographic regional context (third group) are combined[5] to build a European dynamic map describing risk of agricultural land abandonment at grid level. Annex 2 shows each individual factor per group as an adaptation of different methodologies from the scientific literature (Benayas et al. 2007; Pointereau et al. 2008; Terres et al. 2014; Lasanta et al. 2016). Each criterion corresponds to a spatial thematic layer or statistical information (at NUTS 2/3 level) from different European data sources (Perpiña Castillo et al. n.d.).

In the first group, soil, climate and terrain criteria are used for classifying land according to its suitability for generic agricultural activity. The selected natural conditions are in line with the last EU Regulation No 1305/2013 (European Union, 2013) in its Annex III entitled "Biophysical criteria for delimitation of areas facing natural constraints" where criteria are setup to decide whether a territory is eligible for payments. In the second group, economic and structural agriculture information is used to reflect the stability,

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([5]) Weighted linear addition with the spatial layers belonging to the three groups.

viability and performing for preventing farm land abandonment at regional level (NUTS 3 level mostly). This information is mainly gathered from FADN[6] (Farm Accountancy Data Network) and DG EUROSTAT-FSS[7] (Farm Structure Survey) due to the availability and coverage of the data (EU-28). The last group endows the dynamic character of the method in LUISA at grid level. Two main variables are used to identify places where agricultural abandonment is more likely to occur: low population density areas and remote areas. Population densities below 50 inhabitants/km2 are considered as very low. The modelling mechanism counts for each cell the allocated residents within a surrounding kernel with an area of (approximately) 1 km2. On the other hand, remote areas are identified as those that are farther than a 60 minute drive by car from the closest town.

Naturally, the above outlined spatial components in the allocation of agricultural land abandonment play an important role only in raster cells where the current land use is an agricultural production system (modelled in LUISA). Those are arable farming (including rice), livestock grazing, mixed crop-livestock or permanent crops. Those agricultural production systems can be converted into "abandoned agricultural classes", namely: arable abandonment, livestock abandonment and permanent crops abandonment.

5.3 Firm checks on modelled population distribution

In previous LUISA scenarios (Baranzelli et al. 2014; F Batista e Silva et al. 2013), the base year input maps with population at the grid level were leading total population allocated, and regional projections were used to provide aggregate changes in regional population. Thus, if the summed grid level population was not consistent with the official regional-level statistics, this was not corrected in the projections. In each time step the projected regional population change was applied on the uncorrected base map. That approach has, however, led to a number of issues, most importantly - inconsistency with the projected data. To solve this drawback, the 2012 grid population map in the LUISA Territorial Reference Scenario 2017 has been made consistent with the regional population counts. A margin of error of 5 inhabitants per NUTS 3 regions is now accepted; any larger error causes the model to halt. The same firm checks on projection-allocation consistency have been imposed on modelling. This ensures nearly absolute compliance between allocation and projections.

Furthermore, in the LUISA Territorial Reference Scenario 2017, the allocation procedure also halts when population values below zero are detected. This is particularly useful to spot technical problems.

(6) The Farm Accountancy Data Network (FADN) is an instrument for evaluating the income of agricultural holdings and the impacts of the Common Agricultural Policy.

(7) Farm Structure Survey (FSS) covers all agricultural holdings with an UAA of at least one hectare or using market production as a threshold. The main purpose of FSS is to obtain reliable data, at regular timing intervals (two three years), on the structure of agricultural holdings in the European Union, in particular in land use, livestock and labour force. The legal basis for the FSS is regulation (EC) No1166/2008 of 19 November 2008.

6 Implementation improvements

A number of improvements have been done to the modelling code. Those improvements made it easier to develop, maintain and expand the LUISA platform.

6.1 Administrative boundary management

Discrepancies in administrative boundary versioning are a returning issue in the LUISA platform. To facilitate data processing with non-homogenized spatial units and identifiers, LUISA now supports a simple matching of data with their administrative units, as well as in-model conversion of data between administrative units. The new procedures to manage administrative data consist of three parts: 1) a general catalogue; 2) routines that prepare administrative boundaries necessary within the scope of a modelled region; and 3) routines that are tasked with aggregation, disaggregation and/or re-aggregation of data.

6.1.1 General boundary catalogue

The LUISA platform now contains an easily modifiable boundary catalogue where all potentially useful administrative boundaries are made available to the modelling system. At this point, this catalogue contains 22 generic boundary systems including all NUTS nomenclature zones from version 8 to version 10. Those generic systems are supplemented with a number of specialty units that have been defined especially for LUISA, for example – the LUISA run regions and the LUISA forest demand regions. This catalogue provides an automated way of loading boundary system shapefiles, after which all systems obtain a unique name. This is useful for consistency.

The catalogue also allows in-model appending of shapefiles through simple rules. Thus, when a loaded boundary system does not contain relevant zonal units, those can be appended to the first boundary system through the "add_layers" element in the catalogue. This is currently put to use to add Balkans-specific zone systems to the NUTS nomenclature, and to add territory without a municipality to the LAU2 zones.

6.1.2 Boundary preparation within modelling scope

Local allocation routines in LUISA are applied within the context of so-called run regions. Typically, one country is run independently. The exceptions are Luxembourg (run together with Belgium) and Serbia, Bosnia-Herzegovina and Montenegro (run together). As part of the modelling preparation process, now the entire LUISA boundary catalogue is available for data processing loading. Raster versions of these boundaries are created by setting geographic relations between LAU2 (base) zones and higher-level zones, rasterizing the LAU2 zones, and using the set relations to obtain rasters for all available administrative boundary sets. Through new GeoDMS routines, Queen's case neighbourhood relations are set for each administrative boundary set as well. This is useful for the future implementation of spatial econometrics methods in regional demand models.

6.1.3 Re-aggregation procedures

Often the data in LUISA needs to be aggregated or reorganized, as input data are often on a different resolution than needed in the model. In previous scenarios, such reorganization was done beforehand, but these operations can be time consuming and prone to inconsistency errors. In the LUISA Territorial Reference Scenario 2017, this has been tackled by the implementation of generalized aggregation routines. Those routines work through first disaggregating the relevant values to a 100x100m grid (either homogenously, or using a dasymetric approach), and then re-aggregating those values to the required level. Aggregation rules can be easily specified. This routine is generic in the sense that it works in simple cases such as no-conflict aggregation and disaggregation, but also in more complex cases of re-aggregation, when boundaries between administrative units do not overlap. This method allows for discrepancies in administrative boundaries between input data and the boundaries used in the model. Currently the re-aggregation routines are used for, amongst others, population data (input NUTS 3 v8, applied NUTS 3 v10, redistributed using population in 2012 as support variable) and urban demand (same inputs and application boundaries as population, but number of urban pixels in 2012 as support variable).

6.2 Local and regional factor definition management

In previous LUISA iterations, the management of dynamic factors was done relatively ad-hoc as a result of rapid developments to the model. Used factors and their definitions were hardcoded, together with modelling references to those factors. In the LUISA Territorial Reference Scenario 2017, the management of all factors has been centralized in the metadata container of the model. These changes in variable management make it less complicated to manage model inputs, reduce occurrence of errors, and ensure better modelling consistency.

Those factors are now separated into local and regional variables; local variables are additionally separated into static and dynamic factors. Dynamic factors are factors that depend, at least partially, on the results of previous modelling time-steps. Their definition can now be given in an even better structured manner. In addition, LUISA now automatically adds versions of the dynamic local factors that are based on interactions with specific variables, such as interactions with different population levels. The model also includes the automatic generation of average Queen's case neighbourhood values of all variables.

Currently, all regionally defined variables are considered dynamic. The definition of those variables, as well as their method of aggregation (sum or mean) can be given in simply changeable tables. Regional variables are available through aggregation from grid level to all administrative boundaries.

6.3 Dynamic demand model management

The LUISA Territorial Reference Scenario 2017 has introduced a number of dynamic regional demand and expectation models. Those are technically handled in the same way as local revenue and distribution models, i.e. through a process of variable definitions and separate parameter files with, for each run region, a set of parameters linked to the variables. The way, in which those dynamic demand models behave, can be controlled relatively easily; key parameters are given in a limited number of places.

6.4 Variable names in parameter files

Previous versions of LUISA used an intricate system of numerical codes to indicate variables. In the work summarised in this report, those numerical codes have been replaced with unique variable names. All local factors are given a unique name. In case of double naming in both the static and dynamic factors list, the prefix 'static_' is added to the static factor names. All neighbourhood-average variables obtain the prefix 'neigh_'. All interacted variables obtain the name '[interaction variable] _x_[interacted variable]'.

7 Concluding remarks

The LUISA modelling modules form one dimension in the LUISA platform, which is set up to provide past-to-future data and analyses to support assessing the impacts of territorial policies and trends. For future-oriented evaluation exercises, a well-defined reference scenario is crucial for enabling sensible assessments of policy impacts. In the LUISA platform, reference scenarios incorporate business-as-usual preferences, official projections, and the implications of European policies that are in force. Within the boundaries of that definition, there is an ongoing effort to augment the model's capacity to simulate often complex interactions amongst policies, trends and activity patterns. Exemplary for that development effort, this report details the substantial amount of changes done to the modelling modules in order to facilitate the LUISA Territorial Reference Scenario 2017. The most significant changes are:

— the introduction of a new base year, namely 2012;

— the extended refinement of base year land cover and, subsequently, population maps;

— updates to macro and meso-level expectations regarding demography, economy and agricultural markets, which in turn inform and restrict the model;

— changes in the way interactions between land function and land cover are modelled;

— the introduction of an utility-based approach in discrete land cover allocation;

— refinement of the way urban and agricultural abandonment is modelled; and

— the introduction of dynamic demand models for some land uses.

The ultimate goal is to arrive to a model that incorporates both functional and physical aspects of a wide range of human activities, and simulates changes in the spatial distributions of those aspects from a deductive logic. With:

— the introduction of an approach to model function/cover interactions generically, which is now used to allocate residents and residential land; and

— with the introduction of an utility-based approach in land-cover allocation,

the development of the LUISA modelling modules has taken a great leap towards this stated goal.

Still, a lot has to be done. The currently ongoing work within the LUISA platform to map various commercial and industrial land covers as well as the distribution of various economic activities will shortly enable the inclusion of other land functions in the function/cover framework. An exercise is underway to understand how well the current modelling modules can reproduce past changes in population and built-up land distribution. That validation exercise will allow quantification of how well the current model performs, and shed light on potential future improvements.

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List of abbreviations and definitions

ANC	Areas with Natural Constraints
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact model
CLC	CORINE Land Cover
EC	European Commission
ESM	European Settlement Map
EU	European Union
FUA	Functional Urban Area
GAEC	Good Agricultural and Environmental Conditions
GDP	Gross Domestic Product
GHG	Green House Gases
GHSL	Global Human Settlement Layer
JRC	Joint Research Centre
LAU	Local Administrative Units
LFA	Less Favoured Areas
LUISA	Land-Use based Integrated Sustainability Assessment model
MMU	Minimum Mapping Unit
NUTS	Nomenclature of territorial units for statistics
OSM	OpenStreetMap crowdsourced geodatabase
TEN-T	Trans-European Transport Networks

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Annex 1. Data sources for the calculation of NPV

Land-use	Conversion costs	Investment costs	Annual costs	Annual revenues	Discount rate	Investment time-horizon
Urban	(ANV 2013; CostHelper.com 2017)	(Turner & Townsend 2016)	(Ernst & Young 2010)	(GPG 2017)	(Cárdenas 2012)	(Cárdenas 2012)
Industrial	(Mackay et al. 2009; ANV 2013; CostHelper.com 2017)	(Turner & Townsend 2016)	(Ernst & Young 2010)	(David & Can 2014)	(Cárdenas 2012)	(Cárdenas 2012)
Arable crops	(Van der Hilst et al. 2010; CostHelper.Com 2017)	(Diogo et al. 2015; WUR 2017; Van der Hilst et al. 2010)	(Van der Hilst et al. 2010; Diogo et al. 2015; WUR 2017)	(Van der Hilst et al. 2010; Diogo et al. 2015; WUR 2017; EC 2016)	(Van der Hilst et al. 2010; Diogo et al. 2015)	(Van der Hilst et al. 2010; Diogo et al. 2015)
Mixed Crop-livestock	(Van der Hilst et al. 2010; CostHelper.Com 2017)	(Van der Hilst et al. 2010; Diogo et al. 2015; WUR 2017)	(Van der Hilst et al. 2010; Diogo et al. 2015; WUR 2017)	(Van der Hilst et al. 2010; Diogo et al. 2015; WUR 2017; EC 2016)	(Van der Hilst et al. 2010; Diogo et al. 2015)	(Van der Hilst et al. 2010; Diogo et al. 2015)
Livestock production	(Van der Hilst et al. 2010; CostHelper.Com 2017)	(Van der Hilst et al. 2010; Diogo et al. 2015)	(Van der Hilst et al. 2010; Diogo et al. 2015)	(Van der Hilst et al. 2010; Diogo et al. 2015; WUR 2017; EC 2016)	(Van der Hilst et al. 2010; Diogo et al. 2015)	(Van der Hilst et al. 2010; Diogo et al. 2015)
Forests	(Pearce 2001; CostHelper.Com 2017)	(Kovalčik 2011; Holopainen et al. 2010)	(Kovalčik 2011; Holopainen et al. 2010)	(Kovalčik 2011; Holopainen et al. 2010; Pearce 2001)	(Kovalčik 2011; Holopainen et al. 2010; Pearce 2001)	(Kovalčik 2011; Holopainen et al. 2010; Pearce 2001)
Transitional woodland shrub	(CostHelper.Com 2017)	-	-	(Koomen et al. 2015)	(Koomen et al. 2015)	(Koomen et al. 2015)
Vineyards	(Vasquez 2009; CostHelper.Com 2017)	(Wunderlich et al. 2015)	(Wunderlich et al. 2015)	(Wunderlich et al. 2015)	(Wunderlich et al. 2015; Diogo et al. 2015)	(Wunderlich et al. 2015; Diogo et al. 2015)
Fruit production	(CostHelper.Com 2017)	(Diogo et al. 2015; WUR 2017)	(Diogo et al. 2015; WUR 2017)	(Diogo et al. 2015; WUR 2017)	(Diogo et al. 2015)	(Diogo et al. 2015)
Olive production	(CostHelper.Com 2017)	(Vossen et al. 2007)	(Vossen et al. 2007)	(Vossen et al. 2007)	(Vossen et al. 2007; Diogo et al. 2015)	(Vossen et al. 2007; Diogo et al. 2015)
SHVA	(CostHelper.Com 2017)	-	-	(Koomen et al. 2015)	(Koomen et al. 2015)	(Koomen et al. 2015)

Bioenergy	(Diogo et al. 2012; Van der Hilst et al. 2010)	(Van der Hilst et al. 2010; Diogo et al. 2012)	(Van der Hilst et al. 2010; Diogo et al. 2012)	(Van der Hilst et al. 2010; Diogo et al. 2012)	(Van der Hilst et al. 2010; Diogo et al. 2012)	(Van der Hilst et al. 2010; Diogo et al. 2012)
Natural grassland	(CostHelper .Com 2017)	-	(Diogo et al. 2015; WUR 2017)	(Hönigová et al. 2012; Diogo et al. 2015)	(Van der Hilst et al. 2010; Diogo et al. 2015)	(Van der Hilst et al. 2010; Diogo et al. 2015)
Rice production	(Espino et al. 2010)	(Espino et al. 2010)	(Espino et al. 2010)	(Espino et al. 2010; EC 2016)	(Espino et al. 2010)	(Espino et al. 2010)

Annex 2. Factors driving agricultural land abandonment

Biophysical land suitability factors	Economic and structural agricultural factors	Population and regional context
Length of growing period	Age of farmers	Low population density
Organic matter	Farmer qualification	Remote areas
Soil texture	Farm size	
Root depth	Rent paid	
Soil pH	Rented UAA	
Salinity and sodic	Farm income	
Precipitation	Farm investment	
Soil drainage	Farm scheme (subsidies)	
Slope		

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