ISSN 1831-9424

European Commission

JRC TECHNICAL REPORT

The Demography-Economy-Land use interaction (DELi) model

A modular and integrated approach to regionalise socioeconomic projections

Curtale, R., Schiavone, M., Deuster, C.,
Alessandrini, A., Ueffing, P., Natale, F., Dijkstra, L.,
Batista E Silva, F.

2024

Joint Research Centre

EUR 31796 EN

Contact information
Name: Filipe Batista e Silva
Address: Via E. Fermi 2749, I - 21027 Ispra - TP 263
Email: filipe.batista@ec.europa.eu
Tel.: +39 0332 78 6470

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC136498

EUR 31796 EN

PDF ISBN 978-92-68-11115-4 ISSN 1831-9424 doi:10.2760/025883 KJ-NA-31-796-EN-N

Luxembourg: Publications Office of the European Union, 2024

Cover page illustration
The illustration in the cover page by © Daniel Bastos shows three people working to extract olive oil with a traditional European method. The arms represent the three main components of the DELi model: demography, economy and land use. This photo is also used here as an allegory and tribute to the virtues of proof of work, a necessary condition to create value.

How to cite this report: Curtale, R., Schiavone, M., Deuster, C., Alessandrini, A., Ueffing, P., Natale, F., Dijkstra, L. and Batista E Silva, F., *The Demography-Economy-Land use interaction (DELi) model*, Publications Office of the European Union, Luxembourg, 2024, doi:10.2760/025883, JRC136498.

Contents

Executive summary

Demographic and economic projections are valuable analytical tools for policy-making, but these are typically produced at country-level aggregations. In this report, we propose a new model that allows to regionalise socioeconomic and demographic projections from the country level to the NUTS3 regional level: the Demography-Economy-Land use interaction (DELi) model.

DELi relies on a set of linked equations that integrate empirically-derived assumptions regarding future regional growth, and estimate regional levels of GDP, employment, population and land use recursively and in an integrated manner, thus capturing demography-economy feedbacks as well as ongoing, expected or assumed processes of divergence and convergence across regions. The model can be configured to generate different regionalisation scenarios based on the same or different input country-level projections. DELi was built as a modular, flexible structure that allows to expand or substitute any of its components by alternative methodological approaches or assumptions.

To the best of our knowledge, a comprehensive, integrated, transparent and flexible framework to regionalise socioeconomic projections like DELi was still lacking for EU policy support. DELi can be used to quantify scenarios of regional socioeconomic trends for anticipatory policy support on domains with a strong regional or territorial dimension. Concretely, DELi can be used to explore scenarios of regional convergence or divergence, demographic change, land use policies, and their territorial implications at NUTS3 level. Examples of country level projections that could be regionalised using DELi are those regularly produced by the European Commission Ageing Reports or the Shared Socioeconomic Pathways (SSPs).

DELi is still an exploratory tool, with substantial room for future improvement. As it stands, the model presents some limitations such as the lack of sectoral detail, and limited degrees of freedom to deviate from given country-level projections. However, DELi offers already a valuable template to regionalise or even generate socio-economic projections and can be subject to further methodological improvement and expanded in its scope, functionality and applications.

Keywords

Regional projections, demography, economy, land use, NUTS3, downscaling, convergence

Acknowledgements

The authors would like to thank Luc Feyen, Ignazio Mongelli, Juan Carlos Ciscar Martinez and David Garcia Leon from the JRC, whose comments stimulated a critical thinking of the model that finally led to the current version.

Authors

Riccardo Curtale, Matteo Schiavone, Christoph Deuster, Alfredo Alessandrini, Philipp Ueffing, Fabrizio Natale, Lewis Dijkstra, Filipe Batista e Silva

1 Introduction

Demographic and economic projections and scenarios are valuable analytical tools for anticipatory policy support. For example, European Services such as Eurostat and the Directorate-General for Economic and Financial Affairs produce demographic and economic projections with a 2-4 year frequency, to assess the economic and budgetary impacts of an ageing population (DG ECFIN, 2021). However, such projections are typically only developed at the country level: a too coarse geographical aggregation for policy domains with a strong territorial dimension.

Assessing future pressures on the environment, socioeconomic risks to natural or other hazards, impacts and challenges associated with demographic and urbanisation trends, for example on the access to services and infrastructure, assessing territorial cohesion, are all areas requiring projections and/or scenarios at the sub-national level. Researchers and analysts often resolve this problem by *disaggregating*, or *downscaling*, socioeconomic projections from national to regional level, a procedure often also referred to as *regionalisation*. The most simple calculation rule for regionalising country-level socioeconomic projections is to keep observed regional shares constant throughout the projection period. Such an assumption, however, does not provide a realistic growth trajectory of the regions, as it simply replicates the status quo of a given observed moment in time by keeping the regional variability constant, and ignoring ongoing or expected processes of divergence/convergence of regions and their factors. Another issue arises when the regionalisation of demographic and economic projections are performed separately, without considering the interaction between economic development, demography and migration.

To fill the gap of sub-national socioeconomic projections and overcome the limitations of simplistic downscaling approaches, we propose a novel model that regionalises long-term, country-level demographic and economic projections in an integrated and recursive manner, while taking also into account a parsimonious set of well-established regional socioeconomic growth factors. The new model, coined DELi (Demography-Economy-Land use interaction), relies on a set of linked equations that integrate assumptions regarding future regional growth, and estimate regional levels of GDP, employment and population dynamically and recursively, while ensuring consistency with any given set of socioeconomic projections at the country level. The approach integrates functional causality between economic factors and human mobility based on the observed strong empirical association between regional net migration rates and GDP per capita levels. In addition, DELi estimates future land use demand for the residential and industrial, commercial and services sectors, also based on empirically derived equations.

DELi can be configured to generate different regionalisation scenarios based on the same or different input country-level projections. The herein described implementation of the model downscales country-level socioeconomic projections to the NUTS3 regions in the EU27 Member States. The model was built as a modular, flexible structure, which allows to expand or substitute any of its components by alternative methodological approaches or assumptions.

Previous work and what's new in DELi

DELi results from the consolidation of previous experience and attempts to obtain demographic and economic projections at the regional level. A first approach was proposed by Batista e Silva *et al.* (2016), who introduced the idea of downscaling demographic and economic projections from country level to the regional level (i.e., NUTS3) in an integrated and recursive manner. In this first implementation, GDP per capita and productivity growth were estimated simply via a linear convergence function. The two growth differentials would lead to employment growth or decline, leading to population change (adopting a "people follow jobs" assumption). Finally, GDP would be the result of the multiplication between previously estimated GDP per capita and total population. When calculating employment, population and GDP, all values at NTUS3 level would be rescaled to match the totals at country level from the source demographic and economic projections.

In subsequent work, Pontarollo *et al.* (2017) improved the empirical basis for the estimation of the GDP per capita and productivity growth rates, introducing a number of relevant factors of regional growth, including spatial spillovers, with empirical estimations based on data from the period 2000-2011. However, the remainder structure of the approach remained the same.

In 2023, a completely new implementation of the regionalisation approach was written in R, as self-contained model, and coined DELi. Similar to the earlier regionalisation approaches, DELi is NUTS3-based, runs on yearly iterations, with integrated population and economic dynamics, constrained by national level demographic and economic projections. The main novelties of DELi in relation to the previous implementations include:

- New empirical estimation for a longer time-frame (2000-2019);

- New modelling sequence for the yearly iterations, with population (projected first based on previous year GDP per capita), followed by estimation of employment, followed by estimation of GDP per capita and total GDP;
- Addition of a land use module, projecting future land use demand for the residential and industrial, commercial and services sectors, based on empirically derived equations.

On-going work is being carried out to assess whether national level constraints can be relaxed and how.

Applications

The DELi model can be used for a variety of applications, and generally as input to any forward-looking assessments requiring population and economic projections at sub-national level.

A first application of DELi was done in the context of the European Commission project on Territorial Risk Assessment on Climate Change in Europe (TRACE), whereby GDP from the European Commission Ageing Report (DG ECFIN, 2021) was regionalised from country level to NUTS3. In this case, though, population per NUTS3 was taken exogenously from the EUROPOP 2019 population projection, as per the specifications of the project.

Future applications of DELi will tend to use fully endogenous population projections at NUTS3 level, to assess how different regional convergence scenarios impact on territorial cohesion and urban-rural population and economic growth. Also, DELi may be used to regionalise alternative GDP and population projections, such as those tied to the Shared Socioeconomic Pathways (SSPs) (Riahi *et al.*, 2017).

Aim of the report

The aim of this report is to provide the conceptual framework of the DELi model, with a technical focus on its components. The most important aspects covered in the report are the structure of the model, the sequence of its components and their interlinkages. Where components of the model are based on econometric estimations, we provide the results of the best estimates available at the time of writing. However, empirical estimates can be updated as new official data are released. The structure of the model is not affected by the methodological choices of its components, so that the estimations could be updated in the future with revised approaches without invalidating the underlying broad structure. In parallel with the development of the DELi model, dedicated scientific research is conducted to validate and consolidate the methodology behind it. Where necessary, references to the specific articles are provided.

The core section of this report is chapter 2, with a detailed description of the structure of the model and its components. Chapter 3 lists the data sources used in the current implementation of DELi, and chapter 4 wraps-up the report with the main takeaways, limitations and future work.

2 Methodology

The DELi model is designed to generate sub-national estimates of population, employment, GDP, and land use for the EU Member States by downscaling or disaggregating a set of existing demographic and economic projections from national to NUTS3 level, a process also referred to as regionalisation. The downscaling approach implies that the sum of the NUTS3 outputs is identical to the source of projections used as input at the national level. DELi's outputs at NUTS3 level can be aggregated to higher level analysis (e.g., NUTS2, metro regions). Technically, DELi can be configured to relax the national constraints in different degrees, but this type of functionality requires further testing.

The regionalisation of projections can be generated based on a variety of assumptions and scenarios, which can be switched on or off, so that for the same exogenous country level projections, different regional distribution of population, GDP and land use can be obtained. Examples of these assumptions and scenarios relate to demography (e.g., migration might depend or not on economic growth) or economy (e.g., regional economic growth might increase depending on changes in education level or quality of institutions). To generate scenarios, different projection periods and assumptions can be explicitly specified when launching the model.

The DELi model is organised in 3 layers:

- **Input layer.** In the input layer, historical data at the NUTS3 level are harmonised and prepared for the core layer. This layer includes also the set of projections at higher levels (e.g., NUTS0) from exogenous source(s).
- **Core layer.** The core layer generates projections of population, employment, GDP and land use at NUTS3 level. The model is *dynamic* in the sense that variables are interlinked, so that what happens to population affects employment, GDP and land use, and vice-versa. The model is also *recursive*, because variables estimated in the previous yearly iterations (t-1) affect the estimation of variables in the current yearly iteration (t).
- **Output layer.** The output layer generates tables, charts and maps from the output of the core layer.

Figure 1 represents graphically the structure of the DELi model. The subsequent sub-sections of this chapter describe in more details the different layers and their components.

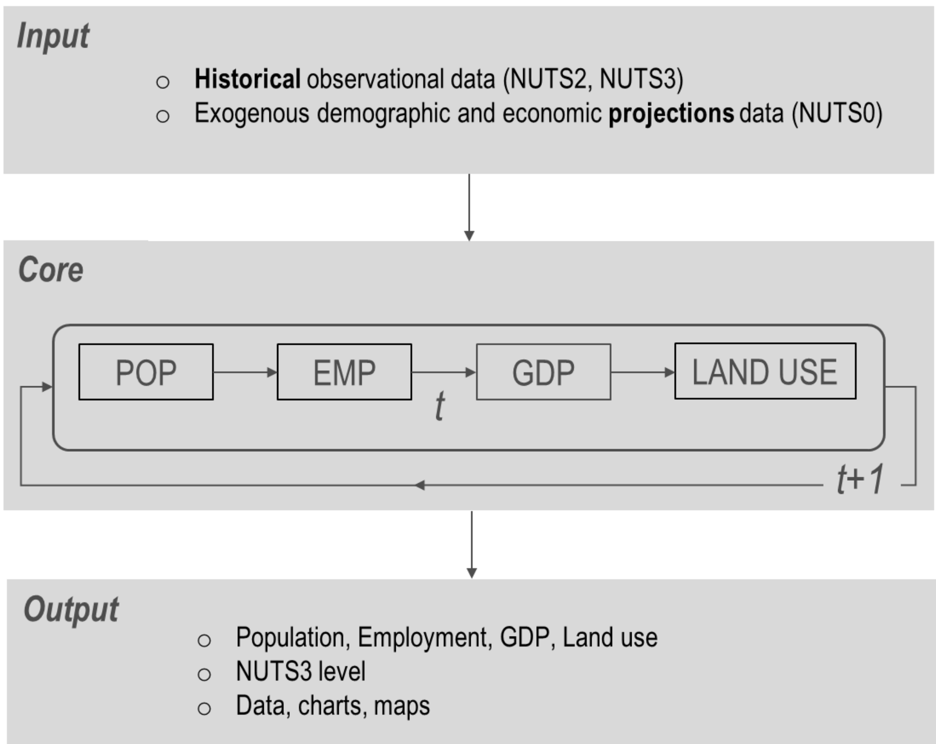

Figure 1. Structure of the DELi model

2.1 The input layer

The input layer is the starting point of the DELi model. It allows to import data from multiple sources, process and format them to create a unique dataset which will be passed to the core layer, where regional projections will be generated. Data with different granularity are imported, including historical data at NUTS3 level, and projected data at NUTS0 and NUTS3 level. In some cases (e.g., education level or quality of institution), data are available at NUTS2 level, in these cases, for every NUTS3 region we assume the value of the specific variable in the respective NUTS2 region.

Different data sources can be used for historical values and projections. The default options are ARDECO and Eurostat datasets for the historical data at NUTS3 level, and demographic and economic projections at NUTS0 level from Eurostat and DG ECFIN, respectively. These projections are published as part of The Ageing Report, with new editions usually every 3 years. More details about the data sources are provided in section 3.

2.2 The core layer

The core layer generates regional values of population, GDP, employment and land use, for every yearly time-step of the projection period. Within each time-step, the sequence of estimation is: population, employment, GDP, and land use. The new values are estimated recursively based on the most recent (historical or projected) available data.

2.2.1 Demographic module

Population is the first variable generated at every time-step. Age-specific data about population can be taken as an exogenous component from external data sources (e.g., Eurostat). Alternatively, population can be assumed to be endogenous, accounting for the effect of economic activity on sub-regional migration patterns.

2.2.1.1 Exogenous population

In DELi, population can be taken exogenously from a population projection available at NUTS3 level. For example, Eurostat has produced in the past demographic projections at the NUTS3 level and these can be plugged directly into DELi. For each year, the projected number of people by one-year age group for each NUTS3 region is aggregated to obtain the working age population (individuals aged 20-64 years). This exogenous population is used in the subsequent parts of the analysis as the demographic baseline scenario.

When using an exogenous source for the NUTS3 population, the demography-economy interaction is limited to unidirectional impact of population on employment and GDP. Because GDP and employment do not influence population in subsequent yearly iterations, DELi's output variables are therefore only partially endogenous. A scenario without full interaction between population and the economy, although less plausible, may still be used in applications requiring the regionalisation of the economic variables based on a mandated regional population projection.

2.2.1.2 Endogenous population

Population growth is the sum of natural growth (births minus deaths) and net migration (in-migrants minus out-migrants). In the fully-fledged DELi setup, population growth at the NUTS3 level is partially-endogenous. Natural growth is calculated by applying age and sex specific fertility and mortality trends at NUTS3 level obtained from Eurostat (e.g., population projection, or trend extrapolation). Instead, net migration is endogenised by accounting for the effect of economic factors as per an econometrically estimated function (equation 1).

$$nmr_r^a = \beta_0 + \beta_1 \cdot GDPpc_r + FE + \beta_2 \cdot \delta_{CapitalMetro} + \beta_3 \cdot \delta_{Metro} + \epsilon_r \qquad (1)$$

Where:

- a = five-year age group
- r = region at the NUTS3 level
- nmr = net migration rate
- $GDPpc$ = GDP per capita (in logarithmic terms)
- FE = country fixed effect

- $\delta_{CapitalMetro}$ = dummy variable for the NUTS3 belonging to the metro region of the capital city of a country
- δ_{Metro} = dummy variable for the NUTS3 belonging to a metro region
- β = coefficient of the parameters
- ϵ = error term

Box 1. Econometric estimation of net migration

For the econometric estimation of net migration, the number of net migrants are pooled for the years 2011-2019 for each five-year age group and NUTS3 region. The dependent variables for the estimation are obtained by dividing these pooled numbers of net migrants by the mid-period population in each corresponding NUTS3 region. The cross-sectional regression analysis provides the coefficients for the key independent variables of GDPpc (in logarithmic terms) and the set of country, capital and metro area fixed effects for all EU27 countries. The sample does not include the years that were most notably affected by the COVID-19 pandemic, to reduce the risk of bias in the estimation results for net migration patterns. Results of the estimation for each five-year age group are depicted in Table 1.

Table 1. Net migration parameter estimates by five-year age group (2011-2019)

Variable	Log(GDPpc)	S.E.	Capital	S.E.	Metro	S.E.	Country FE	Obs.	R^2
Net migration rate:									
Age 0-4	0.037**	0.007	0.021**	0.008	0.040**	0.004	Yes	1,169	0.631
Age 5-9	0.016	0.011	0.043**	0.012	0.002	0.009	Yes	1,169	0.274
Age 10-14	0.047**	0.009	0.035**	0.011	0.002	0.008	Yes	1,169	0.252
Age 15-19	0.091**	0.011	0.014	0.012	0.019*	0.009	Yes	1,169	0.352
Age 20-24	0.346**	0.024	-0.113**	0.027	0.054**	0.014	Yes	1,169	0.390
Age 25-29	0.188**	0.014	-0.003	0.018	0.004	0.011	Yes	1,169	0.409
Age 30-34	0.043**	0.013	0.054**	0.015	0.005	0.010	Yes	1,169	0.468
Age 35-39	0.012	0.011	0.063**	0.013	0.005	0.009	Yes	1,169	0.387
Age 40-44	0.053**	0.010	0.037**	0.010	0.000	0.009	Yes	1,169	0.329
Age 45-49	0.055**	0.009	0.005	0.009	0.000	0.008	Yes	1,169	0.263
Age 50-54	0.030**	0.008	0.013	0.008	-0.006	0.008	Yes	1,169	0.315
Age 55-59	0.009	0.008	0.005	0.008	-0.018*	0.008	Yes	1,169	0.274
Age 60-64	-0.016°	0.008	0.008	0.010	-0.025**	0.008	Yes	1,169	0.239
Age 65-69	-0.008	0.009	0.002	0.010	-0.028**	0.008	Yes	1,169	0.355
Age 70-74	0.044**	0.009	0.006	0.009	0.000	0.008	Yes	1,169	0.432
Age 75-79	0.032**	0.009	0.011	0.009	-0.003	0.009	Yes	1,169	0.446
Age >79	0.038**	0.012	0.016	0.013	-0.008	0.010	Yes	1,169	0.389

Signif. codes: **: $p < 0.01$, *: $p < 0.05$, °: $p < 0.1$

The results indicate that economic factors have a stronger effect on net migration patterns for certain age groups. For instance, the coefficient associated with the effect of GDPpc is larger for younger age groups, with a peak effect for the individuals aged 20-24.

The coefficients of the econometric estimation of net migration described in box.1 and the GDPpc projected by the model (obtained as described in section 2.2.3) are used to project the net migration rates and volumes for each five-year age group and NUTS3 region for the projection period, and effectively linking the demographic and economic modules of DELi. This may result in projected net migration figures that deviate substantially from other population projections, such as Eurostat's.

The NUTS3 projected net migration numbers as well as the Eurostat data on fertility and mortality are plugged into a demographic cohort component sub-module which breaks down the population into age and sex specific cohorts. The sub-module then projects the changes in each cohort over time by considering three demographic components: fertility, mortality, and migration.

In the final step, the projected endogenous NUTS3 population is rescaled to match the population size and structure of the input demographic projection at country level. The final, **rescaled** values of population for the projection period are obtained by applying equation 2:

$$Pop_{r,t}^{R} = \frac{Pop_{r,t}}{\sum_{r\in C} Pop_{r,t}} \cdot Pop_{C,t} \tag{2}$$

Where $Pop_{C,t}$ is the exogenous total Population at the country level of all the NUTS3 belonging to country C. The source for $Pop_{C,t}$ can be Eurostat's demographic projections or projections from other data sources. 'R' and 'r' denote "rescaled" and "NUTS3 regions", respectively.

2.2.2 Employment module

Employment is the second variable generated at every time-step. It is calculated based on the population in working age and projected employment rate, as shown in equation 3:

$$Emp_{r,t} = Pop_{wa\,(20-64),r,t} \cdot ER_{r,t} \tag{3}$$

Where:

- Pop_{wa} = working age population (20-64)
- ER = employment rate

Pop_{wa} is obtained from the demographic module (section 2.2.1). Historical levels of ER are available at NUTS2 level. The ER is the same for all the NUTS3 sub-regions belonging to the same NUTS2 region. Projections of ER are based on the last observed historical value and projected based on the estimated growth of ER at the NUTS0 level from the input demographic projection. Alternative regional projections of ER can be defined according to assumptions on convergence/divergence trends.

The final **rescaled** values of employment are obtained by applying equation 4:

$$Emp_{r,t}^{R} = \frac{Emp_{r,t}}{\sum_{r\in C} Emp_{r,t}} \cdot Emp_{C,t} \tag{4}$$

Where $Emp_{C,t}$ is the exogenous total Employment at the country level of all the regions belonging to country C, obtained from the input economic projection (e.g., DG ECFIN's Ageing Report).

2.2.3 Gross Domestic Product module

Gross Domestic Product (GDP) is the third variable generated at every time-step. The regional GDP is calculated based on expected population and GDP per capita (GDPpc), as shown in equation 5.

$$GDP_{r,t} = Pop_{r,t} \cdot GDPpc_{r,t} \tag{5}$$

Population for every region r is taken from the output of the demographic module (section 2.2.1). NUTS3 GDPpc is estimated based on an econometric model, where GDPpc growth depends on well-established factors such human capital, quality of institutions, and several geographical factors, including agglomeration effects. The econometric approach ca be described as an augmented growth equation (equation 6) following Barro *et al.* (1991), which estimates the impact of factors affecting average GDPpc growth, capturing the so-called beta convergence (i.e., regions with initially lower GDP per capita values are expected to record a faster growth) and additional idiosyncratic factors explaining the heterogeneity of GDPpc growth across regions.

$$\frac{1}{x} \cdot log\left(\frac{GDPpc_{r,t+x}}{GDPpc_{r,t}}\right) = \beta_1 \cdot \log(GDPpc_{r,t}) + \beta_2 \cdot log\big(GDPpc_{r,t}\big)^2 + \beta_3 \cdot \delta_{CapitalMetro} + \beta_4 \cdot Edu_{r,t} + \beta_5 \cdot highEQI_{r,t} + \beta_6 \cdot lowEQI_{r,t} + \beta_7 \cdot Agg_{r,t} + \beta_8 \cdot OADR_{r,t} + \beta_9 \cdot WAP_{r,t} + FE + \epsilon_{r,t+x} \tag{6}$$

Where:

- r = region at the NUTS3 level

- t = starting year
- $t + x$ = ending year
- $GDPpc$ = GDP per capita
- $\delta_{CapitalMetro}$ = dummy variable for the NUTS3 belonging to the metro region of the capital city of a country
- Edu = education level, measured as the share of population with a tertiary education (levels 5–8 of the international standard classification of education – ISCED).
- $HighEQI$ = regions with high values of European Quality of government Index (Charron *et al.* 2019)
- $LowEQI$ = regions with low values of European Quality of government Index
- Agg = agglomeration. Calculated as $POP_{r,t} \cdot \frac{Pop_{r,t}}{RBU_{r,t}}$, where RBU is residential built-up (see 2.2.4.1)
- $OADR$ = Old age dependency ratio. Calculated as $\frac{Pop(>65\ years\ old)_{r,t}}{Pop(20-64\ years\ old)_{r,t}}$
- WAP = Share of working age population. Calculated as $\frac{Pop(20-64\ years\ old)_{r,t}}{Pop_{r,t}}$
- FE = country fixed effect
- β = coefficient of the parameters
- ϵ = error term

Box 2. Econometric estimation of GDP per capita (GDPpc) growth

The starting and ending year of the estimation period for the factors affecting the average GDPpc growth can be chosen arbitrarily. The default is the period 2000-2019. 2000 is selected as starting year as the oldest with data available for all the EU27 countries. 2019 is selected as ending year as the most recent data which is not affected by the COVID-19 pandemic, to reduce the risk of bias. Results of the estimation are shown in Table 2.

Table 2. GDPpc parameters Estimates (2000-2019)

Variable	Est.	S.E.
Intercept	0.253***	0.055
Log(GDPpc)	-0.048***	0.011
Log(GDPpc)^2	0.002***	0.001
Capital metro	0.003**	0.001
Share of tertiary education	<0.001***	<0.001
HighEQI	0.002***	0.001
LowEQI	-0.002°	0.001
Old age dependency ratio (OADR)	-0.001**	<0.001
Working age population (WAP)	0.044**	0.016
Log(Agglomeration)	0.001**	<0.001
Country fixed effects	Yes	
Number of NUTS3-level sub-regions	1,161	
Adj. R^2	0.703	

Signif. codes: ***: p < 0.001, **: p < 0.01, *: p < 0.05, °: p < 0.1

The results are coherent with the expectations, indicating both convergence and divergence effects, or J-shaped GDPpc growth curve (faster growth for regions with lower starting values of GDPpc as well as for very high-GDPpc regions). Additionally, regions belonging to metropolitan areas of the capital regions, higher education, higher quality of institutions, higher agglomeration and higher share of population in working age are associated with higher GDPpc growth rates. A negative effect on GDPpc growth is given by a higher old age dependency ratio. A dedicated scientific article (Curtale *et al.* 2024) shows that the use of the presented methodology provides projections of GDP closer to real values compared to a fixed shares approach. The performance of the methodology improves by increasing the length of the estimation and projection periods.

The specific growth rate of GDPpc per region and year is applied to region specific GDPpc of the previous year. Future values of the independent variables are updated depending on changes in population and land use.

The final **rescaled** values of the GDP are obtained by applying equation 7:

$$GDP^R_{r,t} = \frac{GDP_{r,t}}{\sum_{r \in C} GDP_{r,t}} \cdot GDP_{C,t} \tag{7}$$

Where $GDP_{C,t}$ is the exogenous total GDP at the country level of all the regions belonging to country C, obtained from the input economic projection (e.g., DG ECFIN's Ageing Report).

2.2.4 Land Use module

Projections of demand for land use are estimated in the last module of DELi at every time-step. Land use can be classified in different categories according to the CORINE Land Cover (CLC) nomenclature (Feranec *et al.* 2016), including artificial surfaces, agricultural areas, forest and semi-natural areas, wetlands and water bodies. We model changes of two subcategories of the artificial surfaces: the residential built-up, which corresponds to categories 111 and 112 and built-up for Industry, Commerce and Services, corresponding to category 121 of the CLC nomenclature. The land use can be completely saturated in certain NUTS3 regions, meaning that there is no available land for development. For such regions, we maintain a constant land use over time. For the other NUTS3 regions, we estimate econometrically the future demand for residential built-up, and industry, commerce and services built up.

2.2.4.1 Residential built-up

Residential built-up is calculated as the product between the population, and the expected demand for residential built-up per capita, as shown in equation 8.

$$RBU_{r,t} = RBUpc_{r,t} * Pop_{r,t} \tag{8}$$

Where:

- RBU = Residential built-up
- $RBUpc$ = Residential built-up per capita

Future demand of residential built-up per capita (RBUpc) is estimated econometrically, based on a refined specification of the model presented in Schiavina *et al.* (2022), as shown in equation 9:

$$RBUpc_{r,t+1} = \beta_0 + \beta_1 \cdot RBUpc_{r,t} + \beta_2 \cdot \delta_{Urban} + \beta_3 \cdot \delta_{Rural} + \beta_4 \cdot \log(ALDpc) + \beta_4 \cdot \log(ALDpc)^2 + \epsilon_{r,t+1} \tag{9}$$

Where:

- δ_{Urban} = dummy variable for NUTS3 regions classified as 'predominantly urban' according to the urban-rural typology (Eurostat, 2018). Intermediate regions are used as the reference
- δ_{Rural} = dummy variable for NUTS3 classified as rural, reference is intermediate NUTS3 regions
- $ALDpc$ = Available land for development per capita
- ϵ = error term
- β = coefficient of the parameters

Box 3. Econometric estimation of residential built-up per capita (RBUpc)

We estimated the residential built-up per capita of 2018 based on the values of 2012, which are the only years with data availability.

Table 3. Residential built-up per capita (RBUpc) estimates (2012-2018)

Variable	Est.	S.E.
Intercept	0.001***	<0.001
RBUpc	0.982***	0.005
Urban regions	-0.001***	<0.001
Rural regions	0.001***	<0.001
Log(available land per capita)	0.007***	<0.001
Log(available land per capita)^2	-0.001***	<0.001
Number of sub-regions	1,161	
Adj R^2	0.988	

Signif. codes: ***: p < 0.001, **: p < 0.01, *: p < 0.05, °: p < 0.1

The results show a strong correlation of the residential built-up per capita in the two years, with a higher increase of residential built-up per capita correlated positively with rural regions and (non-linearly) with available land per capita, while negatively with urban regions.

2.2.4.2 Industry, commerce and services built-up

For the estimation of industry commerce and services (ICS) built-up, we follow an approach similar to that of residential built-up, but using employment instead of population as normalization factor. Therefore, projections of industry commerce and services built-up is obtained multiplying the total number of employees by the estimated ICS per employee, as shown in equation 10.

$$ICS_{r,t} = ICSpe_{r,t} * Emp_{r,t} \quad (10)$$

Where

- ICS = built-up for Industry, Commerce and Services
- $ICSpe$ = built-up for Industry, Commerce and Services per employee

The expected $ICSpe$ is obtained econometrically by estimating equation 11.

$$ICSpe_{r,t+1} = \beta_0 + \beta_1 \cdot ICSpe_{r,t} + \epsilon_{r,t+1} \quad (11)$$

Box 4. Econometric estimation of industry commerce and services per employee (ICSpe)

We estimated the built-up for industry, commerce and services per employee of 2018 based on the values of 2012, which are the only years with data availability.

Table 4. ICSpe estimates (2012-2018)

Variable	Est.	S.E.
Intercept	0.475***	<0.114
ICSpe	0.989***	0.004
Number of sub-regions	1,161	
Adj R^2	0.982	

Signif. codes: ***: p < 0.001, **: p < 0.01, *: p < 0.05, °: p < 0.1

ICSpe is function of its previous value and a constant term, the additional factors used to estimate RBUpc (Box 3) were not significant to estimate ICSpe, and were therefore not included.

2.2.4.3 Available land for development

The available land for development (ALD) in each region at the start of the simulation (t) corresponds to the total area of the region subtracted of the already developed land (all artificial surfaces present at year t), protected areas (Natura 2000), wetlands, water bodies and terrain with high slopes. ALD is then updated every time step by subtracting the difference between new and old built up, for both residential and industry, commerce and services, as shown in equation 12.

$$ALD_{r,t+1} = ALD_{r,t} - \left(RBU_{r,t+1} - RBU_{r,t}\right) - \left(ICS_{r,t+1} - ICS_{r,t}\right) \quad (12)$$

Where

- ALD = Available land for development
- RBU = Residential built-up
- ICS = built-up for Industry, Commerce and Services

At the end of the estimation of land use, which is the last for each time period *t*, the core layer continues the loop by estimating population, employment, GDP and land use for year *t+1*. The loop ends when reaching the last year of projections.

2.3 The output layer

The output layer stores the projections in a reusable format for analysis. The main output of the DELi model is a comprehensive table with NUTS3 projections of population, GDP, employment and land use for all the years defined in the projection period. The table is organised in a long-format, sorted by NUTS3 code and year. The files are exported as xlsx, csv and shapefile. Additional automatic generation of charts and maps can be integrated in future developments of the DELi model.

3 Data sources

The model can be applied to regionalise different sources of projections at the national level. DELi's 2023 release used socioeconomic projections at the national level provided by ECFIN in the 2021 Ageing Report (Directorate-General for Economic and Financial Affairs, 2021).

For the calibration, or estimation of the various equations, we used historical data at NUTS3 level based mostly on datasets from Eurostat and ARDECO[1]. ARDECO is the "Annual Regional Database of the European Commission" and its main data source is Eurostat complemented, where necessary, by other appropriate national and international sources. DELi's input database contains a set of long time-series variables and indicators for EU27 regions at various geographical scales (NUTS0, NUTS2, NUTS3, metro regions). For land use, data are based on LUISA[2] and GHSL[3]. Specific details and references are provided in Table 5.

Table 5. Data sources for historical data

Module	Variable	Granularity	Source
Demography	Population	NUTS3	JRC-ARDECO; Eurostat
Employment	Employment	NUTS3	JRC-ARDECO
	Employment rate	NUTS2	Eurostat
GDP	GDP	NUTS3	JRC-ARDECO
	Capital metro region	NUTS3	Eurostat
	Share of population with tertiary education	NUTS2	JRC-ARDECO
	Agglomeration	NUTS3	JRC
	European Quality of Institution	NUTS0/NUTS2	University of Gothenburg[4] (Charron *et al.* 2019)
	Old Age Dependency Ratio	NUTS3	Calculated based on Eurostat data
	Working Age Population	NUTS3	Calculated based on Eurostat data
Land use	Residential built-up	NUTS3	JRC (Pigaiani and Batista e Silva 2021)
	Industry, Commerce and Services built-up	NUTS3	JRC (Pigaiani and Batista e Silva 2021)
	Available land for development	NUTS3	JRC
	Urban region	NUTS3	Eurostat
	Rural region	NUTS3	Eurostat

[1] https://urban.jrc.ec.europa.eu/ardeco?lng=en
[2] https://data.jrc.ec.europa.eu/collection/luisa#datasets
[3] https://ghsl.jrc.ec.europa.eu/
[4] https://www.gu.se/en/quality-government

Table 6. Data sources for projections (2023 release of DELi)

Module	**Variable**	**Granularity**	**Source**
Demography	Population	NUTS0 / NUTS3	Eurostat-EUROPOP19
	Age specific fertility rates	NUTS3	Eurostat-EUROPOP19
	Age specific probabilities of dying	NUTS3	Eurostat-EUROPOP19
Employment	Number of employees	NUTS0	ECFIN (2021 Ageing report)
GDP	GDP	NUTS0	ECFIN (2021 Ageing report)

4 Discussion and future avenues

In this report we present a new, modular framework to regionalise demographic and economic projections from national to the NUTS3 regional level – the Demography-Economy-Land use interaction (DELi) model. DELi downscales population, employment and GDP in an integrated and recursive manner, so that population dynamics influence economic growth and vice-versa, in yearly iterations. GDP growth is determined by empirically derived regional factors including demographics, human capital, and geographical factors, including agglomeration. Population growth is a function of natural growth and net migration. Net migration is influenced by regional levels of GDP per capita in the previous yearly iteration. Residential and industrial, commercial and services land uses are projected for each year to meet the socioeconomic demand. In turn, agglomeration is in itself a function of population and land use dynamics, impacting on future GDP per capita growth.

The relationships currently encoded in DELi are according to expectations and coherent with the literature on regional economic growth and migration, but using parsimonious specifications. It has been demonstrated that DELi is a stronger predictor of future regional GDP growth than null or quasi-null models such as assuming non-changing regional GDP or GDP per capita shares (Curtale *et al.* 2024).

DELi is structured in four different modules: demography, employment, GDP and land use. Although interlinked, each module is sufficiently standalone, requiring only a set of inputs and producing a set outputs. As such, the modelling assumptions within each module can be updated or improved without affecting the overall DELi workflow.

To the best of our knowledge, a comprehensive, integrated, transparent and flexible framework to regionalise socioeconomic projections like DELi was still lacking for EU policy support. DELi can be used to generate regional scenarios for the chief socioeconomic variables, consistently with exogenous country-level projections, thus providing socioeconomic baselines for anticipatory policy support. Concretely, DELi can be used to explore scenarios of regional convergence or divergence, demographic change, land use policies, and their territorial implications at NUTS3 level.

DELi is still an exploratory tool, with substantial room for future improvement. As it stands, the model presents some limitations: 1) the lack of detailed sectoral data constrains the flexibility of the model to react to changes in the regional economic structure, 2) the absence of variables including technological progress does not allow a detailed projection of the labour productivity and its impact on employment, 3) it was calibrated on observed data between 2000 and 2019, thus it is best used for projections for an equivalent period of 20 years, 4) it cannot predict shocks and has limited capacity to assess how the society and the economy reacts to shocks. Other model types, such as general-equilibrium model, are arguably more suited for policy impact assessment and/or assess impacts of shocks, like the Rhomolo model (Brandsma *et al.* 2015). Finally, 5) DELi is currently constrained by national level demographic and economic projections. This means that the growth of one region is made at the expense of another region, making DELi an implausible zero-sum game.

With regard to the latter limitation, future work will test whether national level constraints can be relaxed and how. Currently, GDP is obtained by multiplying population with econometrically estimated regional GDP per capita, and then rescaling the regional GDP to match the exogenously projected GDP totals per country. For population and employment, rescaling is also applied at the end of each yearly iteration. For GDP, an alternative is to use national growth rates from exogenous economic projections and sum regional growth differentials estimated by DELi. This would allow for some deviation from the exogenous GDP projections, and could be useful to assess whether regional growth heterogeneity (e.g., scenarios of higher and lower convergence) impact on aggregate, national outcomes. The relaxation could also be attained by using EU-level totals or growth rates instead of national ones, allowing for cross-border population and economic flows. And finally, the relaxation of national level constraints on GDP projections from exogenous sources opens up opportunities for exploring alternative approaches to economic forecasting, such as considering the role of savings, capital accumulation/formation, monetary and economic freedoms (Ammous 2023) on aggregate economic growth.

Projecting future economic growth at national level is beyond DELi's primary scope, and so it is unlikely that DELi will develop in this direction to avoid duplication with other Commission forecasting tools and models. But, because economic outcomes are more likely the result of the interaction between both top-down and bottom-up processes, rather than just one or the other, exploring ways to relax national constraints may remain an interesting endeavour to explore.

Although an exploratory tool, DELi offers already a valuable template to regionalise or even generate socio-economic projections and can be subject to further methodological improvement and expanded in its scope, functionality and applications. While DELi will continue evolving, the layout presented in this report will remain a key reference for applications in the coming years.

References

Ammous, S. (2023) Principles of Economics. The Saif House. 412p.

Barro, R. J., Sala-I-Martin, X., Blanchard, O. J., & Hall, R. E. (1991). Convergence Across States and Regions. *Brookings Papers on Economic Activity*, *1991*(1), 107. https://doi.org/10.2307/2534639

Batista e Silva, F., Dijkstra, L., Martinez, P. V., & Lavalle, C. (2016). *Regionalisation of demographic and economic projections: Trends and convergence scenarios from 2015 to 2060*. European Commission Joint Research Centre Science for Policy Report. Publications Office of the European Union. https://doi.org/10.2788/458769

Brandsma, A., Kancs, D., Monfort, P., & Rillaers, A. (2015). RHOMOLO: A dynamic spatial general equilibrium model for assessing the impact of cohesion policy. *Papers in Regional Science*, *94*, S197–S221. https://doi.org/10.1111/pirs.12162

Charron, N., Lapuente, V., & Annoni, P. (2019). Measuring quality of government in EU regions across space and time. *Papers in Regional Science*, *98*(5), 1925–1953. https://doi.org/10.1111/pirs.12437

Curtale, R., Schiavone, M. & Batista e Silva, F. (2024) A novel approach to regionalize country level GDP projections in the EU. Forthcoming.

Directorate-General for Economic and Financial Affairs. (2021). The 2021 Ageing Report: Economic and Budgetary Projections for the EU Member States (2019-2070). In *European Commission* (Vol. 2). Publications Office of the European Union. https://doi.org/10.2765/84455

Eurostat. (2018). Methodological manual on territorial typologies : 2018 edition. Publications Office of the European Union. https://doi.org/10.2785/930137

Feranec, J., Hazeu, G., Kosztra, B., & Arnold, S. (2016). CORINE land cover nomenclature. European Landscape Dynamics: CORINE Land Cover Data; Feranec, J., Soukup, T., Hazeu, G., Jaffrain, G., Eds, 17-25.

Pigaiani, C. & Batista E Silva, F. (2021), The LUISA Base Map 2018. European Commission Joint Research Centre Technical Report. Publications Office of the European Union. https://doi.org/10.2760/503006.

Pontarollo, N., Batista e Silva, F., & Jacobs, C. (2017). The determinants of regional growth in Europe: assessing the roles of spatial spillovers and agglomeration. *57th ERSA Congresss, Groningen.*

Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J. C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., … Tavoni, M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change*, 42, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Schiavina, M., Melchiorri, M., Corbane, C., Freire, S., Batista e Silva, F. (2022) Built-up areas are expanding faster than population growth: regional patterns and trajectories in Europe. Journal of Land Use Science, 17(1), 591-608. https://doi.org/10.1080/1747423X.2022.2055184

List of abbreviations and definitions

ALD	Available land for development
DELi	Demography, Economy, Land use interaction
ER	Employment rate
GDP	Gross Domestic Product
ICS	Industry, Commerce and Services
NUTS	Nomenclature of territorial units for statistics
pc	per capita
pe	per employee
POP	Population
RBU	Residential Built-up

List of boxes

List of figures

List of tables

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

Open data from the EU

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

Science for policy

The Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society

EU Science Hub
joint-research-centre.ec.europa.eu

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

@eu_science

Publications Office of the European Union