Integrated uncertainties and risk management for robust decision making

Key Messages

- For policy appraisal of climate adaptation strategies, conventional economic models and methods are often inadequate to deal with uncertainty and risk that inherently accompany climate change and specifically adaptation policies.
- Effectively dealing with uncertainty and risk requires integrated models that take into account cross-sectoral and cross-regional dependencies and interactions in order to hedge the systemic (interdependent) risks.
- The focus is not only on understanding the nature of risk, but on developing models, methods, and tools to manage that uncertainty and risk to help ensure the robustness and stability of relevant systems (e.g. food, water, energy, and environmental security) under a multitude of feasible future scenarios.
- Within the context of adaptation, it is necessary to consider risk distribution and evaluations over long-term horizons, strategic and operational risk management/planning, and risk adjusted performance indicators, goals and constraints. Taking these factors into consideration can help derive various robust solutions.
- Several examples for integrated dynamic modeling for climate change adaptation exist. For example, the stochastic version of the IIASA's Global Biosphere Management Tool (GLOBIOM) is used to analyze land use competition between agriculture, forestry, and bioenergy. Stochastic GLOBIOM allows for the evaluation of robust food, forest fiber and bioenergy provision, which in turn contribute to human welfare, in the face of climate change uncertainties and risks.

Context

Much of the debate on climate change is based on a scientific understanding that the climate will change gradually and incrementally over time. The majority of prominent economic assessment models available fail to account for the uncertainties inherent in climate change. What is also important – they are unable to account for increasing variability and frequency of catastrophic risks, which currently dominate the climate change debates. Multiple studies and decision support models are based on deterministic scenario analysis and their scenario-specific deterministic implementations assume perfect information. This approach risks leading to inaccurate policy implications and lock-in avenues of political development. In turn this can, increase market volatility and reduce the capacity of policy options to address issues of food, energy, water, and environment security.

Climate change risks stem from both natural and anthropocentric causes or can occur simultaneously or in cascades, with for instance the case Fukushima where a natural disaster, the tsunami, triggered the burst of the nuclear power plant. Another example occurred in New Orleans whereby floods induced by hurricane Katrina caused excessive damage due to inadequate disaster prevention and mitigation decisions.

Conventional economic models (i.e. cost-benefit analysis, expected utility, general equilibrium, traditional discounting etc.,) have clear potential drawbacks when applied to evaluate climate change adaptation strategies. Conventional economic models and methods are in some cases not capable of adequately dealing with the uncertainty and risk that accompany climate change. Understanding the drawbacks of these conventional models is key to avoiding inappropriate decisions and developing new methods to deal with the uncertainty of climate change.

Policy and methodological developments

Systemic risks are analytically intractable and cannot be characterized by probability distributions as the occurrence depends on (intentional and unintentional) decisions of agents (Ermolieva et al., 2016). Through interdependencies (e.g. trade) and strong nexus among various socio-economic, environmental, ecological, etc. systems (e.g. food-energy-water-environment nexus), a climate change adaptation policy implemented in one region can cause negative implications in other regions and globally (OECD, 2013; Ermolieva et al., 2016).

Scenario-specific deterministic analysis of agricultural production under alternative plausible yield shocks (e.g. due to increasing frequency of droughts or precipitation events) derives scenario-dependent solutions. Majority of policy recommendations are based on model results derived with a model using “average” scenario. However, implementation of either of the scenario-dependent solution can lead to maladaptation and require adjustments, such as conversion of forest into crop land or additional irrigation capacities if, for example, a drier than anticipated year occurs.

The following three economic models illustrate the feasibility and importance of dealing with inherent uncertainties and risks in large-scale models. They aim to develop effective and robust climate change mitigation and adaptation options.

The Global Biosphere Management Tool (GLOBIOM)

The Global Biosphere Management Tool (GLOBIOM) is a dynamic model that is used to analyze the competition for land use between agriculture, forestry, and bioenergy. GLOBIOM allows for the evaluation of production of food, forest fiber and bioenergy, which all contribute to human welfare. GLOBIOM accounts for interdependencies among main Land Use Systems (LUS) on global, national, and grid-cell levels.

The Stochastic GLOBIOM covers explicitly and analyses interdependencies and trade-offs between structural and financial measures for hedging systemic risks in relation to food, energy, water, environmental security in land use systems, which can be affected by climate change and weather variability. The risks are characterized by the entire structure of the systems including distributions of risks shaped by both external and internal factors (e.g. decisions of agents, costs structure, market prices, technologies, security constraints, Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR) measures, and feasible decisions of agents). Stochastic GLOBIOM’s flexibility and consideration of unpredictable risk is capable of treating cascading events in interdependent climate-agriculture-energy systems, e.g. a shock to corn production possibly leading to a deficit of important feedstocks for biofuels and feeds for livestock, etc.

GLOBIOM enables coherent analysis of both ex-ante measures (taken in front of uncertainties) and ex-post measures (to adjust initially taken decisions when additional information becomes available). The approach minimizes total costs of the decisions providing policy makers with flexibility for revising the measures in light of newly acquired knowledge about uncertainties (O’Neill et al. 2006). The model explicitly accounts for various types of uncertainties, (systemic) risks and climate variability. The set of ex-ante (strategic) measures comprises production allocation, storage and irrigation capacities, whereas the ex-post operational decisions concern the level of demand, trading, and storage control.

Illustration. Integrated management of land use systems under systemic risks and food-energy-water-environmental security targets: a stochastic Global Biosphere Management Model (GLOBIOM)

In Ermolieva et al. (2016) the GLOBIOM model is applied to the case of increased storage facilities, which can be viewed as catastrophe pools to buffer production shortfalls and fulfil regional and global food-energy-water-environmental norms and goals when extreme events occur. Expected shortfalls and storage capacities have a close relation with Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR) risk measures.

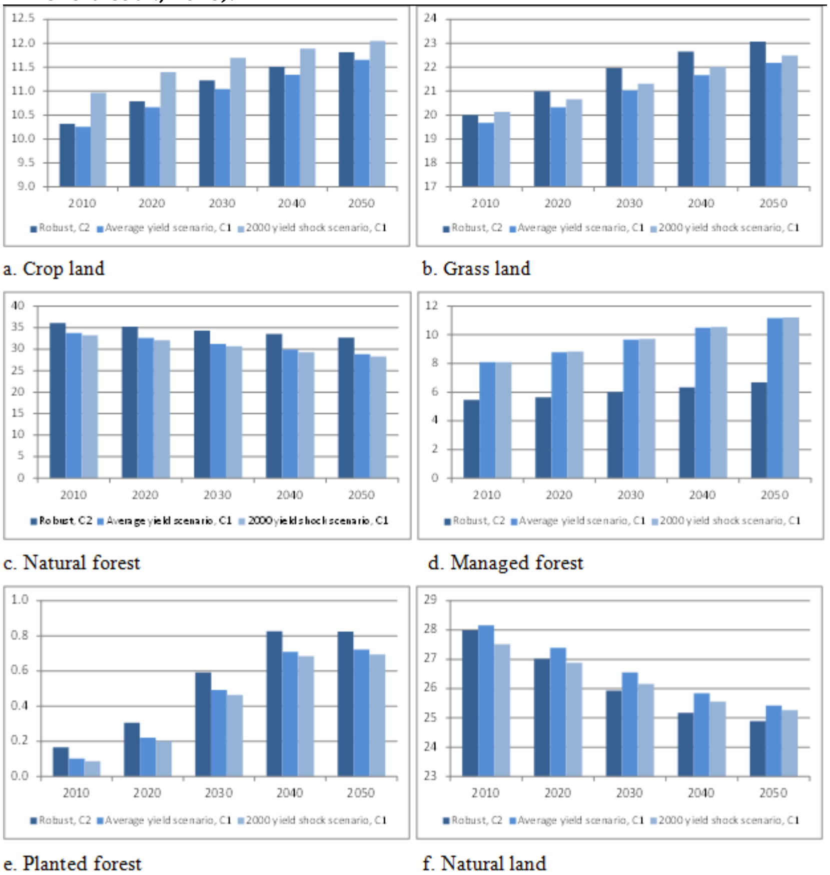
The deterministic average yield scenario can be seen as the base case in the comparison of model structures (Figure 5). Compared with the average yield scenario, the “2000 yield shock” scenario (corresponding to the year 2000 historical yields (characterized by simultaneous droughts in Australia, China, India, Russia, etc. with much lower yields) shows a larger percentage of land allocated to cropland and grassland, but a smaller percentage allocated to natural forest, planted forest, and natural land, and an equal percentage allocated to managed forest. This implies a large loss of biodiversity. Hence, the average yield scenario considerably underestimates land demand, as well as production technologies, able to hedge production risks.

Stochastic GLOBIOM incorporates in the analysis all yield shocks simultaneously and derives solutions accounting for yield variability. To fulfill security targets in the face of all yield shocks, stochastic GLOBIOM suggests that crop land be used only 0.1% more compared with the results of deterministic GLOBIOM (C1) under the average yield scenario (Figure 5, panel a). Having possibility of flexible ex post adjustments to all potential scenarios, stochastic GLOBIOM recommends qualitatively different solutions. For example, natural ecosystems should be preserved, the conversion of natural forests into managed should slow down, grass land should be protected as an important feed source for livestock (see panels b and c in Figure 5).

It is critically important that robust strategic decisions on land allocation among LUS are supplemented with adaptive scenario-specific trade and storage decisions. Stochastic GLOBIOM accounts for spatial dependencies between yield shocks and suggests scenario-specific geographical diversification of trade across uncorrelated (or negatively correlated) regions and commodities. Stochastic GLOBIOM allows that rice and wheat demand are increased and rape and sunflower production are decreased.

By proper crop and trade diversification, stochastic GLOBOIOM allows for less water consumption, therefore, less investments and conversion into irrigated land, which is extremely important under the competition for scarce natural resources. Stochastic GLOBIOM hedges global systemic risks, which influences land use and thereby prices and demand of crops. The benefits of the robust solutions derived using the stochastic model in comparison with the solutions of its deterministic counterpart are measured using the Value of Stochastic Solution, VSS, which is about 25% between the stochastic and deterministic values of the goal function.

Figure 5. Percentage of total land occupied by different land use systems calculated using stochastic GLOBIOM (Robust, C2), deterministic GLOBIOM under the average yield scenario (Average yield scenario, C1), and deterministic GLOBIOM under extreme shock scenario (2000 yield shock scenario, C1). Horizontal axis labels simulation year and vertical identifies percent (source: Ermolieva et al., 2016).



A stochastic model of the market-based emission abatement and trading

This is another model that investigates the role of economic instruments for environmental regulations in the face of various uncertainties and climate change. Emission trading was devised to lower the cost of achieving greenhouse gas emission reductions: emissions are reduced where it is cheapest and emission certificates are then traded to meet the nominal targets for each participant. However, carbon markets, like other commodity markets, are volatile. They react to stochastic "disequilibrium" spot prices, which may be affected by uncertainties, inadequate policies, speculations and bubbles.

The proposed stochastic multi-agent trading simulation system may function as a prototype of a real emission trading market. The model analyses the robustness of emission reduction policies, both abatement and trading, under asymmetric information and other multiple anthropogenic and natural uncertainties. The model explores conditions of market stability by imposing appropriate safety constraints to control the level of admissible uncertainty which would guarantee cost efficiency of trades and safety levels of emission reduction targets (e.g. post-Kyoto pledge targets).

Explicit treatment of uncertainty provides incentives for their monitoring and reduction before trading. In a case study, functioning of the robust market has been illustrated with numerical results involving such countries as US, Australia, Canada, Japan, EU27, Russia, Ukraine. It has been shown that explicit consideration of uncertainty may affect decisions regarding portfolios of technology and trade policies, market prices and structure.

The Integrated Catastrophe Risk Management model (ICRM)

The ICRM model focuses on the design of a flood-loss sharing program as a tool for climate change adaptation and risk hedging. The program can involve private insurance based on location-specific exposures, a mutual catastrophe fund, and a system of governmental compensations. A robust program designed with ICRM substantially reduces demand for other structural and financial risk mitigation and spreading mechanisms. The model consists of a GIS-based flood model and a stochastic optimization procedure with respect to location-specific risk exposures. To achieve the stability and robustness of the program towards floods with various recurrences, the ICRM implies quantile-related risk functions of a systemic insolvency involving overpayments and underpayments of the stakeholders.

The general strength of these three methods and models is their ability to provide more complete information for a decision-maker that includes future possibilities and the measurable outcomes. The risk-based optimization criteria include future flexibilities (strategic vs. adaptive decisions) and provide additional room for adjustments and improvements with time. The concept of risk management allows for finding robust solutions leaving a decision maker more equipped to deal with uncertainty. Integrated stochastic inter-sectoral models provide information on an optimal use of a range of possible options in the face of climate uncertainties and risks (e.g. installation of irrigation systems vs. usage of drought-resistant cultivars). These incorporate regional and global food-energy-water-environmental security indicators.

But the analysis of options providing future flexibility has to be taken into account before making strategic decisions, therefore this analysis would require more time and effort. Furthermore, the transformation of a decision-maker’s preference might be a challenge. In addition, there are still a range of potential disturbances that stem from other economic sectors and also changes in national development goals that can potentially affect the whole modeled system.

Main implications and recommendations

The analysis shows the need for:

- Explicit inclusion of uncertainties and application of risk measures in adaptation projects to obtain robust solutions;
- Emergence of systemic risk across sectors and scales and therefore the need for interdisciplinary research;
- Sequential approach to decision making evaluating future flexibilities in operational decisions vs. strategic decisions.

Since many prominent economic assessment models are deterministic, they fail to account for the uncertainties and risks inherent of climate change realities. They are also unable to account for increasing variability and frequency of risks which currently dominate the climate change debates. Multiple studies and available decision support models are currently based on deterministic scenario analysis.

Policy implementation based on methods that ignore risks may lead to unwanted results. For instance, interdependencies between land use systems constitute a complex network connected through economic supply and demand dynamics. If these systems are governed by incoherent policies, a serious disruption of the network may evoke systemic risks affecting food, energy, water, and environmental security worldwide. To effectively deal with the harmful and often inconsistent impacts of climate change, alternative models and methods that allow risk and uncertainty to inform their analysis may be instrumental in introducing flexibility into the decision making process that allows for revision, evaluation, and redirection if necessary. Such a flexible approach is necessary to avoid ‘locked in’ development plans, market volatility, and conflicts between different sectors and users.

Bibliography

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Further Information

Report on applicability of existing and improvement/development of new methods for decision-making under uncertainty [pdf]

Contact

Tatiana Ermolieva

Nikolay Khabarov

Partner

International Institute of Applied Systems Analysis (IIASA)

BC3 Basque Center for Climate Change

University of Bath

Paul Watkiss Associates