

A Conceptual Framework for Dynamic Modeling of Sustainable Development for Local Government in Latvia

Arnīs Lektauers, Jekabs Trusins, Inese Trusina

RTU Spatial and Regional Development Research Center
Riga Technical University
Pulka 3/3-112, LV-1007, Riga, Latvia
Phone: +371 22004464
arnis@itl.rtu.lv, trusins@gmail.com, inesetrusina@gmail.com

ABSTRACT: *This article presents a concept and theoretical specification for a system dynamics based model of sustainable development for local government of Kuldīga municipality in Kurzeme region, Latvia. Although Latvia aspires to the principles of sustainable development, there exists a relatively small number of theoretical studies and practical results in the area of simulation modeling of sustainable development. Therefore the proposed framework presents a novel approach in the context of spatial and regional planning in Latvia. The modeling framework is based on the concept of sustainable regional development as an unending process defined neither by fixed goals nor by specific means of achieving them. A sustainable region demands a mutual balance among economic, social, political and naturally environmental development. The dynamic modeling framework is considered as a useful tool in assisting decision-makers in development planning allowing to evaluate alternative scenarios and planning options.*

Keywords: Sustainable development, system dynamics

1 INTRODUCTION

Latvia aspires to the principles of sustainable development, which have been included in the Law of Regional Development (01.01.2009) and in the Latvia's Sustainable Development Strategy 2030 (Latvija2030, 2010). Although Latvia aspires to the principles of sustainable development, there exists a relatively small number of theoretical studies and practical results in the area of simulation modeling of sustainable development at national, regional and local levels. Sustainable spatial planning at regional level is very important for Latvia due to increasing disparities between territories and settlements. Contemporary the entry in the European Union is now facing with new challenges: growing globalization and finding the place of Latvia within the European spatial development framework, represented by European Spatial Development Perspective.

This paper describes a conceptual framework for dynamic modeling of sustainable development developed as part of the project "Establishment of the Center for Spatial and Regional Developments Research in Kurzeme" to assist local government in Latvia. This is a multi-disciplinary collaborative project with an overall objective to strengthen cooperation between education establishments, R&D institutions and municipalities at local and international level for promotion of spatial development and regional innovation activities, resulting in increased jobs, revenues and enhanced capacity of municipalities in supporting innovation and sustainable development.

The research project is centered on the Kuldiga municipality of the Kurzeme region, Latvia (Figure 1). Kurzeme Region is one of five planning regions in Latvia, situated in the western part of Latvia, at the shores of the Baltic Sea and Gulf of Riga. The Kuldiga municipality was formed in 2009 by merging 13 parishes and Kuldiga town the administrative centre being Kuldiga. The municipality has a total land area of 1756,7 km², a population of 27 272 people. According to the future vision, Kuldiga municipality should develop as a center of regional importance and there should be located specific institutions and services for whole region.

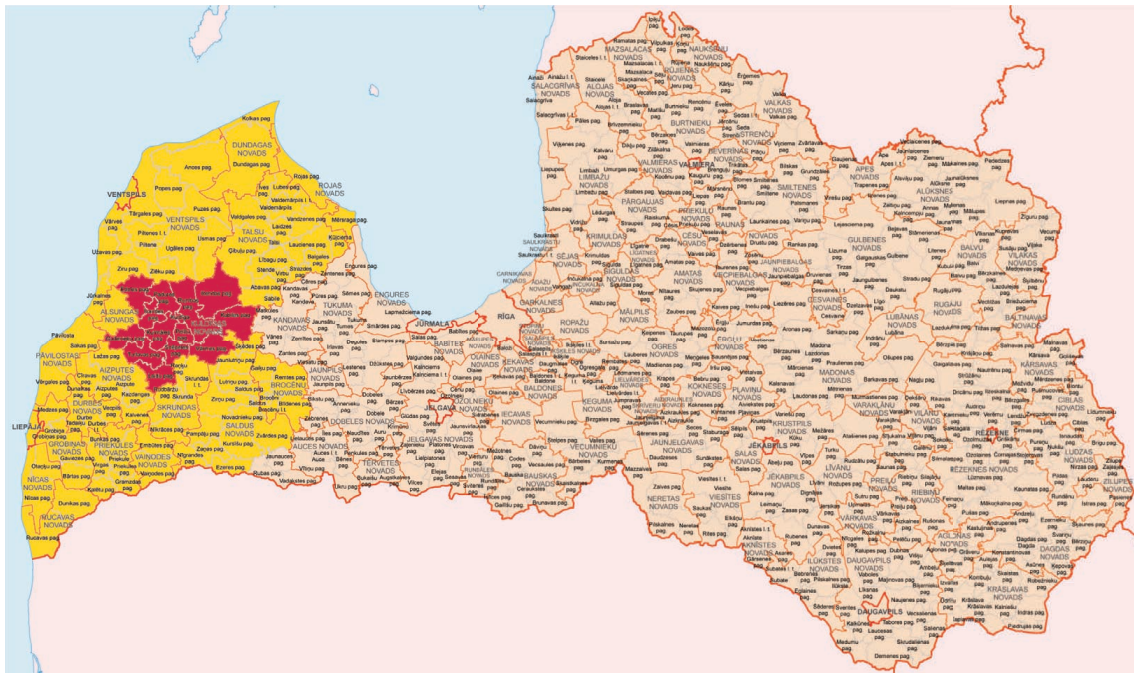


Figure 1: The map of Latvia: location of Kurzeme region (yellow color) and Kuldiga municipality (red color)

The goal of the presented framework is to provide a technical decision support tool for stakeholders and decision-makers in territorial management planning allowing to evaluate alternative scenarios and planning options. The hypothesis of the research is that the quality of life and sustainability are the primary goals and criteria of sustainable development.

The paper is organized as follows: Section 2 provides a description of the methodology used in model development. The conceptual model and a detailed description of the framework structure and implementation are presented in Section 3. The preliminary simulation results and concluding comments are presented in Sections 4 and 5.

2 METHODOLOGY

The use of systems-thinking approach by involving the creation of a system dynamics model has been given increasing attention in recent years. This paper applies system dynamics techniques to formulate, simulate, calibrate and validate the sustainable development of Kuldiga municipality. This study uses the concepts and procedures of system analysis to develop and explore dynamics of sustainable development. To simplify complex real-world phenomena and the inter-relations among the various components in the development planning process, a model, as a real-world abstraction, is used. The model development process includes several iterative steps:

1. Identification of systems and components:
 - (a) Identification of indicators and orientors.
2. Identification of relationships and interactions.
3. Development of conceptual model.
4. Model implementation.
5. Model verification, calibration, validation and approbation for Kuldiga municipality.

2.1 Concept of Sustainable Development

The notion of sustainable development is originated from the term *Limits to Growth* (Owens and Cowell, 1994), which is derived from a report called *Club of Rome* published in 1972 according to Forrester's system dynamics modelling on urban and globe problems in his books *Urban Dynamics* (Forrester, 1969) and *World Dynamics* (Forrester, 1971). The concept of sustainable development has recently been discussed in different studies, and many attempts have been made to define sustainable development as a practical approach (Huser et al., 2009; Mayerthaler et al., 2009).

The European Council in its Sustainable Development Strategy (European Council, 2006) has defined that the overall aim of sustainable development strategy is to identify and develop actions to enable to achieve continuous improvement of quality of life both for current and for future generations, through the creation of sustainable communities able to manage and use resources efficiently and to tap the ecological and social innovation potential of the economy, ensuring prosperity, environmental protection and social cohesion. A sustainable region demands a mutual balance among economic, social, cultural, political and naturally environmental development. Joining together the four dimensions of environment, economy, politics and society, sustainable development refers to a process in which the economy, environment, politics and ecosystem of a region change in harmony, and in a way that will improve over time. Sustainable development must be seen as an unending process defined neither by fixed goals nor the specific means of achieving them (Hjorth and Bagheri, 2006).

Sustainable development can be mathematically characterized by two main constituents: security of population (I_{sec}) and quality of their life (I_{ql}) (Zgurovsky, 2009). A generalized sustainable development measure (sustainability) I_{sd} may be presented as a modulus of a complex number:

$$I_{sd} = |jI_{sec} + I_{ql}| = \sqrt{I_{sec}^2 + I_{ql}^2}. \quad (1)$$

The quality of life component of sustainable development can be defined as follows:

$$I_{ql} = \sqrt{I_{ec}^2 + I_e^2 + I_s^2} \cdot \cos\alpha, \quad (2)$$

where I_{ec} is economic dimension (economical cohesion);

I_e is ecological dimension (environmental balance);

I_s is social / institutional dimension (social cohesion);

$\cos\alpha = \frac{I_{ec}+I_e+I_s}{\sqrt{3(I_{ec}^2+I_e^2+I_s^2)}}$ is degree of harmonization.

2.2 Identification of Systems and Components

All of the components in the system, which are related to sustainable development, should be considered. A key challenge to developing a sustainable development model is deciding on the scope of the system to study and prioritizing the issues or questions to address.

2.2.1 Indicators and Orientors

In order to select key components to represent system behavior, this study examines analytical indicators, which are used in the previous studies dealing with sustainable development (Meadows, 1998; Bossel, 1999; Ministry of Environment and Energy, National Environmental Research Institute, 2001). Indicators are quantitative or qualitative measurements of the state of something that is important to us, like our body temperature, heart beat or blood pressure (Bossel, 1999). The choice of indicators is a critical determinant of the behavior of a sustainable system, poorly chosen indicators can cause serious malfunctions (Meadows, 1998). Orientors are labels for certain categories of concerns or interests (Bossel, 1999). Different systems may have the same orientors, but would have different corresponding indicators.

In this study, 33 key indicators based on expert discussions and workshops are chosen grouped into three subsystems (human system, support system, natural system) and categorized by 7 composite indicators or basic orientors proposed by Bossel (Bossel, 1998). The seven basic orientors are aggregated into three dimensions (Zgurovsky, 2009): social cohesion, economical cohesion, environmental balance. From the basic orientors and dimensions the main indicators - the quality of life and sustainability are calculated.

2.3 System Components

The top-down model should cover a broad range of issues that a region faces on the path to sustainable development, for example, demographic shifts, environmental degradation, education, healthcare, economic growth. Summarizing these key issues the model framework distinguishes four main systems containing six aggregated sub-components or sectors. The proposed model structure is based on well accepted works in the field (Bossel, 1998, 1999):

1. **Human system:** the human system represents the social dimension of sustainable development. The sustainable development concept requires a strong human basis, such as people capability of acting effectively, accordingly, efforts must focus on promoting education, abilities, and opportunities for each individual as well as for the community. The human system has three components:

- (a) The **Individual development** sector.
 - (b) The **Social system** sector.
 - (c) The **Government** sector.
2. **Support system**: the support system implements the economic aspect of sustainable development. The growth of economy is the most important precondition of human needs and for any lasting improvements in the living conditions. The support system has two components:
- (a) The **Infrastructure** sector.
 - (b) The **Economic system** sector.
3. **Natural system**: the natural system represents the environmental aspect of sustainable development. The natural-environmental constraint to human development is the main reason for any concern about sustainability:
- (a) The **Resources and environment** sector.
4. **Indicator system**: the indicator system consolidates information from the other components for the purpose of calculating indicators of the system state.

2.4 Identification of Relationships and Interactions

The long-term goal of the research project is to develop a multi-scale, spatially explicit, dynamic systems model linking components at five spatial scales (Figure 2): global (world and Europe Union), country, regional, municipality and local. The given concept of a multi-scale model is borrowed from an integrated spatial decision support system developed for local government in New Zealand (Huser et al., 2009).

The world, Europe Union and Latvia scales represent external drivers and scenarios such as climate, economy and legislation change that will influence Kurzeme region and Kuldiga municipality. The regional scale represents a system dynamics model of economy-environment interaction model of Kurzeme region. The municipality scale contains an economy-environment interaction model of Kuldiga municipality.

A sustainable development should be compliant with legislation of the Republic of Latvia and European Union. The model should balance and integrate the social, economic and environmental components of the region community.

3 MODEL IMPLEMENTATION

Based on the conceptual model, this study develops a sustainable development system dynamics model using the software Vensim 5.10. The model implementation is based on the existing experience presented by such well known system dynamics models as WORLD2 (Forrester, 1971), Miniworld (Bossel, 1994), WORLD3 (Meadows et al., 2004), T21 (Threshold 21 (T21)).

Sustainable development requires a long-term perspective, and uncertainty in long-term prediction is high. The time horizon of the model is 30 years, from 2010 to 2040. This time

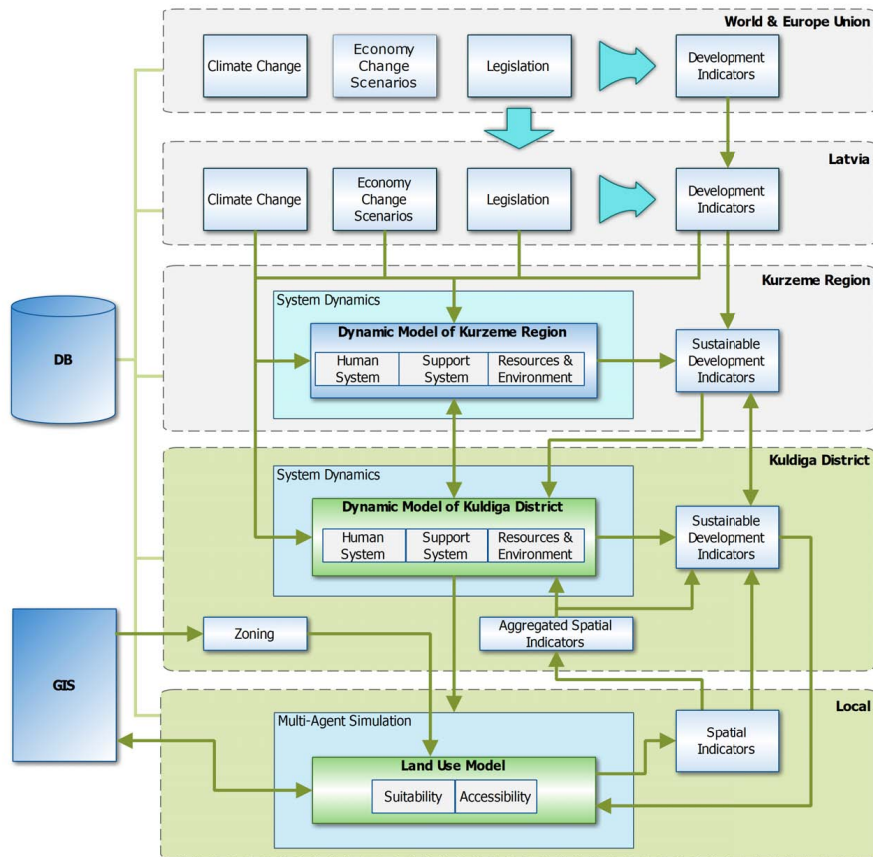


Figure 2: Conceptual system design of a multi-scale model for Kurzeme region and Kuldiga municipality

horizon is sufficiently long meaning that the future of the system is relatively independent from its initial conditions. The time step of the calculations is one year.

3.1 CONCEPTUAL SYSTEM DYNAMICS MODEL

In Figure 3 a conceptual structure of the system dynamics model is shown. The model consists of four main components including human system component, support system component, natural system component and indicator system component.

On the basis of the conceptual model, the flowcharts of the sustainable development system are defined below, with consideration of system characteristics. The variables are identified and relevant equations are established based on the feedbacks and cause-and-effect loops. The details of the contents and structures of the four submodels and their components are described as follows and their according stock-flow diagrams are presented in each section, respectively.

3.2 Human system component

The human system component contains individual development, social system and government sectors.

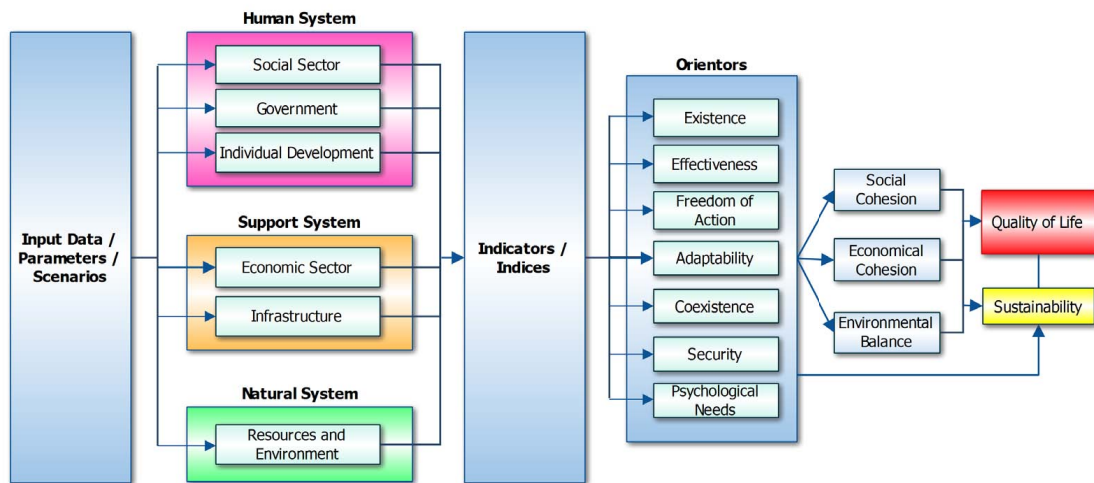


Figure 3: Conceptual structure of system dynamics model for Kuldiga municipality

The individual development sector contains elements of social integration and participation, material standard of living, adult education, leisure and recreation.

The social system sector implements behavioral aspects of population development (Figure 4), income composition, social groups and organizations, social security, medical care and old age provision.

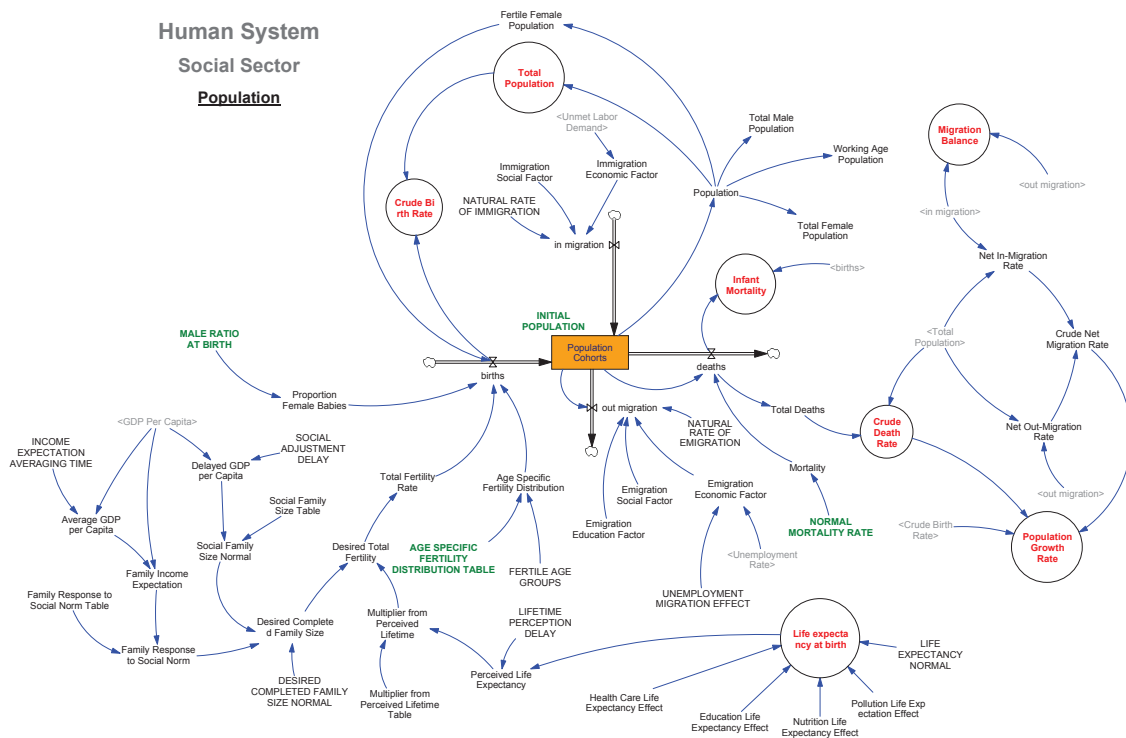


Figure 4: Population sub-model

The all population is divided into population cohorts of 5 years each. Each cohort has the births and in migration input flows, as well as deaths and out migration output flows. Both

out-migration OM and in-migration IM are modelled based on a *logit* function of the form (Mayerthaler et al., 2009):

$$OM = e^{\alpha_0 + \alpha_1 POP + \alpha_2 LR + \alpha_2 GL + \alpha_3 ACC},$$

$$IM = e^{\alpha_0 + \alpha_1 POP + \alpha_2 LR + \alpha_2 GL + \alpha_3 ACC},$$

where $\alpha_0 \dots \alpha_3$ are parameters;
 POP is number of residents in a region;
 LR is land rent;
 GL is area of green land in a region;
 ACC is access attractiveness in modelled region.

The government sub-model (Figure 5) represents a regional government and administration, public finances and taxes.

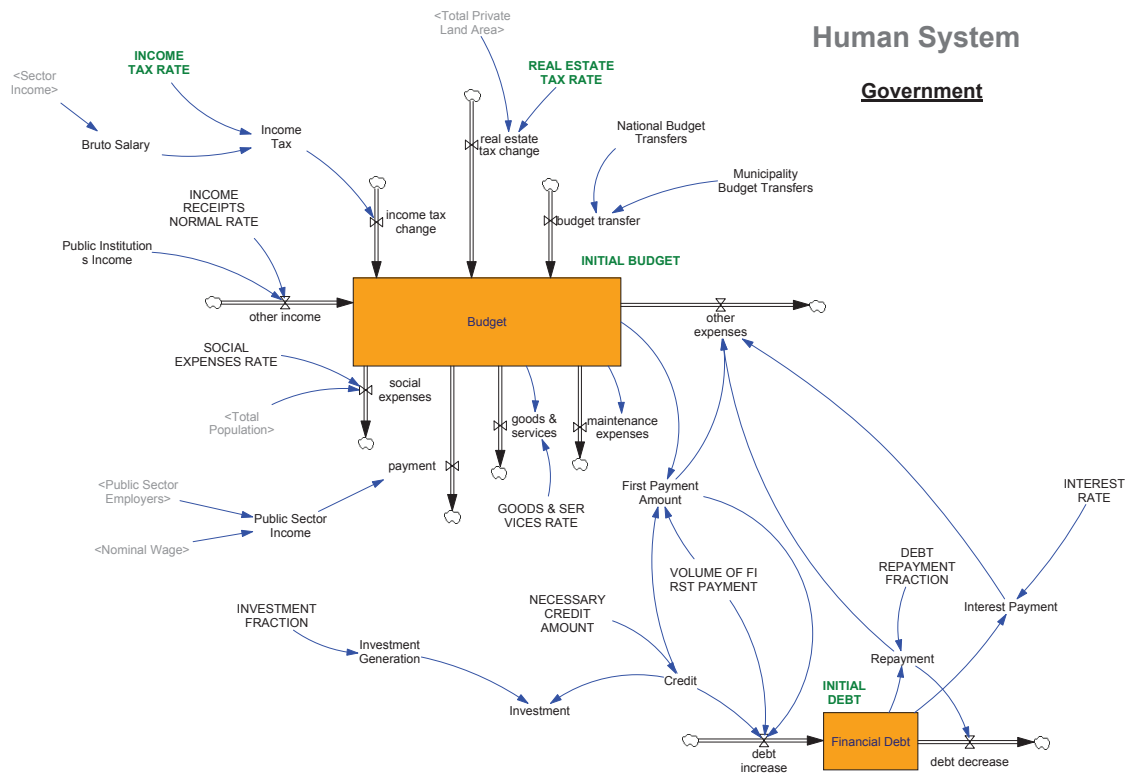


Figure 5: Government sub-model

3.3 Support system component

The support system component consists of two sectors - infrastructure sector and economic system sector.

The infrastructure sector implements elements of supply system (energy, water, food, goods, services), waste disposal, health services, tourism objects, facilities for education and training, research and development. Increasing population results in increasing demand for infrastructure capacities.

The economic system sector simulates industrial production (Figure 6), agricultural production, consumption, commerce and trade processes, labour and employment.

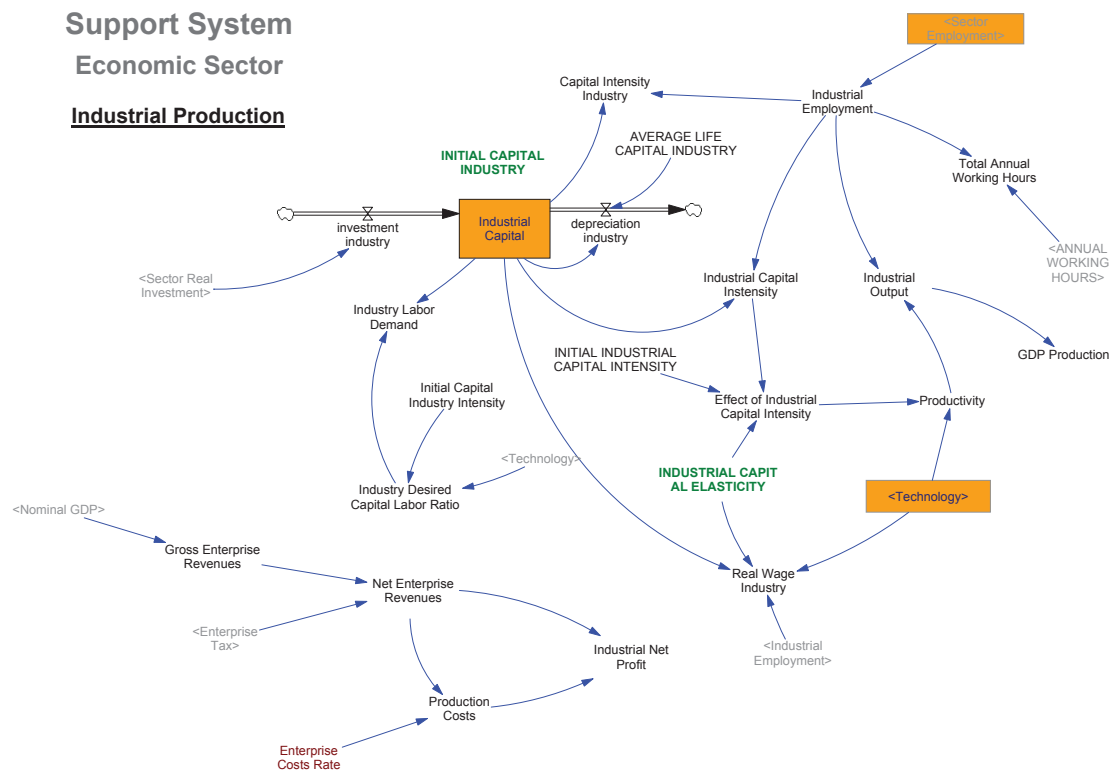


Figure 6: Industrial production sub-model

The industrial production sub-model is based on the classical Cobb-Douglas production function with parameters adapted to Latvia (Benkovskis and Stikuts, 2006; Dāvidsons and Meļihovs, 2006):

$$Y = A \cdot K^\alpha L^{1-\alpha},$$

- where Y is industrial output;
- A is total factor productivity or Solow residual;
- K is industrial capital input;
- L is employment in industrial production;
- α is capital elasticity.

Currently the parameters of industrial capital and employment elasticity are constants, whose values are obtained from a regression analysis performed by a Bank of Latvia. In the future, the industrial capital and employment elasticity should be made as variables, to more precisely model a long term economical development.

The services sub-model has a similar structure to the sub-model of industrial production.

For modeling of agricultural production (Figure 7), a modified Cobb-Douglas function is used, where as an additional factor the area of agricultural land is used (Barro, 1998):

$$Y = A \cdot L^\alpha \cdot K^\beta \cdot Z^{1-\alpha-\beta},$$

- where Y is agricultural output;

A is agricultural technology;
 K is agricultural capital input;
 Z is land input;
 L is employment in agriculture;
 α is employment elasticity;
 β is capital elasticity.

Similar function has been previously used (Vira and Narnicka, 2003; Ozolins et al., 2007) to describe and model agricultural output for certain time period in Latvia.

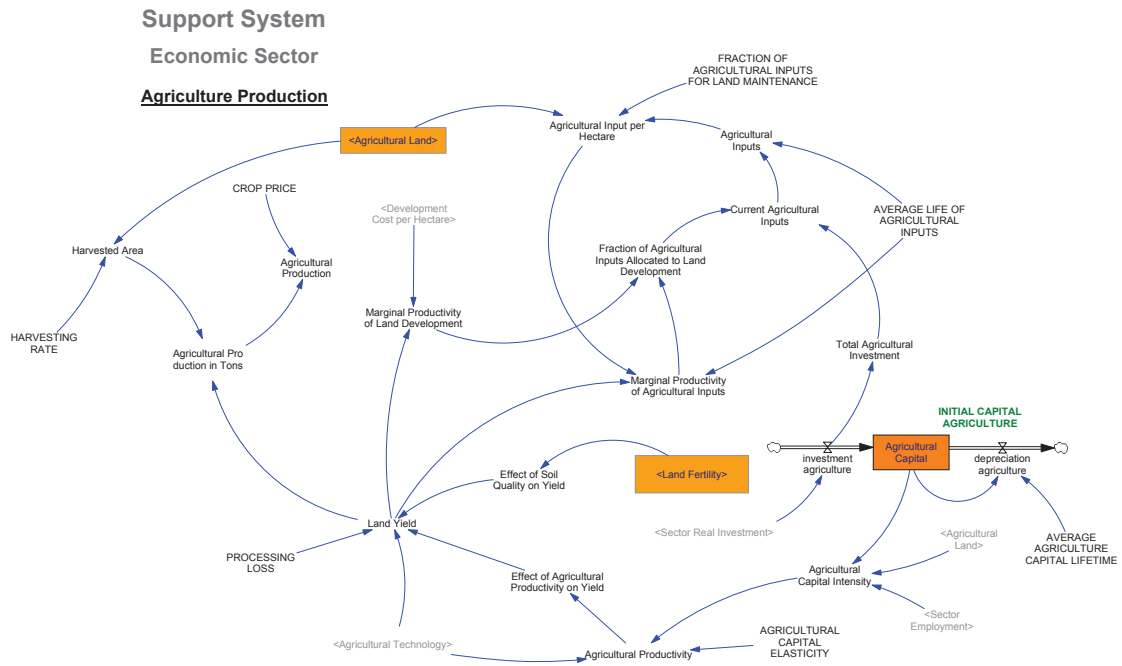


Figure 7: Agricultural production sub-model

3.4 Natural system component

The natural system component by implementing the resources and environment sector represents a natural environment, atmosphere and hydrosphere, natural resources, ecosystems, depletion of nonrenewable resources, regeneration of renewable resources, waste absorption, material recycling and pollution. It also examines the effect of soil erosion and other forms of environmental degradation and their impact on other sectors, such as agricultural productivity and nutrition.

In Figure 8 a land sub-model of the natural system's resources and environment sector is shown. The total land area consists of different land types such as forest, agricultural land, unused land and land used for urban & industrial settlements referring to Kuldīga municipality. A transition between different land types is driven by economical and environmental factors. The expansion/increment of the agricultural and urban areas is a process of transformation/conversion of the undeveloped land to the developed land.

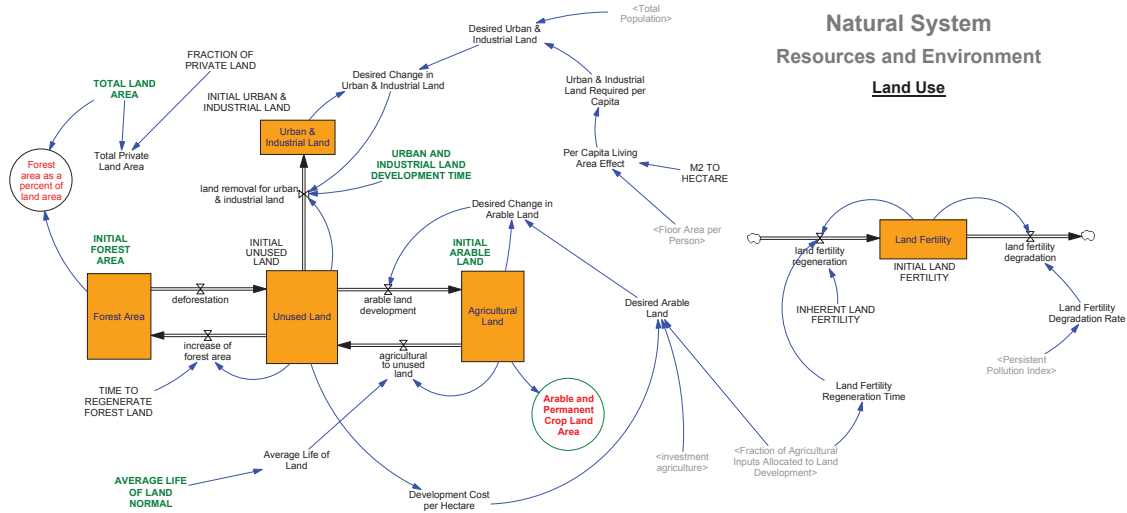


Figure 8: Land use sub-model

3.5 Indicators component

The indicators component (Figure 9) performs the housekeeping tasks of consolidating information from the other components for the purpose of calculating indicators of the state of the system. This component implements 33 indicators aggregated into seven basic orientors and three dimensions, as previously discussed in Subsection 2.2.1.

The quality of life is calculated by Equation 2 described in Subsection 2.1. The sustainability is calculated by Equation 1.

4 PRELIMINARY RESULTS

Currently the model isn't fully completed and a model calibration isn't performed. However, the first preliminary simulation results are obtained based on statistical data for Kuldiga district at 2009.

The simulated population dynamics (Figure 10a) shows a pattern corresponding population change trends to currently observable in Kuldiga municipality, respectively, a rapid population decrease due to high emigration rate and a predomination of deaths over births. Latvia and also its regions show the first signs of a recovery from economical crisis, and by economical growth the emigration rate will decrease. However, if birth rate stays low then a trend of population dynamics still will be decreasing.

The simulated GDP per capita (Figure 10b) shows an increasing trend, however in 2030 begins a decline. That can be explained by constrained demographical resources needed for a sustainable economical development.

In Figure 11 two possible population change scenarios are shown. In the first scenario (Figure 11a), the birth rate is increased by a factor 1.6. In this case the total population after an initial decline period will return to level close by the initial value. In the second scenario (Figure 11b), the initial birth rate is increased by a factor 2. In this case the total population after an initial period of decline will start to grow. The initial decrease of population in these scenarios can be explained by the relatively high out-migration rate.

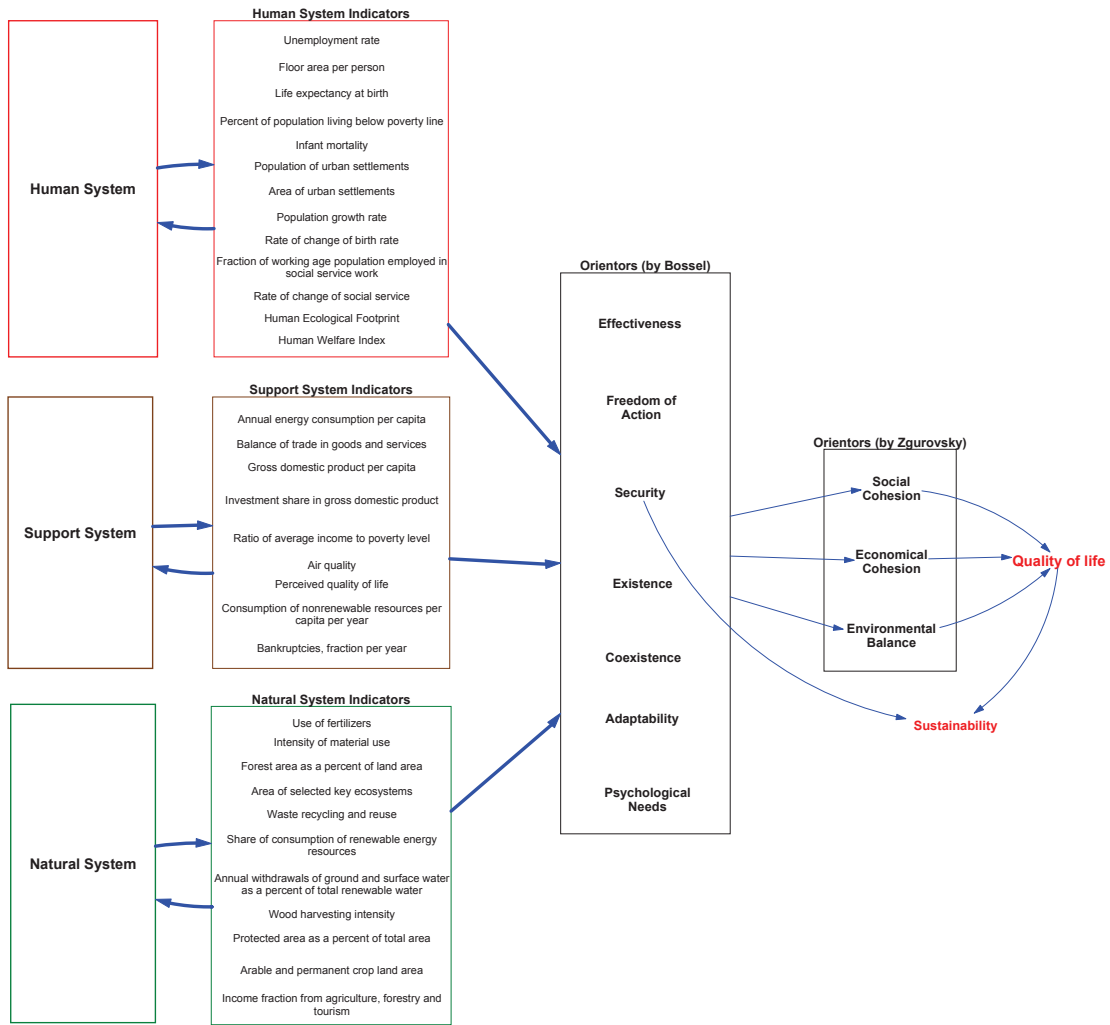


Figure 9: A simplified structure of indicators component

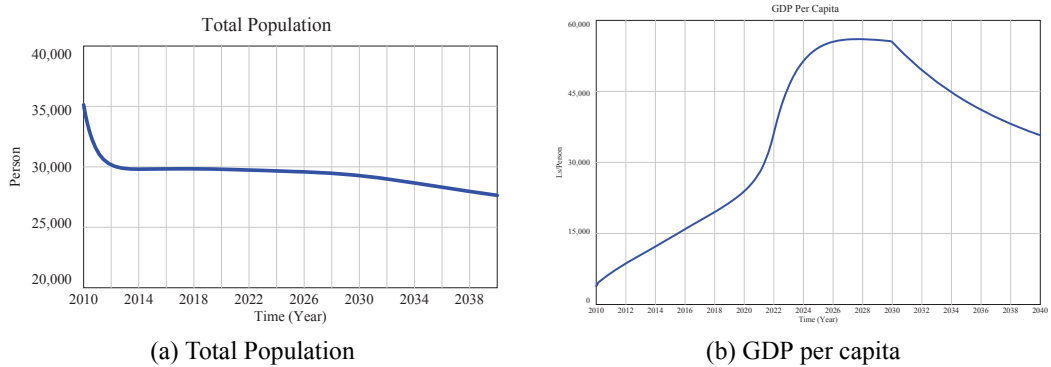


Figure 10: Preliminary simulation results

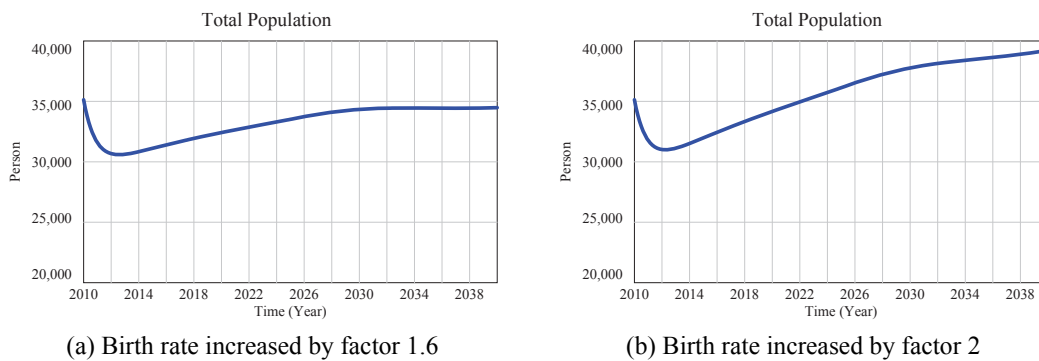


Figure 11: Simulated population change scenarios

5 CONCLUSION

The goal of the proposed model is to explore alternative scenarios to improve the quality of life and sustainability of Kuldīga municipality within a regional and national context. A dynamic model within a systems-thinking framework is considered beneficial both as useful tool for existing decision-makers in development planning and as an educational mean in understanding how various regional sub-systems function.

The calibration will be based on data for the Kuldīga municipality, including population, land use and energy production. The calibration might be described as impressionistic in the sense that the overall magnitudes are in the right ballpark, but it must be emphasized that a great deal more effort would be required to understand and exploit additional data.

The long-term goal of the project is to develop a spatially explicit systems model operating at five scales: global, country, regional, municipality and local.

Research work and development continues and the model framework is currently being enhanced to correctly represent regional and municipal processes along with interaction with policies coming down from national and EU levels. Once fully developed, calibrated and tested (December 2010), the proposed framework will be an invaluable tool in assisting decision-makers in sustainable development planning, as well as an educational mean in understanding how various regional sub-systems function.

References

- Barro, R. J. (1998, July). Notes on growth accounting. *NBER Working Paper (W6654)*.
- Beņkovskis, K. and D. Stikuts (2006, February). Latvijas makroekonomiskais modelis. Latvijas Banka. (In Latvian).
- Bossel, H. (1994). *Modeling and Simulation*. AK Peters.
- Bossel, H. (1998). *Earth at a Crossroads: Paths to a Sustainable Future*. Cambridge University Press.
- Bossel, H. (1999). *Indicators for Sustainable Development: Theory, Method, Applications*. International Institute for Sustainable Development.

- Dāvidsons, G. and A. Meļihovs (2006, March). Ražošanas progresa un cilvēkkapitāla nozīme Latvijas tautsaimniecības izaugsmes nodrošināšanā. Latvijas Banka. (In Latvian).
- European Council (2006). The renewed European Sustainable Development Strategy 2006. http://ec.europa.eu/sustainable/docs/renewed_eu_sds_en.pdf.
- Forrester, J. (1969). *Urban Dynamics*. Pegasus Communications, Inc.
- Forrester, J. (1971). *World Dynamics*. Wright-Allen Press.
- Hjorth, P. and A. Bagheri (2006, February). Navigating towards sustainable development: A system dynamics approach. *Futures* 38(1), 74–92.
- Huser, B., D. Rutledge, H. van Delden, M. Wedderburn, M. Cameron, S. Elliott, T. Fenton, J. Hurkens, G. McBride, G. McDonald, M. O'Connor, D. Phyn, J. Poot, R. Price, B. Small, A. Tait, R. Vanhout, and R. Woods (2009). Development of an integrated spatial decision support system (ISDSS) for local government in New Zealand. In *Proceedings of the 18th World IMACS/MODSIM Congress*, pp. 2370–2376.
- Latvija2030 (2010). Latvijas ilgtermiņa attīstības stratēģija līdz 2030. gadam. Reģionālās attīstības un pašvaldību lietu ministrija, Latvija2030, http://www.latvija2030.lv/upload/latvija2030_saeima.pdf. (In Latvian).
- Mayerthaler, A., R. Haller, and G. Emberger (2009). A land-use/transport interaction model for Austria. In *Proceedings of the 27th International Conference of The System Dynamics*, Albuquerque/USA, pp. 1–21.
- Meadows, D. (1998). *Indicators and Information Systems for Sustainable Development*. The Sustainability Institute.
- Meadows, D. H., D. L. Meadows, and J. Randers (2004). *Limits to Growth - the 30-Year Update*. Chelsea Green Publishing Co.
- Ministry of Environment and Energy, National Environmental Research Institute (2001, March). PSSD - planning system for sustainable development: The methodical report. Technical report, Department of Policy Analysis.
- Owens, S. and R. Cowell (1994, July). Lost land and limits to growth : Conceptual problems for sustainable land use change. *Land Use Policy* 11(3), 168–180.
- Ozolins, G., R. Kalnins, and R. Sile (2007). Agricultural production and income dynamics in Latvia. In *Proceedings of the 25th International Conference of the System Dynamics Society*.
- Threshold 21 (T21) (2009). Overview of Threshold 21 (T21) model. <http://www.millenniuminstitute.net/resources/elibrary/papers/T21overview.pdf>.
- Vira, V. and K. Narnicka (2003). Semi-subsistence farming in Latvia: Its production function and what will be the impact of proposed EU support? In *SSE Riga Working Papers*.
- Zgurovsky, M. (2009). Global analysis of sustainable development in context of quality and security of human life. *System Research and Information Technologies* 1, 7–21.