Joint Research Project

between National Academy of Sciences of Ukraine and
International Institute for Applied Systems Analysis

1. Title of the NASU-IIASA project: Integrated robust management of food-energy-water-land use nexus for sustainable development

2. Key words: global-local changes, uncertainty, endogenous and exogenous systemic risks, food, energy, water, land use, nexus, security, sustainable development, asymmetric information, linkage

3. Duration: January 2017 to December 2021

4. Applicant information

4.1. NASU's participants

NASU's participants create a partnership of seven leading institutes of NASU collaborating also with networks of national and international organizations, advisors, and policy makers. Financially, the NASU's participants are supported by NASU. The following participants (institutes) provide science-based advises to diverse policy makers in Ukraine (IIASA Policy Brief, 2017).

Principle Investigator (Ukraine): NASU Vice-President, Deputy Chairman of the NASU Committee for Systems Analysis, Ukrainian representative at IIASA, Academician Prof Dr. A. G. Zagorodniy

Deputy Principal Investigator (Ukraine): Member of the NASU Committee for Systems Analysis, Ukrainian representative at IIASA, Academician, Prof. Dr. V.L. Bogdanov

Institute of Cybernetics, NASU: Director, Academician Prof. Dr. Ivan V. Sergienko, Academician Prof. Dr. V. M. Shestopalov, Prof. Dr. P. S. Knopov, Dr. V.S. Kyrylyuk, Ph.D. K.L. Atoev, Ph.D. T.V. Pepelyaeva, Ph.D. O.M. Golodnikov, Dr. E.F. Galba, Ph.D. M.V. Belous, Ph.D. Yu.F. Rudenko, Ph.D. M.I. Zheleznyak

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Institute of Economics and Forecasting, NASU: Director, Academician Prof. Dr. Valery M. Heyetz, Dr. O.M. Borodina, PhD. S.V. Kyryzyuk , PhD. G.Yu. Lopatynska, PhD. R.Z. Podoletz, PhD. O.A. Dyachuk (Divisions: Agricultural economics, Energy developments)

Institute of Theoretical Physics, NASU: Director, Academician Prof. Dr. Anatoly G. Zagorodny

Institute of Demography and Social Studies, NASU: Director, Academician Prof. Dr. Ella M. Libanova, PhD. L.M. Cherenko, M.Sc. O.A. Vasiliev, M.Sc. A.G. Reut

Institute of Applied Systems Analysis, National Technical University, Ministry of Education of Ukraine, NASU: Director, Academician Prof. Dr. M.Z. Zgurovsky, Prof. Dr. N.D. Pankratova

4.2. IIASA's participants

Principal Investigator, Academician Prof. Dr. Y. Yermoliev (ASA) will coordinate collaboration between NASU's institutes, IIASA's team and the Ukrainian NMO, and will contribute to performing the integrated modeling tasks. Prof. Yermoliev's scientific interests are on decision processes in the presence of risks and uncertainties, non-smooth stochastic and dynamic systems optimization, optimization on networks, nonlinear dynamics, linkage methods, systemic risks, security management, and robust solutions. Prof. Y. Yermoliev is a co-editor of four books on "Coping with Uncertainties", Springer Verlag, 2004, 2006, 2010, 2012 and books on Integrated modeling of food-water-energy security management (Zagorodny et al., 2014; 2013; 2012).

Deputy Principal Investigator, Dr. T. Ermolieva (ESM) will contribute to the development of models for robust coherent policies and data harmonization (upscaling, downscaling), model linkage methodologies. Dr. T. Ermolieva has rich experience in modeling complex socio-economic, environmental and agricultural systems under risks and uncertainty including incomplete and/or asymmetric information.

Dr. E. Rovenskaya (ASA) will contribute to the development of downscaling and model linkage methodologies to integrate global models with national and subnational models for the analysis of robust food-water-energy nexus.

Dr. P. Havlik (ESM) will contribute to the development of downscaling and model linkage methodologies to integrate global models with national and subnational models for the analysis of robust food-water-energy nexus.

Dr. M. Obersteiner (ESM) will contribute to the development of downscaling and model linkage methodologies to integrate global models with national and subnational models for the analysis of robust food-water-energy nexus.

Dr. K. Taher (WAT) will contribute to the development of linkage algorithms between land use and water modules.

Dr. M. Obersteiner (ESM); Dr. J. Linerooth-Bayer, Dr. R. Mechler, Dr. N. Komendantova (Risk and Resilience); Dr. F. Wagner, Dr. W. Winiwarter (AIR); Dr. K. Riahi (ENE, TNT), Dr. V. Krey (ENE), Dr. M. Strubegger (ENE); Dr. K. Taher, Dr. G. Fischer, (WAT) will provide intellectual support without dedicated efforts in terms of person/months.

5. Abstract

The project is a new stage of the IIASA-NASU project "Integrated modeling of food, energy and water management for sustainable social, economic, and environmental developments" completed in the period from 2012 to 2016 (Options Magazine Winter 2016; IIASA Policy brief, 2017; Zagorodny et al., 2012, 2013, 2014). The goal of the 2017-2021 project is to develop further and implement novel systems analysis (SA) approaches addressing problems of common interest for Ukraine, IIASA and globally, emerging in designing solutions for robust sustainable Food-Energy-Water-Environmental-Social (FEWES) nexus management, which cannot be solved by traditional approaches. The robustness is achieved by spatially-explicit portfolios of interdependent strategic (long-term) and adaptive (short-term) feasible solutions.

Traditionally, FEWES sectors are being governed by independent policies, and the impact of each policy on the other systems is inadequately considered—if at all. Ignorance of these interdependencies in Ukraine led to uncontrolled agricultural production intensification, imbalanced land utilization, and soil, water, air pollution/contamination by heavy metals and other components of wastes and residues of agricultural activities, application of fertilizers and pesticides. Land concentration with focus on profits led large enterprises to reducing payments on human's capital resulting in massive migration; agricultural dualization characterized by small domestic-market-oriented and large international-market-oriented producers; destructions of rural settlements; income polarization and loss of welfare; depopulation and increase of unemployment and poverty.

The project will investigate coordinated robust solutions accounting for complex linkages and differences in spatial and temporal scales between agriculture, energy, water systems, potential exogenously and endogenously generated collective systemic risks and new coherent feasible policies enabling FEWES nexus security. The policies will take into account interregional and international trade, current and future national and international agreements and directives (WTO agreement, EU Water Framework Directive, Common Agricultural Policies, etc.), pollution and GHG emissions targets, current and future energy and water technologies, insurance markets, financial instruments, grain and water storages, direct and indirect exchange of resources, e.g. pollution trading, virtual water trade, etc.
The goal of the project is to develop a harmonized approach for integrated robust management of FEWES nexus under natural and human-related intentional and unintentional threats. Developing new linkage methods under asymmetric information will allow integrated modeling without revealing information about individual sectorial models. In order to achieve long-term sustainable functioning of FEWES systems, robust policies will comprise both interdependent strategic long-term (anticipative, ex-ante) decisions and short-term (adaptive, ex-post) decisions (adjustments), which will be designed with a help of integrated stochastic optimization models based on novel ideas of systems' linkage under asymmetric information and other uncertainties. Nested strategic-operational and local-global models, including deterministic and stochastic GLOBIOM, will be used in combination with non-Bayesian probabilistic downscaling procedures for analyzing and managing global systemic risks having local implications. Quantile-based indicators will be used to cope with new type of risks and extreme events generated by decisions of various stakeholders and potential adversaries. A harmonized Ukrainian data base will be compiled to serve as models input. Appropriate strategic-adaptive Decision Support System (DSS) will be developed enabling a dialogue among national and international stakeholders.

In contrast to traditional studies using different research principles, isolated (independent) models and data from diverse regions at different time intervals, this project aims at systematic and coherent multimodel approaches by a research team from seven non-profit institutes of the National Academy of Sciences, Ukraine, working in collaboration with International Institute for Applied Systems Analysis and other national and international organizations.

6. Project Description

6.1. Introduction

Increasing global-local inter- and intra-regional and sectorial interdependencies may significantly affect systemic instabilities even under insignificant at the first glance peripheral changes, e.g. due to introduction of new technologies, policies, or weather variability and natural disasters. This project will continue developing initiated in the first period 2012-2016 (Zagorodny et al., 2012; 2013; 2014) adequate integrated models enabling evaluations of critical global-local multi-sectorial nexus and systemic risks with potential cascading impacts.

Detailed sectorial models have been traditionally used to anticipate and plan desirable developments of the respective sectors. However, independent analysis and policies supported by these models ignore joint goals and constraints, which can lead to wrong policy implications. The absence of joint monitoring of available resources under increasing interdependencies among countries and their sectors can cause "unexpected" shortages, systemic instabilities and insecurity. For example, during extensive droughts and high water demand for agriculture, several power reactors in US had to shut-down in August 2007.

In the project, security is understood as an ability to fulfill the needs of the society for food, energy, water, environment, etc., under standard requirements for their qualities, quantities, and risks. The increasing interdependencies among FEWES sectors require coordinated policies. At the same time, on regional and local levels, especially in energy and agriculture, we can observe inconsistent decentralization and deregulation processes creating heterogeneous independent producers and distributors deciding their production plans and other activities according to instantaneous market conditions. In this case, the lack of proper coherent long-term policies may easily induce global systemic risks and failures, preventing sustainable developments. This requires new systemic regulations which will be designed by developing linkage methods enabling to analyze coordinated solutions without revealing sectorial information.

The importance of coherent integrated modeling approaches for analyzing secure access to food, energy, and water became especially evident for NASU researchers after the Chernobyl disaster. Institutes of NASU accumulated significant experience in this area. The Bonn Conference on the Water, Energy, Food Security Nexus emphasized that to "ensure the interdependency between water, energy and food security is explicitly identified in decision-making within and across all levels to realize the potential for mutually beneficial action and avoid conflicting policy objectives and unintended consequences (Bonn Conference 2011, see also OECD Studies on Water, 2012).

The lack of coherent integrated governmental policies in Ukraine created the dualization of agriculture (Zagorodny et al., 2014; Atoyev et al., 2014; Golodnikov et al., 2013; Keyzer et al., 2013, 2017; Acs et al., 2013; Borodina et al., 2013) between small domestic market-oriented household farms, playing a central role in domestic food supply and national food security, and large market-oriented agricultural enterprises with strong priority for producing highly demanded on international markets crops such as "bioenergy" crops. This created strong exposure to (international) market risks and led to uncontrolled agricultural production intensification, imbalanced land utilization, soil, water, air pollution by heavy metals and other components of wastes and residues of fertilizers and pesticides. Land concentration with focus on profits led large enterprises to reducing investment in humans capital resulting in migration, destructions of rural settlements, income polarization, loss of welfare, depopulation, increase of unemployment and poverty.

The new methodological challenge of the project concerns proper SA of controversies, which are characterized by increasing interdependencies among countries and their sectors, but at the same time - increasing decentralization and deregulation of sectors generating potential global risks shaped by intentional or unintentional actions of various, including agricultural, water, energy and environmental, stakeholders. These endogenous risks can harm sustainable developments (Ermolieva et al., 2016; Borodina et al., 2016; Ermoliev and von Winterfeldt, 2012), e.g., causing cascading black-outs and power shortages in California, price surges in Norway, floods from hurricane Katrina, events in Japan, and world-wide financial and economic crises.

Therefore, the integrated management of FEWES under various threats will be based on developing non-Bayesian stochastic models with "learning", comprising strategic long-term anticipative decisions linked to the adaptive responses. Apart from linkage in time by strategic and adaptive decisions aiming to make optimal robust short-term decisions from long-term perspectives, the project will develop and implement linkages of distributed models. This allows for proper representation of interdependent collective systemic risks and robust sustainable policies. Simple approaches using aggregate treatment of the risks leads to wrong policy implications (Cano et al., 2016; Ermolieva et al., 2016a, b;), as e.g. in agriculture average seasonal temperature or average precipitation, cannot reveal potential critical variability of crop yields and crop production. The average treatment would negatively affect the composition of technological portfolios; underestimate the role of grain storages, water retention areas or reservoirs, advanced irrigation technologies for buffering food production and price surges; overestimate the role of markets for risk-reduction and sharing; provide misleading view on insurance and risk pricing mechanisms; which as a result will affect sustainable developments.

6. 2. Approach

The main methodological goal of the project is to develop and implement integrated modeling approaches allowing joint planning of FEWES sectors under asymmetric information about the sectorial models, e.g. when a sector does not have information about models of other sectors. The standard approach for integrated modeling by linking submodels in one place requires full access to sectorial models for recoding, rescaling and reparametrization of them. Often this is an infeasible task unless the sectorial models have a very simple structure. The project will develop and implement new methods enabling linkage of sectorial models under asymmetric information and other uncertainties. Idea of using a cloud computing under asymmetric information will be developed further for the analysis of sustainable robust management of interactions and systemic risks in interdependent distributed FEWES systems.

The long-term concept of sustainable developments calls for proper spatially explicit treatment of uncertainties because the linkage in combination with on-going deregulation processes may create interdependent collective systemic risks of high consequences. Explicit modeling of linkages allows evaluation and treatment of such “insensible” risks under standard independent planning of sectors. For example, increasing demand for bio-fuels magnifies weather-related risks affecting energy sector. At the same time, the extensive bio-fuels production affects food security, intensifies land use, causes pollution of land and water, increases health risks. Therefore, in this project we develop models and methods for SA of FEWES nexus under risks affected (intentionally and unintentionally) by decisions of various agents.

The standard risk management approaches are based on evaluations of probability distributions using repetitive observations of the same system and solving then decision making problems with found probabilities (see discussion in Ermoliev and von Winterfeldt, 2012). The focus of this project is on designing new systems never observed in reality, hence real observations are not available because they may be expensive or simply impossible. Therefore, exact predictions are practically impossible. Hence, this project will use a concept of robust solutions which are in a sense optimal for any scenario of potential uncertainties. The following simple example illustrates this concept.

Example. Assume that the next agricultural season may be dry (scenario 1) or wet (scenario 2). A crop A is the best solution (for sustainable developments) in scenario 1, whereas a crop B is the best solution in scenario 2. Because exact prediction is impossible, the best robust solution would be a crop C, which is good for both scenarios although it is not as good as crop A in scenario 1 and crop B in scenario 2. A robust solution may also be a mixture of crops and grain storages, and an access to markets.

The concept of robust solutions equally optimal (in a sense) for all sectors under all potential scenarios will be based on ideas of multi-model nested stochastic maxi-min type models proposed in (Ermoliev and Norkin, 2013; Ermolieva et al., 2016a, b; 2013; Ermoliev et al., 2000, 2013. See also numerous references therein).

It is important to compare this approach with traditional approaches used for natural systems governed by laws. In this case it is possible to use rich sets of observations of the same system, identify the governing law and build a model predicting state of the system under consideration. The project is dealing with decision-based FEWES systems, affected by unknown in advance decisions and threats induced by these decisions. Therefore, instead of prediction, the main role of the SA is shifted to designing a robust policy that is better-off for all potential uncertainties, i.e. equally efficient paths of sustainable sectorial developments.

Thus, the project is directed to development, improvement and adaptation of models and systems-analytical approaches for effective robust decision support in field of food, water, energy security and related natural resource management, support of sustainable social, economic and ecological development using case studies in Ukraine. In particular, related economic studies of FEWES nexus extending previous modeling work (Zagorodny et al., 2012, 2013, 2014; Atoyev et al., 2014; Golodnikov et al., 2013; Borodina et al., 2010, 2013, 2016; Kyryzyuk et al., 2011, etc.) will be carried out as cross-cutting activities in WPs described in section 7. Research methods include: systems analysis, mathematical modeling, nonlinear programming, stochastic optimization for robust solutions, new “leaders-followers” or two-stage dynamic “public-private” decision analysis under uncertainty, data harmonization, GIS-analysis, thematic interpretation (including remote sensing) data.

In its initial stage, the project will rely on studies where the integrated FEWES nexus management models have been already analyzed by researchers from NASU, IIASA and other collaborators (e.g., Zagorodny et al., 2012, 2013, 2014; Keyzer et al., 2017; Borodina et al., 2013, 2016; Xu et al., 2015; Kiczko and Ermolieva, 2011; Yarovyy et al., 2008) using important case study regions in Ukraine, European countries, China. This work creates a solid basis for the initial stages of the project.

The future work within the project will be focused on improvement of data treatment, incorporating better interdependencies among sectors of different countries by integrating stochastic version of global models, e.g. stochastic GLOBIOM, with probabilistic non-Bayesian downscaling (Ermolieva et al., 2016a; Ermolieva et al., 2015; Ermoliev et al., 2017; Ermolieva et al., 2017) and other sectorial models by using new linkage methods.

Modeling of typical “public-private-partnership” character of FEWES nexus policy debates in Ukraine similar to (Ermoliev and von Winterfeldt, 2012; Ermoliev et al., 2013; Ermolieva et al., 2016a,b; Cano et al., 2016; etc.) will use proper representation of links between short-term and long-term decisions, multidimentional risks and extreme events generated by natural disasters and inadequate policies including e.g. the agricultural dualization (Borodina et al., 2013; 2016). This work will require adequate spatio-temporal modeling of FEWES nexus affected by decisions of different stakeholders, other agents and scenarios. The project will design a Decision Support System (DSS) based on developing FEWES nexus management models and a version of a DSS proposed for European ENRIMA (Cano et al., 2016) project. The DSS will enable a model-based stakeholders’ dialogue interrupted by random stopping time moments allowing adaptive adjustments of long-term strategic policies to emerging “unexpected” events. The stopping time concept induces also endogenous social discounting enabling to account for impacts of extreme events which may disturb long-term sustainable developments (Ermoliev et al., 2010; Ermoliev and Ermolieva, 2013; etc.).

There are important similarities between methodological tasks of the IIASA Integrated Solutions for Water, Energy, and Land (IS-WEL) Project, NEXUS Research Cluster (see e.g. iiasa.ac.at/web/scientificUpdate/2015/program/ene/Water-energy-land_nexus.html; iiasa.ac.at/web/scientificUpdate/2013/researchArea/nexus), in particular, NEXUS++ initiative (iiasa.ac.at/Research/IRC/internal/Documents/2017/Nexus++) and methodological goals of the IIASA-NASU, 2017-2021, project. These similarities, especially for designing robust paths of sustainable developments, will be explored and implemented during the period

2017-2021. Designing sustainable development paths under risks and feasibility constraints will be achieved by solving a dynamic optimization model having non-additive and non-smooth structure restricting the use of standard optimal control methods, e.g. the Bellman equations and the Pontrjagin maximin principle.

Production of food essentially depends on balances of water resources and extreme events generated not only by natural disasters but also by failures of policies and regulations. Proper integrated modeling results will be achieved by developing new adequate decision-theoretic approaches in principal agent (PA)- (see motivating discussions in Ermoliev and von Winterfeldt, 2012) or “public-private”-partnership type situations under inherent uncertainty and "intelligent" risks generated by various agents. This framework will allow to achieve robust short-term solutions from long-term perspectives using distributional details with explicit treatment of variability and uncertainty rather than aggregate (average) performance indicators.

6.3. Building on current and past NASU-IIASA collaborative achievements

The project will be built on relevant past and on-going collaborations of NASU and IIASA’s programs.

- Past and on-going collaborative work in Zagorodny et al., 2012; 2013; 2014 (see also other publications in section 10) between NASU`s Institutes and IIASA`s researchers will be a basis of the NASU-IIASA project, 2017-2021, as well as studies on IS-WEL, the NEXUS research cluster and NEXUS++ initiative.

- A methodology for policy assistance using the “leader-follower” or “public-private partnership” principle under inherent uncertainty and extreme events will rely on further developments of approaches proposed by IIASA-NASU researchers and collaborators (Zagorodny et al., 2013, 2014; Ermoliev and von Winterfeldt, 2012; Ermolieva et al., 2016a,b). This methodology has already been successfully applied to large-scale problems of energy security, homeland security, food and water security management.

- A large-scale stochastic integrated model for long-term global energy developments (Gritsevskyi and Nakichenovich, 2002; Gruebler and Gritsevskyi, 2002; Gritsevskyi and Ermoliev, 1999; Messner et al., 1996) under increasing returns and uncertainty was developed by IIASA researchers jointly with researchers from the Glushkov Institute of Cybernetics and General Energy Institute, NASU. The model has a complex network structure. It was solved by using parallel computing on a network of IIASA's computers. It is planned to apply linkage methods for other models based on cloud computing approaches.

- Integrated spatio-temporal catastrophic risk management models incorporating cascading multidimensional extreme events were developed (Golodnikov et al. 2013; Atoyev et al., 2014; Haivoronskyy et al., 2015; Borodina et al., 2015, 2016; Ermolieva et al., 2016a,b; Ermoliev et al., 2000, 2010), in collaboration with the Glushkov Institute of Cybernetics, Institute of Economics and Forecasting, and Scientific Center for Aerospace Research of the Earth, NASU. These spatio-temporal models were used to analyze, in particular, the impacts of the optimal robust mixes of policy instruments on mitigation of extreme multidimensional events, e.g. floods, and on welfare growth in regions and countries (Ermoliev and Ermolieva, 2013). The model allows to evaluate in integrated manner robust mixed decisions of central and local governments, insurers and reinsurers, households, floods and other disasters mitigation decisions regarding land use patterns, reliability of dams, vulnerability of infrastructure, and buildings, the role of catastrophe bonds and contingent forward credits, etc. In these studies, integrated catastrophic risk management models will be based on upscaling and downscaling of several related disciplinary models and related multi-scale massive data sets (e.g., cat models, hydrological models, engineering vulnerability models, multidimensional stochastic cash flow models, insurance models, and financial market models). More references can be found in (Zagorodny et al., 2013, 2014).

• Researchers from NASU's General Energy Institute collaborated with IIASA's programs in global energy assessment studies, assessment of energy pollution, CO2 emission mitigations and trading studies, which are planned to be extended by the project to modeling of water permits trading and water markets (see references in (Zagorodny et al., 2013, 2014).

• Researchers from NASU's Scientific Center for Aerospace Research of the Earth collaborated with IIASA's scientists in climate- and water-related studies, in particular, data treatment on ground and surface water levels, their pollution and changes (Zagorodny et al., 2013, 2014).

• Researchers from NASU's Institute of Demography participated in joint with IIASA studies on scenarios of population growth and issues of poverty in Ukraine (Zagorodny et al., 2013, 2014).

6.4. Research themes

This subsection provides some specific comments on the research plan described in Section 7 having the following workpackages:

1. Developing new and adjusting existing integrated models and DSS for robust food-energy-water resource management for sustainable developments in the face of uncertainty and collective systemic risks

2. Managing agricultural and energy potential under increasing challenges to achieve robust sustainable goals under FEWES nexus

3. Analyzing variations of regional water balances, ecosystems productivity and disasters risk distributions using remote sensing data, climate and environmental change assessment

4. Integrated modeling and planning of sustainable energy sector developments

5. Designing of scenarios and integrated modeling of energy sector transition paths (Shulzhenko, 2015) contributing to sustainable socio-economic and environmental developments ensuring cost-effectiveness, technical reliability, in view of newly adopted norms and targets

6. Modeling and management of recession in socio-economic, technological and environmental systems (Gritsevskyi and Nakichenovich, 2002; Grübler and Gritsevskyi, 2002; Gritsevskyi and Ermoliev, 1999)

7. Analyzing socio-economic and environmental population vulnerability and exposure

These themes reflect critical aspects of food, energy and water sectors and their impacts on sustainable developments according to general conclusions of Bonn Conference 2011; OECD Studies on Water, 2012; FAO research on food security, Water Framework Directive, 2000; etc. In particular, the following issues are incorporated in the WPs:

- Increasing security in one sector affects costs in other sectors

- Water shortages, droughts, floods, heat waves increase the risk of electricity (e.g. blackouts) and food supply

- Increase of energy (water) supply is related to increasing energy (water) supply and reducing energy (water) consumption

- Increase in energy prices are leading to growing interests in bioenergy remaining complex and uncertain issues linking long-term energy developments with short-term location-dependent weather-related extreme events

- Biofuel feedstocks need significant amount of water during photosynthesis. Due to the size of energy markets even a small percentage of biofuels may have critical impacts on water balances and food security

- Biorefineries generate high local water demands

- Increased production of biofuels and agriculture can increase water pollution from nitrogen, phosphorus, pesticides, soil sediment and new emerging contaminants. There are social, economic and environmental costs of pollutants. Optimization of nitrate loading requires long time horizons

- Water distribution, collection, treatment, and heating represent a major consumer of energy. Use of groundwater requires energy for well pumping. Much energy is wasted by irrigating lawns and toilets using high quality drinking water

- Pricing and subsidy provide incentives to develop and adopt the most appropriate technologies. Short-term instantaneous adaptive responses on market signals may create wrong individual incentives with lock-in states of insecure and unsustainable developments

- Agriculture, energy, and water systems are vulnerable to climate changes and weather-related extreme events

- The increasing frequency and severity of droughts and floods is often due to the lack of coordination and regulations leading to increasing costs for local and central governments, farmers, rural and urban communities and insurance industry with potential contributions to poverty. Coherent new policies for land use, agriculture, water and energy security can play a central role in mitigation and adaptation policies for climate change, floods and droughts risk management

- Integrated modeling demonstrates that strengthening linkages between ex-ante long-term decisions (such as floods and droughts risk mitigations) with other short-term ex-post adaptive multi-stakeholders decisions significantly improves the robustness, efficiency and environmental safety of solutions with respect to inherent uncertainty and extreme events

- Secure coherent sustainable FEWES nexus management requires proper governance equipped with adequate decision support systems

- Robustness of policies can be achieved by using appropriate non-smooth systemic risk indicators enabling to properly represent “hit-or-miss” type decision situations regarding sustainability targets. The use of standard mean values, least square and variance-covariance approaches is not robust under asymmetric variability and uncertainty with non-normal distributions.

6. 5. Scientific goals

The following methodological issues will be in the focus of the project:

1. Developing methods for linking distributed sectorial models under asymmetric information and feasibility constraints, i.e. when a sector doesn't reveal information about its model. Specific attention will be paid to dynamic models with endogenously generated systemic risks, strategic long-term decisions combined with adaptive corrections (operational decisions) after obtaining new information. This approach requires developing new methods of dynamic stochastic optimization because traditional optimal control theory is not applicable (see e.g. discussions in Ermoliev and von Winterfeldt, 2012) due to non-additive and non-smooth uncertain (hit-or-miss) type of decision making.
2. Designing optimal robust trajectories of integrated dynamic systems incorporating random stopping time moments enabling adjustments of solutions to new information via a dialogue of stakeholders with sectorial models.

3. Analyzing driving forces of threats (the lack of needed quality and quantity of food, decreasing quality of water and land, decreasing stability of energy supply, decreasing energy use efficiency, conflicting policies, etc.) and robust in particular quantile-based indicators of FEWES security characterizing coherent sustainable policies.

4. Collecting and properly representing relevant spatio-temporal data on agricultural activities, natural resources, demographic, socio-economic and environmental indicators at the national level and at the level of districts and regions in Ukraine (496 and 25, respectively) from real observations and experts opinions by using appropriate data harmonizing methods, e.g., probabilistic downscaling and upscaling methods, non-parametric estimation, uncertain distributions.

5. Create stochastic scenario generators (including catastrophe generators) for "threats-decisions" interactions.

6. Build integrated nested stochastic optimization model(s) for evaluating robust solutions ensuring secure and sustainable FEWES nexus under diverse uncertain threats and corresponding stopping time moments.

6.6. Connections with IIASA's Strategic Plan.

Because sustainability cannot be achieved only in a single country due to increasing interdependencies among countries, the project aims to develop approaches enabling to design (robust and secure) sustainable solutions from the perspective of all countries. Hence, central methodological issues are connected with developing new multimodel linkage methods which can be combined with proposed in (Ermolieva et al., 2016; Ermoliev et al., 2017) and further developing stochastic version of global model GLOBIOM and probabilistic downscaling methods. It is essential that the linkage methods can be applied in cases with asymmetric information about submodels, applicable in various current and future studies and cross-cutting activities of ASA; ESM, RAV, Energy, Water, AIR IIASA's programs, NEXUS and NEXUS++ initiatives. The methodology being developed within NASU-IIASA project has common character and it is applicable to other case studies having global, regional, local scales, e.g. downscaling GLOBIOM SSP scenarios (Fricko et al., 2017), new approaches to GLOBIOM, BeWhere, MESSAGE linkage, sustainability studies in China (Xu et al., 2015).

7. Project Stages, Workpackages and Teams

During the research period the following plans may be adaptively adjusted, therefore, in a sense, they have a tentative character. The WP research teams may have alterations. Work in data analyses and programming will be directed by the senior scientists whose names are given in the WP team lists (see below), and carried out by Ukrainian PhD students and junior scientists whose names are currently not given in the WP team lists.

Workpackage 1. Development of models and methods for integrated analysis of sustainable robust food, energy and water security policies

Stage	Term	Problems & Key Questions	Deliverables
Analysis of natural and anthropogenic risks to sustainable developments, challenges and threats associated with adaptation to new economic situation in Ukraine, e.g. created by free trade with EU, WTO agreements, transition to low carbon energy and agriculture sectors, etc., and the transformation of the security space. Review of existing approaches and models, analysis of their applicability in Ukrainian conditions	2017	Drivers and trends of global-local changes contributing to increasing interdependencies between sectors, inducing systemic risks	Set of developed methods and models, data sets Scientific publications
Development and adjustment of bio-physical, statistical and simulation crop growth models for the analysis of food security risks under production shocks induced by weather variability; Development of a data base including data on hydrological resources and inherent uncertainties, multiyear agricultural productivity and agro-meteorological information Development of robust downscaling (rescaling) and data harmonization procedures Models and scenarios of low carbon agriculture, models of agricultural nutrients (nitrogen, phosphorus) balances, allocation and trading for sustainable agricultural development	2018	Analysis and harmonization of data and information from different sources, at different levels, across various models	Set of developed methods and models Joint-access databases Scientific publications

Development of methodologies and models for distributed models linkage; Using linkage models for integrating multi-objective stochastic optimization models with agricultural, land use, energy models; Development and analysis of robust sustainable agriculture-energy-environment- social pathways	2019	Methodological challenges associated with linkage of distributed sectorial models under asymmetric information and uncertainties	Set of developed methods and models Joint scientific papers Joint-access databases
Development of new risk measures for catastrophic and systemic risk management in natural and anthropogenic systems; Development of water balance and water trading models; scenarios of regional groundwater dynamics in Kiev region, identification of regional threats and risks	2020	New type of collective systemic risks and systemic risks measures; indicators of sustainable developments based on systemic risk measures and FWEE security constraints	Set of developed methods, models, and data Joint scientific papers Reports
Summary of main findings Perreviewed publication in national and international journals Book volume	2021		Set of developed methods, models, and data Joint scientific papers Reports

Research Team: Glushkov's Institute of Cybernetics, NASU

#	Name	Title	Position	Involvement
1	Ivan V. Sergienko	Prof., Dr.	Director, Academician	Full time counselor (no salary)
2	P. S. Knopov	Prof., Dr.	Head of Dept.	0,5 (6 month/year)
3	V.S. Kyrylyuk	Dr.	Leading Research Scientist	0,5 (6 month/year)
4	K.L. Atoev	Ph.D.	Senior Research Scientist	0,5 (6 month/year)
5	T.V. Pepelyaeva	Ph.D.	Senior Research Scientist	0,25 (6 month/year)
6	O.M. Golodnikov	Ph.D.	Senior Research Scientist	0,5 (6 month/year)
7	M.V. Belous	Ph.D.	Senior Research Scientist	0,25 (6 month/year)
8	M.I. Zheleznyak	Ph.D.	Senior Research Scientist	0,25 (6 month/year)

Workpackage 2. Analyzing variations of regional water balances, ecosystems productivity and disasters risk distributions using remote sensing data, climate and environmental change assessment

Stage	Term	Problems & Key Questions	Deliverables
Analysis of existing methods based on remote sensing data for the analysis of land use and land use change dynamics, bioproductivity, etc. Collection of recent data and estimation of main spatial indicators to characterize land cover to be used in bioproductivity models	2017	Selection of case studies and focus areas What is the available data, reliability of the data, how to estimate corresponding (both aleatoric and epistemic) uncertainty of the data?	Data bases: meteorology measurements reduced to study areas for 1910 – 2015, disaster statistics on study areas 1960 – 2015, bio-productivity on study areas 1990 – 2015; publications on case studies
Generation of regional scenarios of bioproductivity change for varied types of ecosystems, climate changes (both on global and regional scale) and remotely observed environmental changes Development and improvement of regional models evaluating spatio-temporal water and nutrients balances Analysis and justification of indicators for sustainable environmental developments	2018	Which way of metrics reduction is the optimal for analysis of stochastic sets of in-field and satellite observations? Analysis of data should allow for introduction of local peculiarities (in distributions of disaster frequency, bioproductivity, water balance, climatic and with respect to meteorological parameters) toward existing regional and global trends.	Set of developed methods and models Data bases: meteorology measurements reduced to study areas for 1910 – 2015, disaster statistics on study areas 1960 – 2015, bio-productivity on study areas 1990 – 2015; Publications on case studies
Development of technique for problem-oriented harmonization of geo-referenced data of in-field measurements and satellite observations for integrated multi-objective stochastic optimization models evaluating impact of natural disasters and	2019	Which drivers lead to most dangerous disasters from viewpoint of socio-ecological vulnerability? Should pollution be described as integrated aftermath of complex disasters? What is relative input of meteorological variations,	Set of developed methods and models Data bases: meteorology measurements reduced to study areas for 1910 – 2015, disaster statistics on

induced threats to environment in view of regional changes Analysis of multivariate distributions for frequency and intensity of different types of disasters, climatic and ecological parameters (using satellite data)		climatic trends, land-use and agricultural practices, water management into registered regional drought statistics? Does statistic reflects climatic conditions or it is indicator of inadequate policies?	study areas 1960 – 2015, bio-productivity on study areas 1990 – 2015; Publications on case studies
Analysis and assessment of drivers and indicators of land-cover changes connected with disasters, climate and environmental changes, its links to bioproductivity and food, energy and water security	2020	How regional bioproductivity reflects observed global trends of climate change and local water balances? Analysis of integrated contamination/pollution (using bio-indicators and suspended matters) of surface water bodies. Key threats identification for regional and trans-boundary water security.	Set of developed methods and models Data bases: meteorology measurements reduced to study areas for 1910 – 2015, disaster statistics on study areas 1960 – 2015, bio-productivity on study areas 1990 – 2015; Publications on case studies Reports
Generation and analysis of regional scenarios of disaster impact to environment (including analysis of pollution propagation over surface water bodies) using satellite observation data Summary of main findings Perreviewed publication in national and international journals Book volume	2021		Publications on case studies Reports

Research Team: Scientific Centre of Aerospace Research of the Earth, NASU

#	Name	Title	Position	Involvement
1	Vadym I. Lyalko	Prof., Dr.	Director, Academician	Full time counselor (no salary)

2	Y. V. Kostyuchenko	Assoc. Prof., Ph.D.	Leading Research Scientist	0,5 (6 month/year)
3	O. I. Sakhatsky	Assoc. Prof., Dr.	Leading Research Scientist	0,25 (3 month/year)
4	D. Movchan	Ph.D.	Junior Research Scientist	0,25 (6 month/year)
5	G. Zholobak	Ph.D.	Research Scientist	0,25 (3 month/year)
6	M. Yuschenko	M.Sc.	Engineer	0,5 (6 month/year)
7	O. Apostolov	M.Sc.	Engineer	0,25 (3 month/year)

Workpackage 3. Energy Security: Technological Aspects. Analysis of energy developments and its security as a key factor for sustainable socio-economic, technological regional developments minimizing GHG emissions and environmental impacts of energy sector developments under uncertainty and obligations on emissions of noxious and greenhouse gases, and harmful matters

Stage	Term	Problems & Key Questions	Deliverables
Analysis and formalization of requirements for sustainable energy sector developments under transition to low carbon low water intensity technologies, in view of Paris agreements on reduction of GHG emissions and pollution, obligations towards 2020 on introduction of renewable energy sources; Analysis of energy-water security and vulnerability from viewpoint of energy sustainable supply-demand relations	2017	Key threats and impacts factors identification in energy sector, analysis of basic technological links	Set of developed methods and models
Development of integrated models for the analysis of energy-environmental-social nexus accounting for energy-water-environmental security towards robust management of the nexus under natural and anthropogenic uncertainties and systemic risks	2018	How market variations and technological innovations will reflect on effectiveness of functioning of different objects of energy system?	Set of developed methods and models
Development of stochastic scenario generators (including catastrophe generators) for analysis of sustainable development of energy sector	2019		Set of developed methods and models Joint scientific papers

and its links with food and water sectors			
Development of integrated stochastic models of energy sector planning as an infrastructural block in the complex socio-economic and technological system aimed at efficient and secured energy supply under uncertain influence of external factors (including catastrophic threats)	2020		Set of developed methods and models Joint scientific papers
Modeling and analysis of energy development pathways and their impacts on sustainable developments under new conditions Summary of main findings Perreviewed publication in national and international journals Book volume	2021		Set of developed methods and models Joint scientific papers

Research Team: Institute of General Energy, NASU

#	Name	Title	Position	Involvement
1	Mykhaylo M. Kulik	Prof. Dr.	Director., Academician	Full time counselor (no salary)
2	S.V. Dubovsky	Dr.	Leading Research Scientist, Head of Dept.	0,5 (6 month/year)
3	O.Ye. Malyarenko	Ph.D.	Senior Research Scientist, Head of Dept.	0,5 (6 month/year)
4	I.Ch. Leschenko	Ph.D.	Senior Research Scientist	0,5 (6 month/year)
5	S.V. Shulzhenko	Ph.D.	Senior Research Scientist	0,5 (6 month/year)

Workpackage 4. Energy Security: Economic Aspects. Integrated modeling of energy supply in the context of coherent food, water, energy security and sustainable development of Ukraine

Stage	Term	Problems & Key Questions	Deliverables
Analysis of main global challenges and their potential impacts on socio-economic, ecological, technological etc. developments in the short and long term in Ukraine	2017		Set of developed methods and models

Formalization of methodologies for the analysis of impacts of global transformation processes on socio-economic and energy-ecology-agriculture parameters in Ukraine. Involvement of stochastic GLOBIOM, linkage of national agricultural data and models with GLOBIOM and potentially MESSAGE models	2018		Set of developed methods and models Per reviewed publications
Development of an integrated Decision Support System for robust management of energy (+renewables+bio)-water-agriculture nexus under uncertainties and risks, global-local interdependencies,	2019	Introduction of security indicators based on CVaR-type risk measures	Set of developed methods and models Per reviewed publications
Complex modeling and analysis of sustainable development scenarios under global change processes: Socio-economic and socio-technological aspects	2020	Development and harmonization of existing and new multiscale data sets and data analysis tools	Set of developed methods and models Scientific publications
Identification of robust sustainable scenarios for energy sector developments consistently with global drivers, trends, SSP scenarios, accounting for risks and security targets. Perreviewed publication in national and international journals Book volume	2021	Development and harmonization of existing and new multiscale data sets and data analysis tools	Set of developed methods and models Scientific publications

Research Team: Institute of Economics and Forecasting, NASU

#	Name	Title	Position	Involvement
1	Valery M. Heyetz	Prof. Dr.	Director., Academician	Full time counselor (no salary)
2	G.Yu. Lopatynska	M.Sc.	Junior Research Scientist	0,5 (6 month/year)
3	R.Z. Podoletz	Ph.D.	Senior Research Scientist	0,5 (6 month/year)
	O.A. Dyachuk	Ph.D.	Senior Research Scientist	0,5 (6 month/year)

Workpackage 5. Modeling and management of agricultural strategies for sustainable agricultural and rural developments under global-local interdependencies and threats

Stage	Term	Problems & Key Questions	Deliverables
Analysis of risks, threats, vulnerability and exposure of agricultural sector in Ukraine to new challenges; indicators and characteristics of sustainable developments	2017	Risk-adjusted sustainability indicators; The role of robust policies from short and long perspectives	Set of developed methods and models Per reviewed publications
Analysis of agricultural and financial potentials to fulfill food security requirements under natural and anthropogenic uncertainties and risks; rural area developments, issues of rural-urban migration	2018	Better modeling of rural sector planning accounting for rural-urban migration processes	Set of developed methods and models
Development of spatio-temporal models and data harmonization procedures for planning agricultural production under risks; Analysis of financial policies (subsidies, microcrediting) to improve socio-economic conditions of household and small farms.	2019	Analysis of multi-level impact (global, regional, local) of climate changes (observed, registered, forecasted according different scenarios) to agrarian and other sectors	Set of developed methods and models
Public-private partnership models for innovations and investments into advanced agricultural technologies, in view of recent agreements (EU associated member, WTO agreements, Water directives, Paris agreements), under transformation of security space	2020	It is necessary to address strategic long-term planning incorporating adaptive short-term responses of various stakeholders	Set of developed methods and models, data base, scientific publications and reports
A DSS to support policy analysis towards sustainable agricultural reforms and rural areas developments	2021	It is necessary to address strategic long-term planning incorporating adaptive short-term responses of various stakeholders	Set of developed methods and models, data base, scientific publications and reports

Research Team: Institute of Economics and Forecasting, NASU

#	Name	Title	Position	Involvement
1	O.M. Borodina	Dr.	Leading Research Scientist, Head of Dept.	0,5 (6 month/year)
2	S.V. Kyryzyuk	Ph.D.	Research Scientist	0,5 (6 month/year)
3	V.V. Yarovyy	Ph.D.	Research Scientist	0,5 (6 month/year)
3	A. I. Frayer	M.S.	Research Scientist	0,5 (6 month/year)

Workpackage 6. Geographically-detailed analysis of population dynamics, poverty and health risk vulnerability and exposure in Ukraine: drivers, emergencies, impacts, trends

Stage	Term	Problems & Key Questions	Deliverables
Review of methodologies, indicators, constraints, factors, affecting demographic condition in Ukraine	2017	Depopulation, decrease of fertility rates	Set of developed methods and models
Analysis of heterogeneities of population distribution by groups in Ukraine. Analysis of economic parameters of poverty	2018	Poverty, health care and social security risks	Set of developed methods and models Scientific publications Reports
Modeling and analysis of population dynamics in Ukraine: drivers, trends, etc. parameters	2019	Indicators of vulnerability, exposure	Set of developed methods and models
Analysis of indicators to characterize socio-economic and health-risk exposure of population in Ukraine	2020	Indicators of vulnerability, exposure	Set of developed methods and models
Spatio-temporal model-based analysis of population vulnerability and exposure to socio-economic and health risks in Ukraine.	2021		Set of developed methods and models

Research Team: Institute of Demography and Social Studies, NASU

#	Name	Title	Position	Involvement
1	Ella M. Libanova	Prof, Dr.	Director, Academician	Full time (no salary)
2	L.M. Cherenko	Ph.D.	Senior Research Scientist	0,5 (6 month/year)

3	O.A. Vasiliev	M.Sc.	Junior Research Scientist	0,5 (6 month/year)
	A.G. Reut	M.Sc.	Junior Research Scientist	0,5 (6 month/year)

8. Selected publications:

[1] IIASA Policy Brief (2017). http://www.iiasa.ac.at/web/home/about/achievements/scientificachievementsandpolicyimpact/iiasa-nasu.html

[2] Options Magazine Winter 2016. Planning for the future to ensure no one goes hungry.

[3] Zagorodny AG, Ermoliev YM, & Bogdanov VL (Eds.) (2014). *Integrated Management, Security and Robustness.* NASU, ISBN 978-966-02-7376-4

[4] Zagorodny AG & Ermoliev Y (Eds.) (2013). *Integrated Modeling of Food, Energy and Water Security Management for Sustainable Social, Economic and Environmental Developments.* NASU, ISBN 978-966-02-6824-1

[5] Zagorodny A, Bogdanov V, & Ermoliev Y (2013). *On integrated management of food, water, energy and environmental security.* In: Integrated Modeling of Food, Energy and Water Security Management for Sustainable Social, Economic and Environmental Developments. In: Zagorodny, A & Ermoliev (Eds.), Y, Kiev pp.187-197: NASU, ISBN 978-966-02-6824-1

[6] Zagorodny A, Ermoliev Y, Kostyuchenko Y, Ermolieva T, & Borodina O (2012). *Integrated modeling of food, energy and water security management for sustainable social, economic and environmental developments.* Poster presentation, IIASA 40th Anniversary Conference, 24-26 October 2012, Laxenburg and Vienna, Austria

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[14] Ermolieva T, Havlík P, Ermoliev Y, Mosnier A, Obersteiner M, Leclère D, Khabarov N, Valin H, et al. (2016a). *Integrated Management of Land Use Systems under Systemic Risks and Security Targets: A Stochastic Global Biosphere Management Model*. Journal of Agricultural Economics 67 (3): 584-601. DOI:10.1111/1477-9552.12173.

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Other relevant joint publications:

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Kostyuchenko, Y.V., Laszlo, M., Yuschenko, M., Kopachevsky, I., Bilous, Y. (2010). Transboundary socio-ecological safety assessment: sustainability toward anthropogenic hazards and bioproductivity degradation. In: Proceedings of the 4th International Workshop on Reliable Engineering Computing “Robust Design – Coping with Hazards, Risk and Uncertainty”, March 3 – 5, 2010, Singapore, National University of Singapore.

Golodnikov, A., Ermoliev, Y., Knopov, P. (2010). Estimating reliability parameters under uncertain information. Cybernetics and Systems Analysis, 46(3): 443-459.

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Kostyuchenko, Y. V., László, M., Yuschenko, M.V., Kopachevsky, I., Bilous, Y. (2012). Socio-ecological safety towards natural and technological disasters: Earth observations and ecological monitoring for water quality analysis. J. Reliability and Safety, 6(1/2/3):204 – 224

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Bonn 2011 Conference. The Water, Energy and Food Security Nexus – Solutions for a Green Economy. Pre-Conference draft, www.water-energy-food.org/en/conference/policy_recommendations/ch3.html.