

Methodology of system dynamics for decision support in agriculture

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ABSTRACT

The sustainable development of complex systems, and therefore agriculture as a relevant part of ecology, should be the permanent development paradigm of mankind. Conditions should be provided so that nature could regenerate itself by allowing for only a reasonable impact of human activity and presence on nature and in such a way preserve resources for the next generation. In this article, we discuss system dynamics as a holistic research methodology in the support of dynamic complex problems. Our goal is to demonstrate the usefulness of System Dynamics (SD) methodology in research and its implementation for public decision support. We briefly discuss the fundamentals of SD methodology models and causal loop diagrams (CLD) as well as model validation. Some examples of modelling for public decision assessment of sustainable development using SD have been demonstrated. The advantage of SD is in its natural language problem definition, which can be easily transformed into a directed graph that is convenient for qualitative and quantitative analysis in computer programs. System Dynamics enables studying the behaviour of complex dynamic systems as the feedback processes of reinforcing and balancing loops.

Key words: system dynamics, modelling, complex systems, decision assessment, systems approach, agriculture

INTRODUCTION

In this article, we discuss the research methodology of system dynamics (SD) application in agriculture. Agriculture is highly relevant for the human race and its survival; its problems are very complex; therefore, a variety of research methodologies addressing this field has been developed. This variety of approaches is conditioned by the context of the users and the perspectives and methodological abilities of the scientists. Agriculture as part of ecological systems (biological) and organisational systems (human-made) has the main purpose of providing food and, as such, it is an inseparable part of ecology and society. For research purposes, it should be considered as the part of the whole with the goal of providing functionality of the whole. When we refer to agriculture as a process, we have in mind a research methodology that considers all relevant aspects of the whole system. For example, one of the established methodologies is the Systems Approach (SA). SA methodology was discussed in greater detail in (Ackoff 1998, Kljajić and Farr 2010) and its philosophical implications in (Bounias et al. 2002). SA as the paradigm of holistic methodology to complex problem solving is not very new. Humanity has already solved several "big picture" problems in previous historical periods but in a simplified way. However, scientific approaches to solving problems in social systems were started with the first and second industrial revolutions. In first industrial revolution, the main agent was the machine, and manpower was replaced by machine; the knowledge and understanding of the processes to be mechanised were called "industrial engineering." This period of human development Ackoff termed "the Machine Age" (Ackoff 1998).

The second industrial revolution brought about many important technological achievements, which affected organisational development and management. Of these achievements, computer and information technology was most important one, with which a new epoch of society organisation and management research started. Many repetitive and primitive human operations have been replaced by automata and, more recently, with artificial intelligence. Mechanisation of this particular type of mental work required from scientists and engineers an interdisciplinary approach, which resulted in information theory, decision theory, control theory, cybernetics, general systems theory, and operation research and systems sciences. According to Ackoff, the methodology to cope with complex systems is called "the Systems Age" (Ackoff 1998).

This means, that every part of the concrete system is a part of the larger system. For example, the agricultural system is a part of social system and also of ecological systems; thus strategic decision making about the functioning of agriculture has long-term consequences and has to take in consideration ecology and the social implication in coming generations. Nowadays, such requirements are known as

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"sustainable development". It seems that System Dynamics SD (Forester 1958) represents a proper methodology for the behaviour of complex sustainable systems. As a methodology, applying SD in analysing complex system behaviour is very important for several reasons: it is simple, because it is based on the natural laws of Rate and Storage that describe relations between elements in quantitative/qualitative relations; it is transparent, because it allows unique discussion about elements relations defining problem; it is coherent, because it consists of simulation tools harmonised with methodology. The advantage of SD as a part of SA is in the fact that a problem defined in natural language can be easily transformed into a directed graph convenient for qualitative and quantitative analysis in a computer program. In this case, the user can always check the validity of the stated problem and the model developed. SD enables studying the behaviour of complex dynamic systems as a feedback process of reinforcing and balancing loops. As such, it provides testing of dynamic hypotheses about the anticipated properties of any systems: Life Cycle Development, Quality of Systems and assessment in the decision process.

Although the system dynamics (SD) modelling method (Forrester 1958, 1971, 1973 and 1982) was promising in dealing with complex research questions, there is only a modest amount of articles using SD methods in researching agriculture and ecology, in comparison to other methodologies. As far as the most well-known model for the modelling of complex systems, there was World Model 1 (Forrester 1971) and World Model 2 or The Limits to Growth of Meadows (1972) as well as Mankind at the Turning Point, by Mesarovic and Pestel (1974). All three models were developed within so-called Club of Rome and considered global behaviour from the perspective of certain development policies. In the Web of Science (WOS Expanded 2012), there are 1400 articles published in last 10 years on the topics of agriculture, but just a few using SD methodology, i.e. one of the most powerful trans-disciplinary methodologies.

SD methodology (Forrester 1958) can be used as an alternative to the econometric and mathematical programming approaches (Bockermann et al. 2005, Elshorbagy et al. 2005, Saysel et al. 2002) for policy modelling. Recently, there have been many important SD applications in the field of agriculture and environment: Nalil (1992) describes the conceptual development of FOSSIL2, an integrated model of U.S. energy supply and demand, which is used to prepare projections for energy policy analysis in the U.S. government's Department of Energy Office of Policy, Planning, and Analysis. Guo et al. (2001) presented an environmental system dynamics model for supporting an environmental planning task. The model consists of dynamic simulation models that explicitly consider the information feedback that governs interactions within the ecosystem. Such models are capable of synthesising component-level knowledge into a system behaviour simulation at an integrated level. Shen et al. (2009) presented an SD model for sustainable land use and urban development in Hong Kong. The model is used to test the outcomes of different development policy scenarios and to make forecasts. It consists of five sub-systems, including population, economy, housing, transport and urban/developed land. Yin and Struik (2009) reviewed recent findings on modelling genotypes and environmental interactions at the crop level, moving from system dynamics to system biology. However, the most important works in the field of simulation of development policy scenarios are presented by Shi and Gill (2005), who developed a system dynamics-based simulation model for ecological agriculture development for Jinshan County (China), and by Kljajić et al. (2002 and 2003), who developed an integrated system dynamics model for development in the Canary Islands, where interactions between agriculture, population, industry and ecology were taken into consideration. The preliminary investigations into SD simulation of organic farming development were conducted by Rozman et al. (2007) and by Škraba et al. (2008).

The goal of this article is to highlight the present state and perspectives of the theory and practice of decision assessments based on SD and simulation models. In the following section on the general approach to the system modelling paradigm, we discuss the principle of SD and Causal Loop Diagrams (CLD), and its appropriateness for research methodology in agriculture. Some examples from the authors and from the literature of development of DSS based on SD and simulation, and its success will be demonstrated. System dynamics is a computer-based approach to complex policy analysis and design for decision-making assessments. Our motivations were to bring to the attention of agriculture researchers the usefulness of SD methodology for more intensive applications in agriculture.

MATERIAL AND METHODS

System dynamics conception

The fundamentals of System Dynamics were defined by Jay Wright Forrester in the mid-1950s (Forrester 1958) as a method for the modelling of industrial dynamics. At the beginning of the 1980s, the dawn of the information era, the method was renamed "System Dynamics" (SD). The method is straightforward in its essence, based on the principle of conservation of mass. Nevertheless, the genius of Forrester is that, as a pioneer of computer science, he noticed that the power of computers could be used in business systems, not only for collecting, processing and storing data, but also for strategic decision making. For this purpose, dynamic models of systems were needed. Consequently, the method of modelling was developed: one which is clear, straightforward, user friendly and holistic. Forrester developed the methodology and simulation tool, i.e. the program. The idea of modelling is based on the supposition that every real system (S), including business systems, could be described by the system of equations, which is represented by the interconnected flows, or rates (R) and storages or levels (L):

$$S = (L_j, R_i, A_r)\ j = 1,2,\ldots n,\ i = 1,2,\ldots m,\ r = 1,2,.l \quad (1)$$

Here L_j represents the set of Levels (stocks) and R_j the set of R (flows) and A_r the Auxiliary expression by which we can express arithmetic relation among L and R. Each level L or state element has its own input, i.e. input rate *Rin* and its own output rate, *Rout* as is shown in Figure 1.

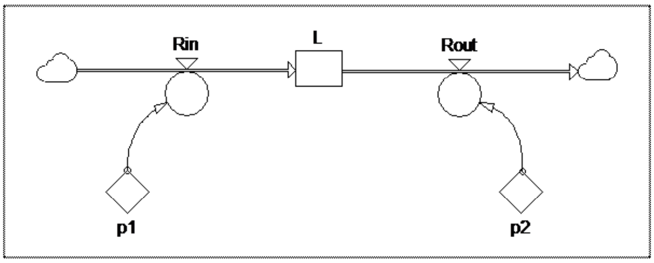

Figure 1: Basic elements *L* and *R* in System Dynamics

The principle of conservation of mass for the above model could be described by the dynamics equation in the form of difference equation:

$$L(k+1) = L(k) + \Delta t(R_{in}(k) - R_{out}(k)) \quad k = 0,1,2,...n \quad (2)$$

Where k represents discrete time, Δt is the time interval of computation. Each entrepreneur understands that the value of Level element L(k+1) increases if Rin(k) > Rout(k); it is unchanged if Rin(k) = Rout(k), and decreases if Rin(k) < Rout(k). For example, in Figure 1, squares represent Level elements (Population, Natural Resources, Environment Degradation), circles symbol represent Rate elements (e.g., Regeneration, Consumption etc.) while P1 and P2 represents decision parameters by which one regulates flow in and out from elements. The clouds at the beginning and at the end represent the environment of the model. This is, therefore, our boundary of modelling of the addressed model. From a formal viewpoint, this method is indeed straightforward and clear, as well as understandable. In Table 1, possible meanings of L and R elements for different classes of systems are given.

The methodology of solving problems by the principles of System Dynamics could be concisely described by the following steps:

- Definition of problem
- Determination of goals
- Concept of investigation
- Formulation of mathematical model
- Coding of computer program
- Validation of model
- Preparation of experiment (simulation scenarios)
- Simulation and analysis of results

When defining a problem, one addresses the parts with which one is not satisfied or those that demonstrate undesirable dynamics. Usually, these are the values of Level elements of the addressed process, L, and the interconnections between them, R. The goal of the research is to determine the goal states that should be achieved. Here, the question "How?" emerges. With the application of the dynamic hypothesis, the dynamics of the system is determined as the consequence of key feedback loops in the system. In this phase, with complex problems, the key role is played by a team with an interdisciplinary approach. State elements and their relations are nonetheless the main part of the analysis, which could be performed in several different ways. In the end, the validated model is the tool for the testing of the dynamic hypothesis at the different visions (scenarios). In order to address complex problems, one has to apply systematic and team approaches (Škraba et al. 2003, 2007) in the process of solution.

Causal loop diagrams and system dynamics models

The determination of model structure and its parameters is the most important part of the assignment. There are several methods and tools to aid in the articulation of the model structure. An exceptionally practical one is the method of Causal Loop Diagrams; these are directed graphs with polarity. Each Level and Rate element has a directed arrow assigned, so that one element represents the cause and the other the consequence. Directed arrows from cause to consequence have the "+" sign if the cause and consequence have the same direction and "-" if the opposite direction exists.

Table 1: Describing different systems with Level, Rate and Desired state

System	Level	Rate	Desired state
Population	Population	Birth, Death	Sustainable Growth
Warehouse	Inventory	Delivery, Consumption	Desired level of inventory
Cash balance	Cash	Income, Expenses	Positive level of cash
Room heating	Room temperature	Temperature input flux, Temperature loss	Desired room temperature
Knowledge	Knowledge level	Learning, Forgetting	Appropriate level of knowledge
Information system	Information system capacity	New technology, Technology decay	Adequate IS for controlling real system

Another very important aspect of the SD methodology is the feedback loop. When several arrows in the CLD return to one element, a closing path or a loop is created, which gives some feedback to the original element; therefore, it is called a feedback loop. There are two kinds of feedback loops: a positive feedback loop (reinforcing loop) and a negative feedback loop (balancing loop). Reinforcing loops tend to grow or decline without limits and make the system unstable. Balancing loops tend to adjust themselves to some intended value. Hence, they tend to stabilise the system and guide it to the goal.

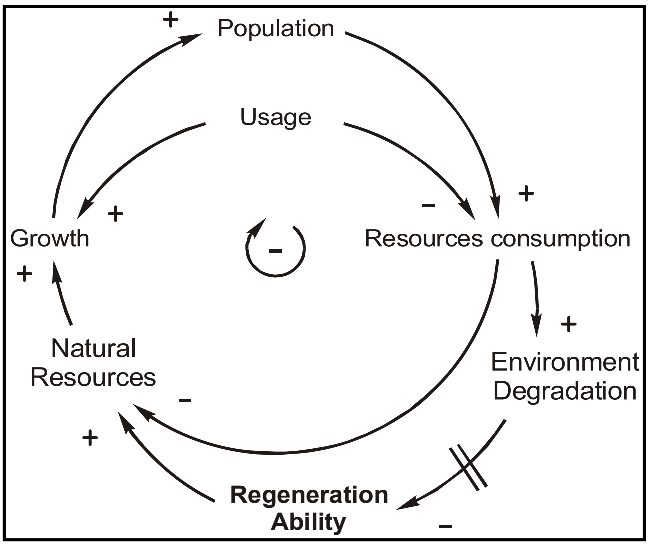

Figure 2: Causal Loop Diagram of Population ~ Natural resources

The following simplified case of a Causal Loop Diagram for a paradigm of sustainable development is shown in Figure 2. Here we consider the extent and growth of population as well as the exploration of natural resources. The higher population level results in a higher usage of natural resources. The volume of natural resources is dependent on the intensity of regeneration. The higher volume of natural resources consequently provides better conditions for the development of the population, which positively influences the growth of the population. The important factor is the efficiency of the natural resource usage, which both negatively influences resource consumption and positively influences the population growth. In this case, the negative feedback loop is considered, which has the property to converge to the goal state, i.e. the reference value. In our case, the goal state is determined by the regeneration of the natural resources, which is the key message of the described structure. In this manner, one could conclude that the growth of the population over the longer time frame is not dependent on the volume of the natural resources stock, but rather on the regeneration of natural resources. Regeneration in the sense of System Dynamics is represented as the Rate element, i.e. the element that represents the change, rather than the stock.

In the model analysis, one has to start with the model equilibrium. Special care should be taken for the definition of the user-defined functions that are applied in the model. Figure 3 shows a model of sustainable development, in which the regeneration is taken into account as the Rate element. The model has three (3) Level elements: Population, Natural Resources and Environment Degradation. The user-defined function "Limits of natural resources" is applied as the limiter of the consumption of population members in the case that

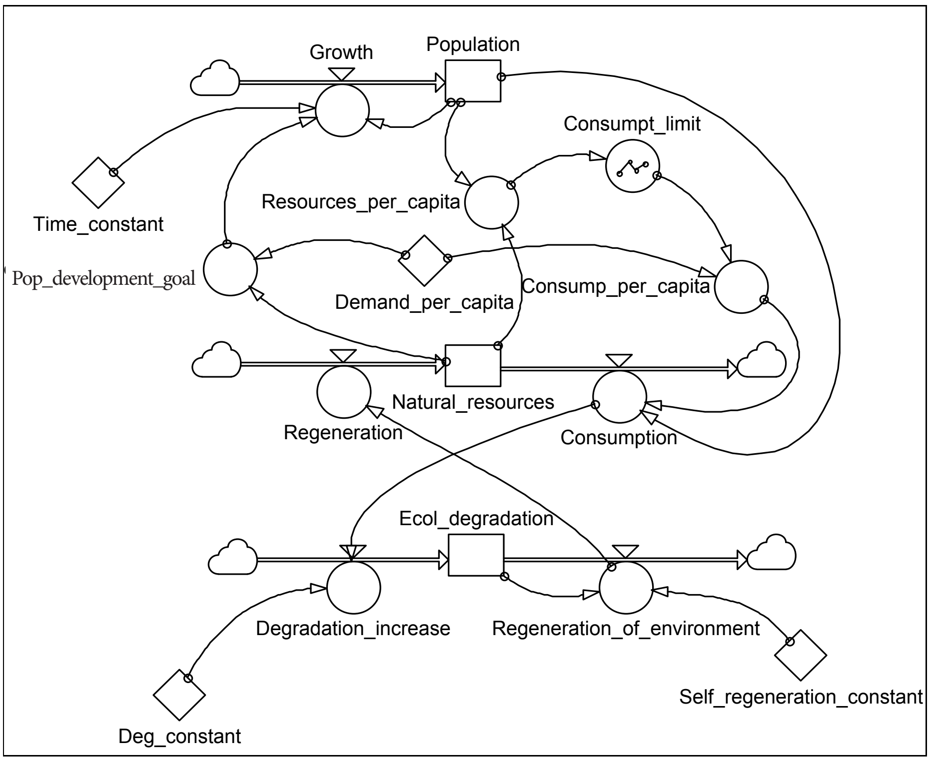

Figure 3: The model of sustainable development ~ natural resources

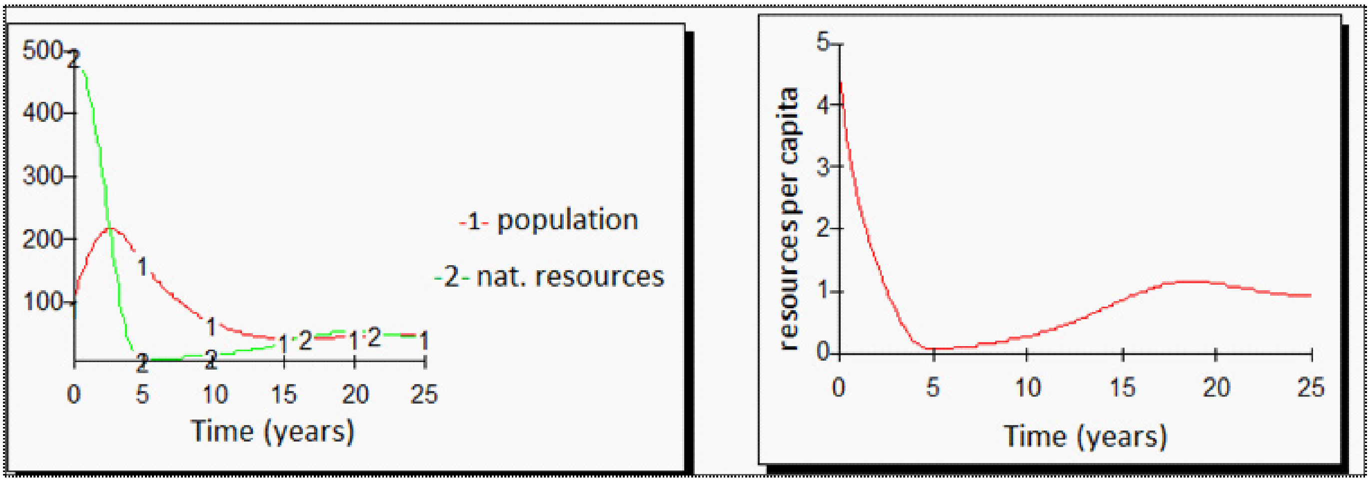

Figure 4: Time course of population and Natural resources as function of resources consumption per capita

the supply of natural resources would shrink below the normal level. This function also considers that (in the case of increased volume of natural resources above the normal level) the consumption would increase for a certain, rather small, part. The goal of the population development is determined by the volume of natural resources and the demand of natural resources with respect to the population. The growth is therefore limited by the stock of natural resources and by the consumption "Per capita". The dynamic response of the system with regard to the goal is determined by the rate element "Regeneration", which could be dependent on the investment in new technology, shown in Figure 4.

In order to demonstrate the usefulness of the SD method for the qualitative analyses of economic growth, we will analyse the partly generic model shown in Figure 5. Investment in new production caused Employment opportunities, which increased Workforce demand and consequently engaged new workers. This loop will be called "Economic growth", which has a positive loop or reinforcing loop denoted with "A". However, for new factories and the new working force, we need new industrial land, which cause losses of Available land, which restricts Economic growth. This loop denoted with "B" represents a balancing or regulation loop. Further, the lessening of Available land (agriculture land) causes decreased capability for food production (Self-supportability). Let us suppose that we invest in high technology: we need less agriculture land, but more knowledge as consequence of better education and research, and the gain of loop A is higher. In this case, contribution to GDP and well-being is higher with preserved available land, for food production or preservation of ecology. The CLD model of GDP, Research, Production and Education was analysed in greater detail in (Kljajić 2009). In contrast, in the case of the investment in less-sophisticated technology, one needs more land and economic growth is diminished. The gain of A is lower and land and the ability to produce one's own food decreases. All this activity has remains constant over a long time and requires careful long-term planning. (Note that land is constant and conversion from agricultural land to industry is an almost irreversible process. Reverse conversion is possible but price is too high). In next paragraph, we will describe the same case in greater detail.

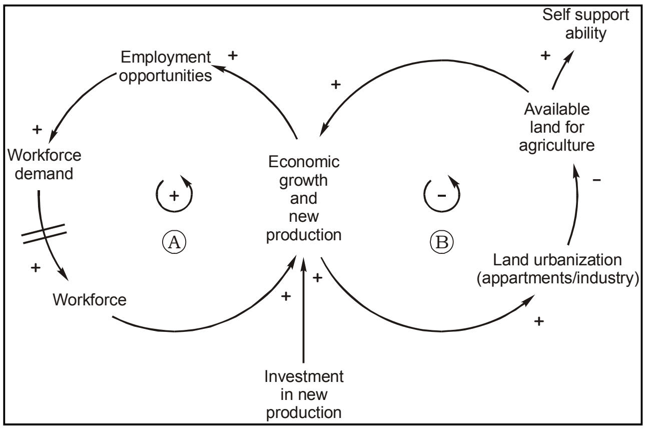

Figure 5: Generic model of investment in new technology, economic growth and ability to produce sufficient food

Simulation-based decision support systems based on sd

A simulation-based decision support system (DSS) is an important part of the Management Information Systems (MIS), which support business or organisational decision assessment. The simulation model is used as an explanatory tool for better understanding of the decision process and/or for defining and understanding learning processes. The advantage of the simulation model as a part of DSS is in the fact that a problem defined in natural language can be easily transformed into CLD convenient for qualitative and quantitative analysis in computer programs. In this case, the user can always check the validity of the stated problem within a certain theory as well as its translation to computer programming. This is especially important in cases of complex problems in which feedback loops and stochastic relations are present, regardless of the process being a continuous or discrete event. Big picture presentations and simulating the process make this technique flexible and transparent for testing a system's performance in all phases of system design and deployment. This has made it possible to examine the projected performance of systems through wide-ranging investigations of design and environmental assumptions very early in the development process, when key resources are committed.

RESULTS AND DISCUSSION

System dynamics model for the public decisions support

The SD model for public decision support in the Canary Islands (Kljajić et al. 2003), particularly as related to strategic issues, involves qualitative and quantitative aspects of social systems. Quantitative variables are often crucial for strategic decisions. In addition, qualitative information is provided by a social actor and decision maker (DM) with an implicit character of uncertainty (Legna and Rivero 2001, Legna 2002). The main pillars of our approach are the following:

• the building of qualitative models that integrate qualitative and quantitative information;

• the application of system dynamics that is particularly useful in determining the interrelations between the subsystems, building scenarios and running strategic simulations;

• the analysis of the leading forces that help to identify the role of the variables, their leverage potential and, consequently, to highlight key areas of the social system to implement policies.

This approach is based on the building of qualitative models and the application of system dynamics for the development of a simulation model. Variables were identified that affect the sustainable improvement of the quality of life in the Canary Islands. The relationships between the variables are expressed as an influence square Matrix M with dimension n = 53×53, of which 12 are exogenous. Consequently, it has 41 state variables. More about the influence matrix can be found in (Kljajić et al. 2002).

To move to a quantitative model capable of cause-consequence analysis of decision makers' impacts on the long-term behaviour, the influence matrix must be transformed to SD methodology. In this way, a direct connection between scenario planning (as a consequence of DM) and variable behaviour is possible. Fifty-three variables represent a rather demanding problem, especially with regards to model validation. In this case, it is necessary to specify the initial value of variables, parameters and other functions necessary for model implementation. Therefore, we developed a procedure of influence matrix transformation into a Causal Loop Diagram (CLD). The influence diagram is obtained from the influence matrix. Next, we analyse the interconnection between the main variables relevant for the causal loop diagram CLD as shown in Figure 6. Feedback loops and interactions of particular subsystems are shown in the causal loop diagram. The locations, which are defined with variables, represent the system state element, while arrows show the direction of influence between a particular pair of elements. In the simulation process, an expert group in the form of a suggested policy heuristically determines key parameters. The causal loop diagram in Figure 6 represents interactions in the context of regional development and its influence on regional prosperity and quality of life.

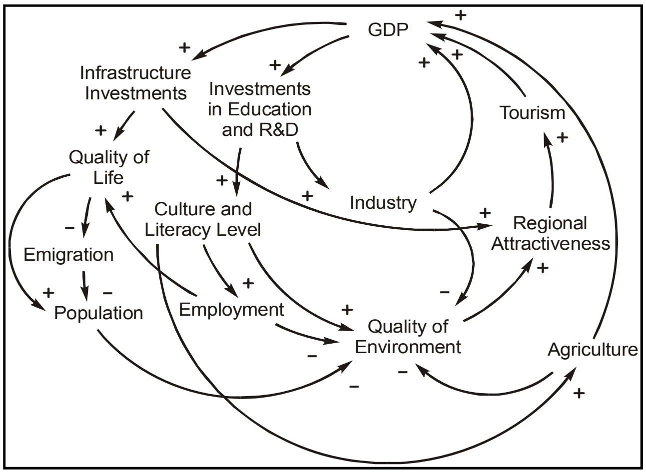

Figure 6: Causal Loop Diagram of the Canary Islands case

The structural analysis of the system is of great significance, since mental models of various kinds can be captured using the proposed methodology. For example, if Gross Domestic Product increases, the Investments in Education and R&D production increase above what they would have been and vice versa; therefore, the arrowhead is marked with the "+" symbol. If the Investments in Education and R&D production increase, the Economic volume increases above what it would have been, which is also marked with the "+" symbol. If the Population increases, the Quality of Environment decreases and the cause effect is marked with the "-" symbol. All other causal connections are marked in the same manner. After the aggregation of variables, i.e. the joining of similarities, the next step is the determination of levels and rates according to system dynamics methodology.

With the proposed methodology, the system can be entirely determined by the System Dynamics models that form the general simulation model for the regional development of the considered case. Such decomposition allows for a multilevel approach in modelling, which facilitates the process of model validation. A preliminary sub-model was developed for population dynamics, which incorporated 150 parameters (Kljajić et al. 2003). The model enables changes for the different population variables that are relevant for decision makers. Users have the opportunity to actively participate in the decision process by defining relevant criteria and their importance, in spite of the large number of different simulation scenarios. The decision process is clear and creative. The preliminary model is built using the Powersim simulation tool (www.powersim.com), which provides results for the real application of the organisational strategy. Simulation also enables an internal view of system behaviour for the selected scenario. The system makes it possible to analyse different situations, which is the basis for achieving the consistent formulation of a policy. The building of the model is still in progress (Legna and González 2005, Legna and Škraba 2010).

Model of organic farming in Slovenia

This case presents the system dynamics model of organic farming development in order to support decision making. The model seeks answers to strategic questions related to the level of organically utilised area, levels of production and crop selection in a long-term dynamic context. The model will be used for the simulation of different policy scenarios for organic farming and their impact on economic and environmental parameters of organic production at an aggregate level. Using the model, several policy scenarios were performed.

The preliminary investigations into SD simulation of organic farming development were conducted by (Rozman et al. 2007, Škraba et al. 2007, Rozman et al. 2011) This case is a survey of the previous model and presents a system dynamics model for the development of organic agriculture in Slovenia. The goal was to identify key variables that determine conversion dynamics and to propose development policy. First, we present the main flows and feedback loops within the systems and the development of the system dynamics model. The results present scenarios (different policies in organic farming) and their evaluation through application of the developed SD model. The simulation model should consider the key variables that influence the development of organic farming, such as:

- the number of conventional farms,
- the number of organic farms,
- conversion process,
- subsidies,
- the promotion of organic farming (marketing, market development, education),
- the organisation of a general organic farming support environment,
- a system of self-awareness, and
- the delay constants of process change.

A key variable in the model is the number of organic farms. These are the farms that are under the control system of one of the control organisations. The growth in the number of organic farms was initially (in 1998) almost linear; however, in the years from 2003 to 2005, the growth moderated to approximately 4%, despite an increase in subsidies of 20% to 30%.

During the development of the CLD diagram (Figure 7), the following key variables were identified as the first steps

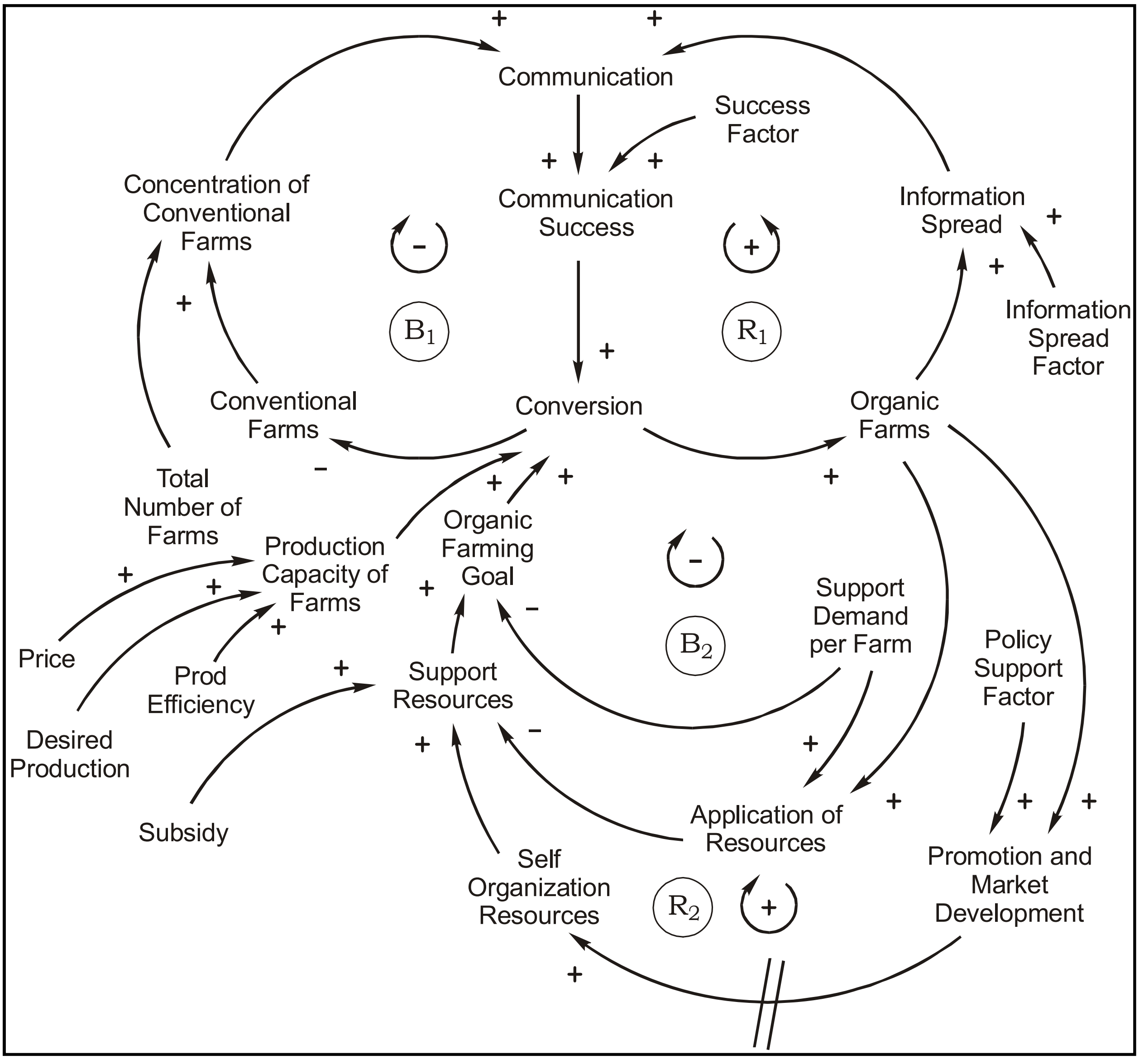

Figure 7: Causal Loop Diagram (CLD) of conversion process to organic farming

toward the development of the SD model:
(1) the number of potential candidates (farms) for conversion to organic farming,
(2) the number of farms already converted to organic farming, and
(3) the flow between (1) and (2): conversion rate (transition).

Loop B1 represents a negative loop, with a goal value of 0 (depleting the number of "Conventional Farms"). The number of "Conventional Farms" divided by the "Total Number of Farms" yields the "Concentration of Conventional Farms", which is initially high, meaning that there should be a high initial preference for "Conversion". "Concentration of Conventional Farms" positively influences the "Communication". This variable represents the general communication between the conventional approach members and the organic approach members. "Conversion" positively influences the number of "Organic Farms". If the number of "Organic Farms" increases, the "Information Spread" increases above the level that it would otherwise have been. "Information Spread" by "Organic Farms" members is positively influenced by the "Information Spread Factor" which could be, for example, increased by marketing campaigns. "Information Spread" positively influences "Communication". The number of "Conversion" farms is determined by the "Success Factor", which determines the "Communication Success", yielding the number of convinced conventional members that decide to make a "Conversion". Loop R1 is a reinforcing feedback loop compensated for by the initial balancing feedback loop marked with B1. If the number of "Organic Farms" increases, the "Promotion and Market Development", supported by the "Policy Support Factor", increases as well. Higher "Promotion and Market Development" positively influences the "Self Organisation Resources", which contribute positively to the "Support Resources" on which the "Conversion" is dependent.

There is a delay mark between the "Promotion and Market Development" and "Self Organisation Resources". Longer delays should be expected here, since a significant amount of time is needed in order to promote both the organic farming idea and the marketing channels that will support organic farming.

The "Support Resources" are significantly dependent on the government "Subsidy". Furthermore, the higher the "Organic Farming Goal" is set, the more "Support Resources" should be available, meaning that a larger number of organic farms can be supported. If the "Organic Farming Goal" increases, the "Conversion" increases above the level that it would otherwise have been.

The interconnections marked with "R2" have the characteristics of reinforcing feedback loops. According to government policy, the growth in the number of "Organic Farms" should be properly supported in order to promote an increase in self-organisation of, for example, organic food marketing and promotion. Thus, the reinforcing feedback loop R2 should serve as a growth generator in the system.

Loop B2 represents a balancing loop. If the number of "Organic Farms" increases, the "Application of Resources" increases above the level that it would otherwise have been. The "Application of Resources" is also dependent on the resources needed per farm, i.e. "Support Demand per Farm". Higher "Application of Resources" can cause the depletion of the "Support Resources". The "Organic Farming Goal" is dependent on the "Support Demand per Farm". If more resources are needed per farm, fewer organic farms can be supported, and therefore lower numbers of "Conversion" should be expected. In considering a real case, the negative loops B1 and B2 are dominant, leaving the system in an undesirable state of equilibrium. This would mean that the number of organic farms is constant and well below that desired. In order to move the system away from the equilibrium, one should consider the policies that would raise the impact of the reinforcing feedback loops R1 and R2, which should move the system state, i.e. the number of "Organic Farms", to the higher equilibrium values. "Price", "Desired Production" and "Production Efficiency" are also important factors that impact the intensity of the transition.

There are two levels to the elements applied in the upper part of the model: The variable "Conventional_farms" represents the number of conventional farms. With the flow of "Conversion", the "Conventional_farms" become "Organic_farms".

This structure is commonly known as the market absorption model. "Conversion" is dependent on the "Organic_farming_goal". The goal is set by the "Support_resources" available, modelled as a level element. The desired conversion can be achieved only if there are enough "Support_resources" present in order to make a "Conversion". The "Support_resoures" are not only the financial means. Here, the support of society is also considered; for example, education should create positive attitudes in relation to organic farming. In this category, the market development, as well as the demand, should also be considered. However, at present, the "Support_resources" are mainly dependent on subsidies from the government. The important variable "Self_organisation_resources" is driven by the impact of the policy and the level of societal support, which will intensify with increasing numbers of "Organic_farms". This represents the application of a reinforcing feedback loop which should be augmented. The "Development_limit" represents the function that considers the variable of the consumption of the resources. If the resources are scarce, the usage is lower than in the case of abundance. Resources are consumed by the "Organic_farms". The prosperity of the "Organic farms" therefore depends on the "Support_resources", which are not only financial means. Here, the social impact of organic farming represents the supportive environment that should sustain such an activity, which in the world of consumption is counterintuitive. The "Conversion" is also dependent on the total food production and "Food demand".

The model is used in order to simulate different scenarios that enable the assessment of policy scenarios with respect to the development of organic farming.

Scenarios 1, 2 and 3 (Figures) represent the increase of the subsidies and the impact on the transition rate. Scenario 4 shows the impact of the increased promotion factor, which would yield the higher limit conversion to the organic farming. The impact of the increased delay in providing self-support resources is shown by Scenario 5. Here, one assumes that this delay is increased from two to four years on average. Scenario

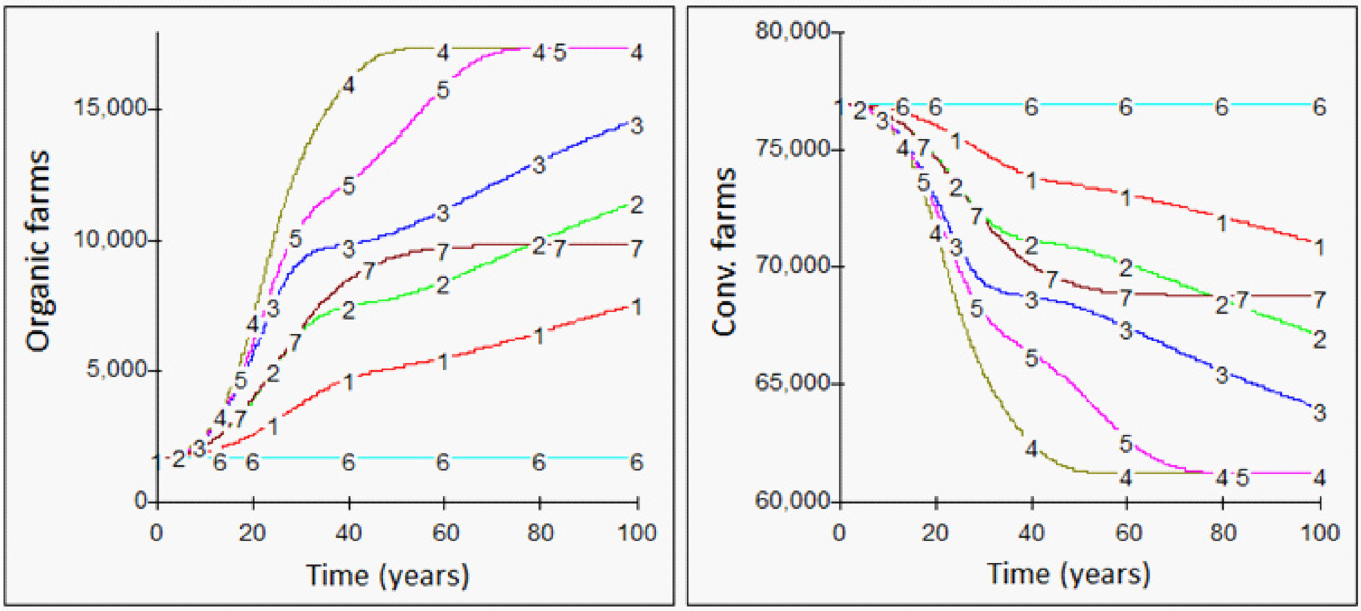

Figure 8: Number of organic farms

6 represents the increase in the population that would lead to the status quo in the number of Organic and Conventional farms. It is supposed that the transition in this case would not occur due to the increased food demand. In this case, the negative conversion could also be considered; however, this is the limitation of the proposed model. Scenario 7 shows the transition to organic farming if the coefficient of food demand decreased, which would be the case if, for example, the imports of food increased.

However, the system dynamics model does not provide numerical forecasts. It is rather a policy tool that examines the behaviour of key variables (number of organic farms) over time. Historical data and performance goals provide baselines for determining whether a particular policy generates the behaviour of key variables that is better or worse when compared to the baseline or other policies. Furthermore, models provide an explanation for why specific outcomes are achieved. Simulation allows us to compress time so that many different policies can be tested, the outcomes explained, and the causes that generate a specific outcome can be examined by knowledgeable people working in the system before policies are actually implemented.

CONCLUSIONS

In this paper, we discuss SD methodology as a proper tool for research in agriculture and ecology. Our goal was to highlight the usefulness of SD methodology in research and its implementation in agriculture, suggest that the methodology be applied in research in agriculture. We briefly discuss the fundamentals of SD methodology, models and CLD, as well as model validation. The advantage of the SD as a part of the Systems Approach is in the fact that a problem defined in natural language can be easily transformed into a directed graph that is convenient for qualitative and quantitative analysis in a computer program. In this case, the user can always check the validity of the stated problem and the model developed. SD enables studying the behaviour of complex dynamic systems as a feedback process of reinforcing and balancing loops. As such, it provides testing of dynamic hypotheses about anticipated properties of the IS: Life Cycle Development, Quality of Systems and Information System Success. As a methodology, applying SD in analysing complex system behaviour is very important from several reasons: it is simple, because it is based on natural laws of Rate and Storage that describes relations between elements in quantitative/qualitative relation; transparent, because it allows unique discussion about elements relations defining problem; and coherent, because it consists of simulation tools harmonised with methodology and the problem to be solved. SD is a trans-disciplinary methodology, because it provides complex problem solving from different perspectives in interconnection with R and L elements.

Simulation, together with the Systems Approach, has become ever more central to the development of complex systems. Human knowledge and the simulation methodology combined in a decision support system offer new levels of quality in decision making and research in the field of agriculture. The utility of SD methodology of complex agricultural process modelling for public decision assessment for sustainable development has been positively demonstrated.

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