SYSTEM DYNAMICS SIMULATION MODELLING OF “KASTELA BAY” REGIONAL SYSTEM

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Abstract

Although large developed System dynamics model can be applied on different ecological system in this paper it is applied on Kastela region in Croatia. The Computer Simulation Sub model of The Ecological Regional Subsystem of the "KASTELA BAY" is an extra relevant submodel of The System Dynamics Computer Simulation Model of the “KASTELA BAY” which has been developed with the help of System Dynamics. It is, in its essence, a continuous model because it is presented as a system of non-linear differential equations. At the same time, it is a discrete model, because it is presented as a system of linear differential equations (System Dynamics DYNAMO - software package). Its DT (length of intervening time = computation interval) is chopped in full accordance with the Sampling Theorem (Shannon and Koteljnikov). The System Dynamics Computer Simulation Model of the "Kastela Bay" also employs certain experience gathered by experts who had worked on the preparation of projects: "Blue Plan" and "The Methodological Basis for the Scenario of the Management of Natural Resources of the "Kastela Bay"" (1991).

Keywords: System Dynamics Modelling; Ecological model; sub model RSKB

1. Characteristics of the Regional System of the “Kastela Bay”

RSKB - The Regional System of the “Kastela Bay” (Figure 1.) is presented as an entity consisting of six relevant subsystems: 1. Population, 2. Economic activities, 3. Social activities (social and national income), 4. space and the environment, 5. economic output (social and welfare activities) and 6. socio-economic development policy. The RSKB is analysed as a “whole” consisting of the four subregional communes: KASTELA, SPLIT, SOLIN and TROGIR (Figure 1.).

Figure1. The Regional System of the “Kastela Bay” – RSKB

These communities communicate with the following entities/environments: 1. The Republic of Croatia (without RSKB), 2. Independent recognised countries of the former Yugoslavia (without current Yugoslavia), 3. The Mediterranean countries (without Yugoslavia) and 4. the rest of the world (the remaining developed countries, except those of the Mediterranean). The RSKB could be presented as a rudimentary communicational model which fully corresponds to the relevant environment: 1. CROATIA, 2. FORMER YUGOSLAVIA, 3. MEDITERRANEAN and THE REST OF THE WORLD (Figure 2.).

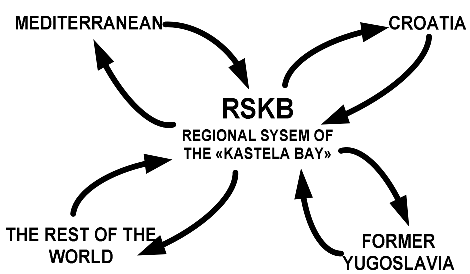

Figure2. Rudimentary Structural Inter-Communicational Model of RSKB

The Regional System of the "KASTELA BAY"- RSKB in a local social and "whole" context, is the territory defined by the acquatorium and the area around the Kastela Bay, the mountain ranges and the Adriatic sea. It is situated in the middle of the Eastern Adriatic Coast. The national context is defined as the area of the Republic of Croatia. At the same time, RSKB is part of the Mediterranean Regional Socio-Ecological System and the Rest of the World-Socio-Ecological System too, and the corresponding territory, i.e. the "continental, maritime and aerial space" which communicate with the environment. System Dynamics Highly-aggregated Structural Model of RSKB could be represented as "a whole".

2. System dynamics simulation sub model of the ecological subsystem of the "Kastela Bay"

This sub model consists of the: 1. qualitative (mental, verbal and structural) and **2.** quantitative (mathematical and computer) System Dynamics Simulation Models. The Ecological Subsystem of the "Kastela Bay" has six subsections: 1.- air pollution; 2.- land pollution; 3.- sea pollution; 4.- pollution of the seabed with radioactive particles, other organic and inorganic matter; 5.- external pollutants (RSKB environment) & 6.- internal pollutants (The RSKB environment has five parts: 6.1. urban areas (settlements, tourist accommodation, industry and services, transport and residential areas), 6.2. agriculture, 6.3. archaeological sites, 6.4. exploitation, and 6.5. forests and other areas).

The system dynamics model of the ecological subsystem of the RSKB has four pollution sectors: 1. Air, 2. Land, 3. Sea, and 4. The seabed. Each of these has three pollution subsections: 1. radioactive particles, 2. other particles (heavy metals) and 3. biological cells.

Using the "analogy" principle between the "a continuous dynamic cycle of water particles interacting with the environment", and the "a continuous dynamic cycle of radioactive particles pollution and other particles pollution interacting with Air, Land, Sea and the Seabed**,** makes it possible to present the continuous Ecological Subsystem of RSKB with the following simplifications of the natural cycle of pollution between AIR, LAND, SEA and the SEABED with the RSKB and its environment, or in short: the structural model (Figure 3.).

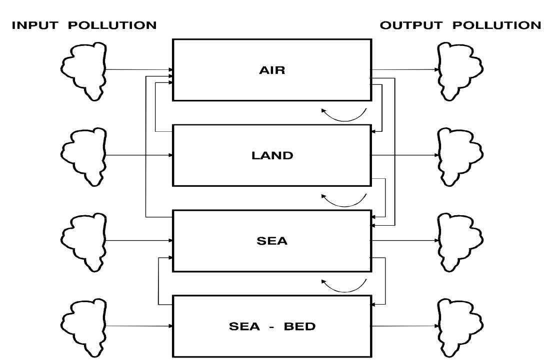

Figure3. Highly-aggregated Structural Ecological Sub model of the RSKB

This ecological highly-aggregated structural sub model, in reality, has many more material and information flows or negative and positive feedback loops, then presented here, and some of them cause consequence variables, mixed between themselves and their environment. Endogenous material and information flows are**:** material and social standard of living of the RSKB, internal pollutant, urbanisation, land use, natural resources, population, economy, socio-cultural framework, development policy, etc., and the exogenous flows are: pollutants in Croatia, former Yugoslavia, Mediterranean and Rest of the World social systems.

But we must bear in mind that RSKB and its environment exist in total harmony with natural laws, and we have to take into consideration the influence of: 1.- wind, 2.- precipitation and 3.- sea-currents. All of these causes or/and consequence variables built into our ecological model represent these variables through "multiplex inter communication channels":1.“A”, 2. “B” , 3.“C”and 4. “D”. In a global structural sense, the sublimated model – the Ecological Subsystem of the RSKB, made in accordance with System Dynamics, could be presented as shown in Figure 4.

2.1. System dynamics qualitative model of the ecological regional subsystem of the "Kastela Bay"

In accordance with all these methodological cognitions and other natural and social laws, it is possible to work out this elementary qualitative model of the pollution subsection of the AIR, LAND, SEA and SEABED of the RSKB in structural-mental-verbal forms in a system dynamics way**.** Each of the pollution material flows and levels (in this case: 1.-radioactive particles, 2.-other particles and biological cells) could be presented with the analogous structural model in a System Dynamics POWERSIM-symbolic way (Figure 5.).

The global input rate of the radioactive pollution at the AIR-RSKB depends on the three variables:

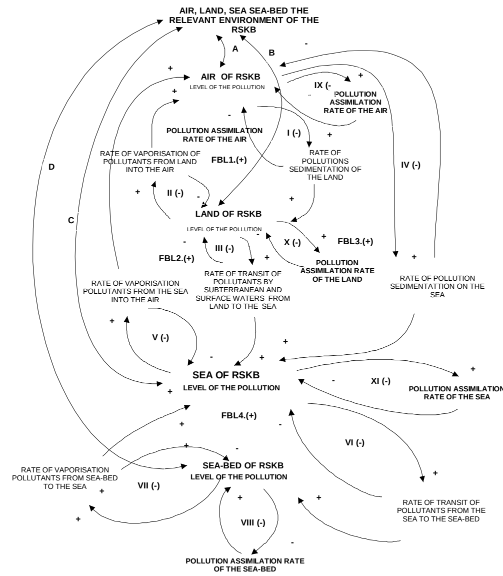

Figure4. Rudimentary System Dynamics Structural Model of the Ecological Subsystem of the RSKB

1. IRPRA **-** input radioactive pollution rate of AIR as the sum of the two components

1.1.**IPFERPA -**input pollution flow of the exterior pollutants.The **IPFERPA** depends on the three variables:

1.1.1.**NPREPA -** normal pollution rate of the exterior pollutants in AIR-RSKB,

1.1.2.**CEECA** - catastrophic radioactive pollution events in the environment with consequences to AIR-RSKB (Chernobyl), and

1.1.3.**WCQFA** - wind consequence factor. The **WCQFAA**-wind consequence factor depends of the:

1.1.3.1.**SWG -** simulated wind **-** generator, respectively as an empirical-statistic software model.

1.2.**IRPIA -** internal radioactive pollution input flow of AIR. The **IRPIA** depends of the three variables:

1.2.1.**INRRAP** - internal normal rate of radioactive AIR pollution. The **INRRAP** depends of the:

1.2.1.1.**RIKB -** regional income of the **RSKB.**

1.2.2. **CIERPAA**-catastrophic internal events of radioactive pollution of AIR-RSKB.

1.2.3.**WCQFA**-wind consequence factor. The **WCQFA**-wind consequence factor depends of the:

1.2.3.1.**SWG -** simulated wind-generator, respectively as an empirical-statistic software model.

2.VRRPS - vaporising rate of radioactive pollution from the SEA into the AIR. The **VRRPS** depends of the three variables:

2.1.**RPLS -** radioactive pollution level of the SEA -RSKB,

2.2.**AVTRPSA -** average vaporising time of radioactive pollution from the SEA into AIR-RSKB,

2.3.**WCQFA-**wind consequence factor.

3.VRRPLA - vaporising rate of radioactive from the LAND to the AIR-RSKB. The **VRRPLA** depends of the three variables:

3.1.**RPLL-**radioactive pollution level of the LAND-RSKB,

3.2.**ATRVPLA -** average time of radioactive pollution vaporising from LAND into AIR,

3.3.**WCQFA-**wind consequence factor.

Seven rate variables make an impact on the **RPLA**-radioactive pollution level of AIR. Three of them are input material flows: **IRPRA; VRRPS; VRPRLA;** and four of them are output material flows: **NRARA-**natural radioactive assimilation (decay) rate of AIR; **ORPRAE-**outflow of radioactive pollution rate from AIR into the environment; **RPSRAL-**radioactive pollution sedimentation rate from AIR to the LAND; **RPSRAS-**radioactive pollution sedimentation rate from AIR to the SEA.

In general, this qualitative radioactive pollution model of the ecological sub sector of AIR-RSKB is very suitable for the presentation of other radioactive particles, other material particles and biological cells ecological RSKB-AREA sub sectors such as: LAND, SEA and SEABED, because all the material flows (radioactive particles, other material particles and biological cells) in AIR, LAND, SEA and SEABED of the RSKB have a high degree of the natural system dynamics analogy. This means that this model is going to be a general representative (modular) for the dynamics behaviour of the 1. Radioactive particles, 2. Other material particles and 3. Biological cells in AIR, LAND, SEA and SEABED of the RSKB and every other pollutant material, which makes it possible to treat it as an analogous global structural model.

System Dynamics Structural Simulation Model of the Ecological Radioactive Pollution Sub sector of the RSKB, in the **DYNAMO (or POWERSIM)-**graphic symbol icons, could be presented as shown in Figure 4.

The level of the “global radioactive pollution” of the RSKB is presented here in two ways: 1.**SSRPKB-**simple sum of the AIR, LAND, SEA and SEABED radioactive pollution levels of RSKB, and 2.**VSRPKB-** vector sum of the AIR, LAND, SEA and SEABED radioactive pollution of RSKB. It is essential to show that this model must have three exogenous simulated generators:

1.-**“SWG”-**simulated wind generator, which has indirect consequential influence on the following variables: **IPFERPA-**input pollution flow of the exterior radioactive pollutant in the RSKB-AIR, **ORPRAE-** outflow of radioactive pollution rate from AIR to the environment**, IRPIA-**internal radioactive pollution input flow of AIR**;**

2.**“SPG”-**simulated precipitation generator-which has indirect consequential influence on the following three variables: **RPSRAL-**radioactive pollution sedimentation from AIR to the LAND,

ERPL-external radioactive pollution rate of LAND, **IRPL-**internal radioactive input flow rate of the LAND;

2.2. System Dynamics quantitative model of the ecological regional subsystem of the "Kastela Bay"

This System Dynamics Quantitative Model has been made in full accordance with the System Dynamics Methodology and DYNAMO PROFESSIONAL PLUS and POWERSIM software package. The authors of this model have used a practical "software modular principle" and have constructed several models of the different media (RSKB's AIR, LAND, SEA, and SEABED) and different pollution (radioactive particles, other material particles and biological cells). Due to limited space in this paper, the authors are going to show only one computer simulation sub model: the radioactive pollution in the AIR, LAND, SEA and SEABED of the RSKB. As the foundation for determining this quantitative model, the presented qualitative (mental, verbal and structural) system dynamics universal model (Figures 1.,2.,3.,4., and 5.) and other heuristic knowledge about radioactivity natural laws can be used.

2.2.1. Behavioural dynamics of radioactive pollution of the RSKB

Behavioural dynamics of this "System Dynamics Computer Simulation Model of the Radioactive Pollution Subsystem of RSKB" is presented in the following figures, where those variables have the following meaning: SPG-Simulated Precipitation Generator; SWG-Simulated Wind Generator; SSCE-Simulated Sea-current Generator; RPLA-Radioactive Pollution Level of AIR; RPLL-Radioactive Pollution Level of LAND; RPLS-Radioactive Pollution Level of the SEA; RPLSB-Radioactive Pollution Level of the SEABED; and RIKB-Regional Income of the "Kastela Bay".

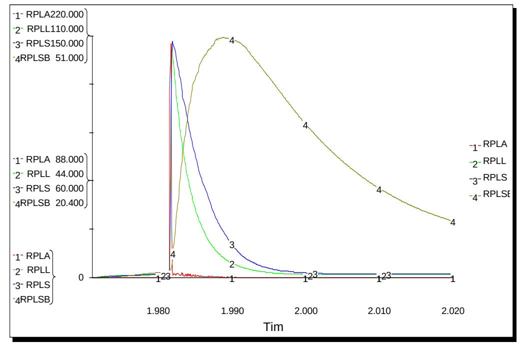

Figure 6. The simulated result of the complete radioactive pollution model of RSKB

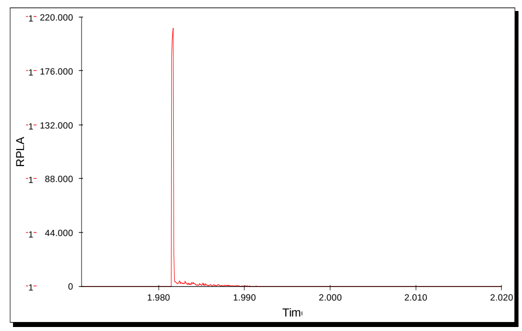

Figure 7. The simulated result of the RPLA-Radioactive Pollution Level of AIR

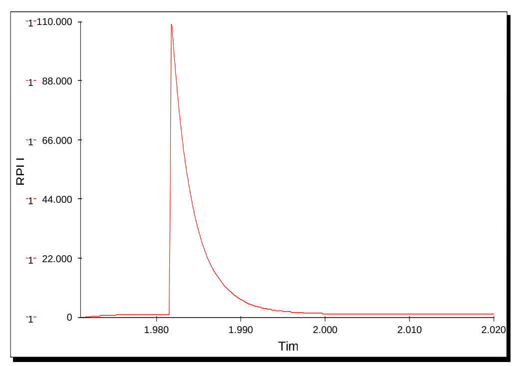

Figure 8. The simulated result of the RPLL-Radioactive Pollution Level of LAND

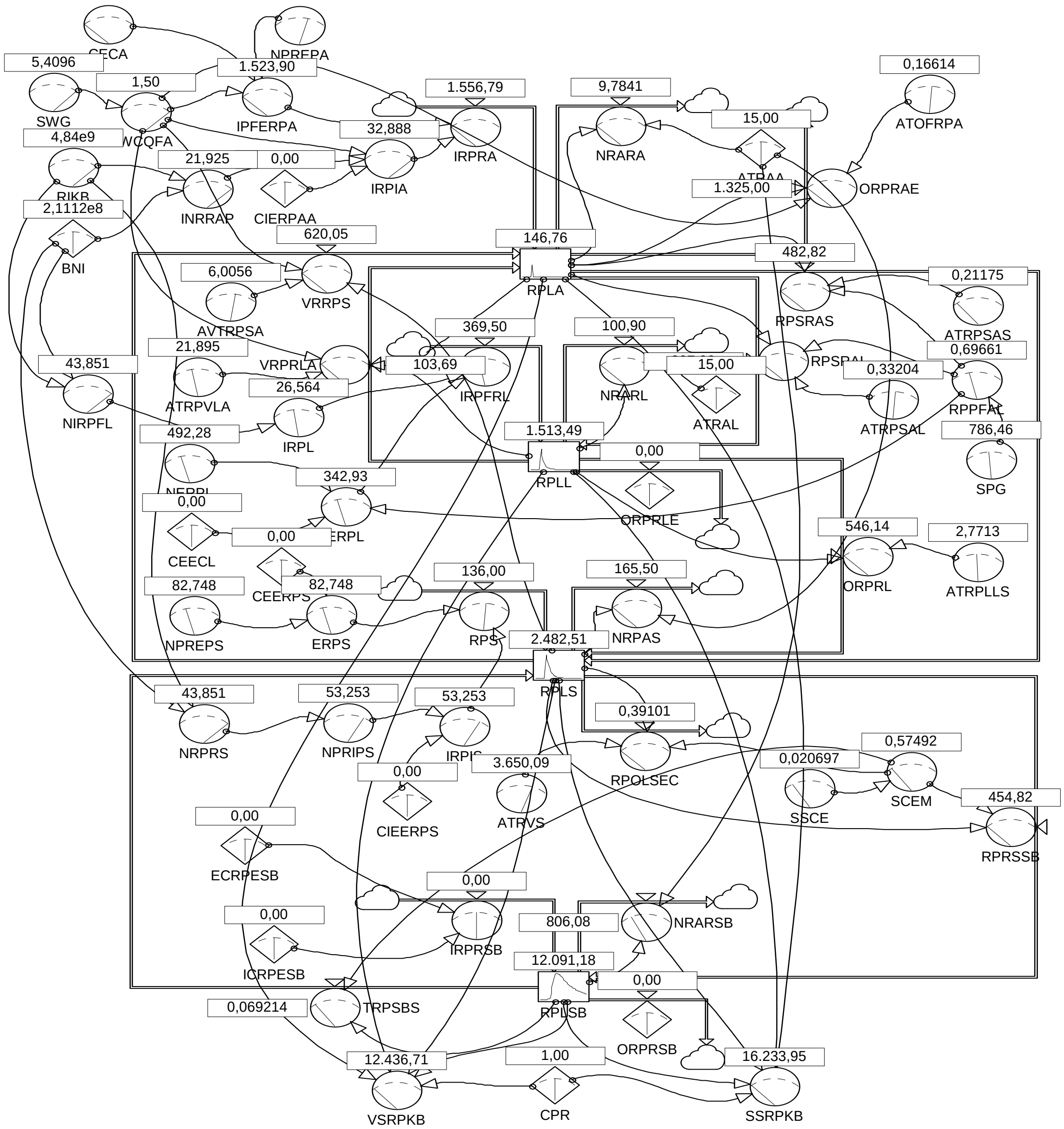

Figure5. System Dynamics Structural Model of the Radioactive Pollution Subsector of the RSKB

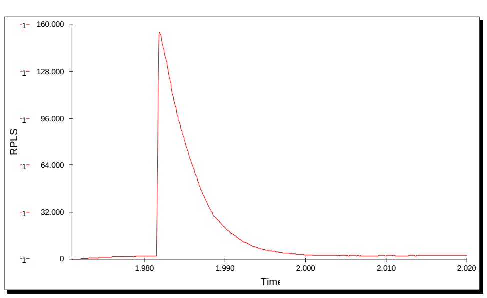

Figure9. The simulated result of the RPLS - Radioactive Pollution Level of the SEA

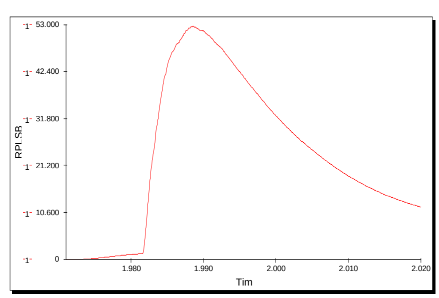

Figure10. The simulated result of the RPLSB-Radioactive Pollution Level of the SEABED

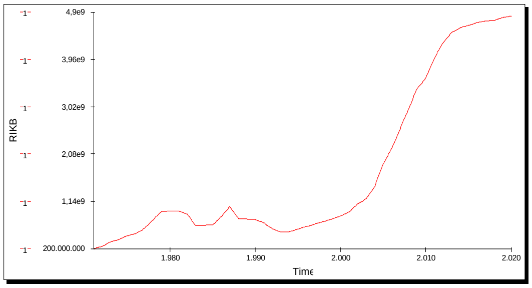

Figure 11. The simulated result of the RIKB-Regional Income of the RSKB

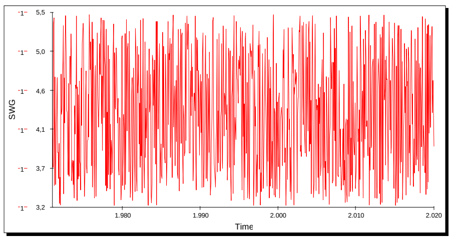

Figure 12. The simulated result of the SWG-Simulated Wind Generator

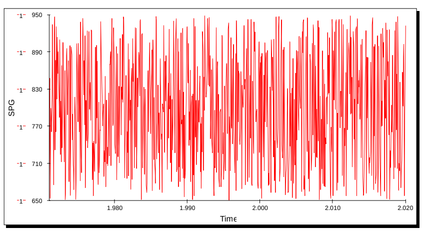

Figure 13. The simulated result of the SPG-Simulated Precipitation Generator

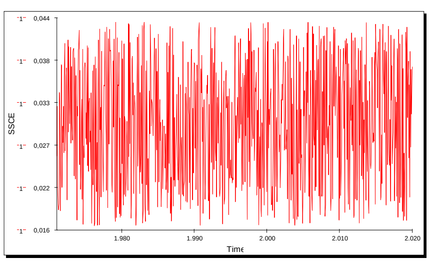

Figure 14. The simulated result of the SSCE - Simulated Sea-Current Generator

3. A complete model of the ecological subsystem of RSKB

The Ecological Regional Submodel of the RSKB has more then three equations because it has three “parallel” pollution sectors: 1.-radioactive, 2.-other material particles (heavy metals) and 3.-biological cells. If a project found a precise and simple way of identifying some other pollutant, new “parallel” sectors could be added.

Every level of the pollution is presented, in this case, as a “first order non-linear differential-integral equation system”. The complete model of the Ecological Regional Subsystem of RSKB is presented through a 12 non-linear differential equation system, and each of the levels is presented, in this case, with a differential equation in the DYNAMO or POWERSIM program language also, because DT was chosen to be in accordance with the Sampling Theorem (DT=0.0625 year). The non-linear dynamic character of the complete model is the result of using numerous stochastically and tabular variables.

A number of different scenarios have also been simulated and this model, as a cause/consequence part of the global model of RSKB, coincided well with a lot of measure experiments. All scenarios are based on the following criteria: 1.-the means to reduce pollution, 2.-quality of development, 3.-quality of environment.

4. Conclusion

The Computer Simulation Model of the Ecological Continuous Subsystem of the "Kastela Bay" is a discrete-digital and continuous model, because DT was chosen to be in accordance with the Sampling Theorem. It is of a high order, non-linear, stochastic, highly complex and relatively simple-modular as a software. Also, it is highly applicative, and adaptable to the computer simulation modelling of other regional analogous systems.

All resultants of simulation gained through the use of the ecological model of the RSKB point to the universal fact that the seabed is exposed to the highest level of jeopardy by long-term pollution of assimilation materials. This means that the seabed fish and other seabed biological organisms make the most dangerous food.

This ecological model of the RSKB has been made as an important part of the global model of RISK and it has been conducted through the Mediterranean Action Plan according to the Joint Venture Agreement signed by national and approved by the local authorities. This entire Program has been defined within the wider national project “Rational management of the Kastela Bay Area”, carried out by the University of Split, in co-operation with numerous national and international institutions. It has been supported by both the European Community and the International bank.

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