The water-land-food-energy-climate Nexus for a resource efficient Europe

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Abstract A novel methodology for addressing policy inconsistencies and knowledge gaps that hinder the transition to a greater resource efficiency Europe is proposed. We focus on the integration of all different sectors that interact and influence each other, namely the "water- energy- food- land use- climate nexus" and we develop tools for identifying and quantifying their complex interlinkages under the influence of climate change. In order to achieve this, we employ a series of sophisticated models (referred to as "thematic models"), each of which addresses a different nexus dimension, or a combination of a few, while none addresses all nexus dimensions in an integrative manner. We use dynamic systems modeling and other complexity science techniques in order to "merge" different thematic model outputs in a single coherent result, which is presented to the user in an easy-to-comprehend Serious Game environment. This way, the effect of policies that are designed to affect one field (nexus dimension) on others can be quantified and simulated, thus informing policy-makers for the unintended consequences of their policies, reducing uncertainties, covering knowledge gaps and leading to a resource efficient Europe faster.

Keywords: Policy Instruments, Nexus, Serious Game, Climate Change, Governance

1. Introduction

Natural resources enable the functioning of the economy (globally, continentally, nationally and regionally) and support our quality of life. These resources include (renewable and non-renewable) energy, wood from forests, food and fibre from crop production, quality of soil, water and air (EC, 2011). Global competition between land, water and energy resources is increasing, and is exacerbated by climate change. Global demand for fresh water, for example, is foreseen to increase until 2030 by 40%, demand for energy to increase by 50% and demand for food by 35% (UNESCO, 2015).

According to the 2015 European Environment-State and Outlook (SOER, 2015), the EU's total resource use has declined by 19% since 2007, less waste is being generated and recycling rates have improved in nearly every country; however, despite this progress and the relative decoupling of economic growth from environmental harm that is observed, a majority of environmental systems are not used or managed sustainably. Among others, targets of the Water Framework Directive are often not met, ecological integrity of river basins is compromised, and land use changes and poor water management together with climate change will increase the risks of both floods and droughts. Moreover, there are a number of problems that slow the EU's rate of transition to greater resource efficiency. Some of the barriers to resource efficiency, according to the Roadmap to a resource efficient Europe, are as follows:

- Policy inconsistencies and incoherence reduce predictability and response/reaction adequacy: policy made for a good reason in one field can have unintended consequences that hold back efficient resource use in another.
- Knowledge gaps about future risks constrain policy-makers from planning for the future; there are significant uncertainties on how environmental systems will change and the impacts they will have, which leave policy-makers unaware of risks in complex, global supply chains.
- Knowledge and technology lock-ins exist when established ideas or practices have a price advantage over innovations, or where they form part of a system of which the other parts are not changing.

SIM4NEXUS comes to address these challenges by proposing the SIM4NEXUS Serious Game, a cloud-based, integrated resource-use and policy assessment tool that will bridge the Nexus knowledge gap effectively, by providing an immersive experience to the user. It will be designed to be used primarily by authorities and policy-makers at all levels (regional/ national/ continental/ global) and will allow them to identify critical areas of the Nexus, to evaluate and quantify the effects on resource levels of new policies and subsidies, of climate change and mitigation practices, of the implementation of technological and social innovations, of adopting low-carbon options, of new investments and interventions.

2. SIM4NEXUS Concept

A schematic overview of the SIM4NEXUS concept is presented in Figure 1. When the Nexus is not taken into account and knowledge remains compartmentalized in different silos, we obtain policy- and decision-making that lacks integration and is inconsistent and incoherent (left panel). Recent trends reflect partial integration (e.g. the water-energy nexus) and produce results based on fragmented knowledge and loaded with high uncertainty (middle panel). SIM4NEXUS is based on thematic models, but uses complexity science approaches to integrate results producing unified knowledge; this way, ll components interact together producing results and Nexus-relevant policies with reduced uncertainty (right panel). all components interact together producing results and Nexus-relevant policies with reduced uncertainty (right panel). The transition towards a resource-efficient and low-carbon economy requires multi-sectoral strategies (e.g. policy, innovations, economic development) and Nexus-compliant practices in the context of climate change (Figure 2). Within the web of interconnections, changing one resource (or policy) may either cause unintended consequences, e.g. unexpected impacts elsewhere, or achieve little change to the overall system. Many of such interlinkages can lead to trade-offs. Uncertainty around future policy and incoherence between policies are some of the barriers that hold back economists' ability to predict change in resource scarcity and in the economy's ability to respond. Weak

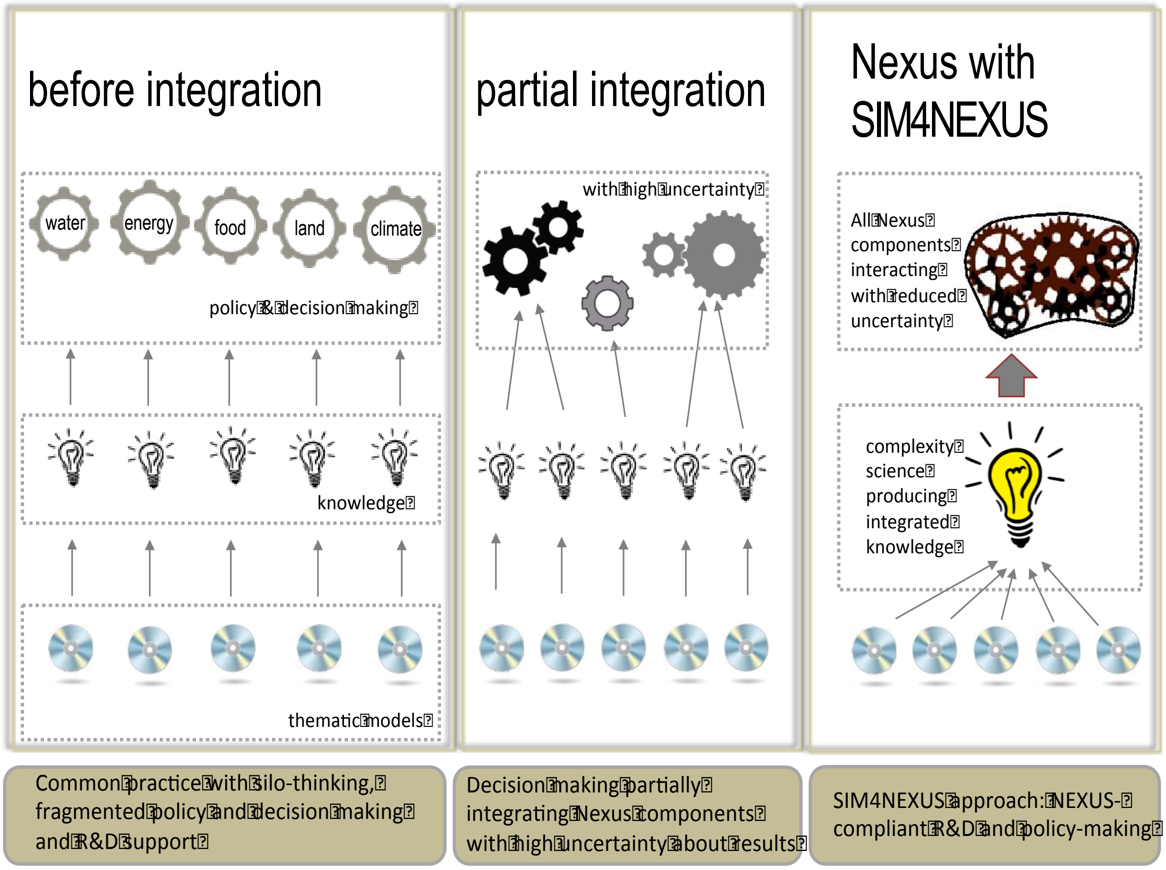

Figure 1. SIM4NEXUS Concept

coordination can lead policies working against each other. This can happen where policy is formed on the basis of inconsistent information or different prioritization of political interests, and can leave business and citizens facing contradictory policy and market signals. Several policy bodies have pointed to the removal of these barriers as essential (SOER, 2015).

2.1. Addressing Key Components of the Nexus

SIM4NEXUS explores the relevance and implications of resource efficiency and a low-carbon economy through a sophisticated analysis of the Nexus. SIM4NEXUS considers five distinct, vitally important resource themes:

(i) Water: Seawater can be desalinated using energy for evaporation or reverse osmosis. Water plays a critical role in agriculture (food and feed production), with irrigation (often energy-demanding) using as much as 90% of the total water consumption (in some areas) making land cultivable. Over-fertilization pollutes water, while its purification requires energy. Water is returned to the atmosphere via evapotranspiration, which is affected by climate.

(*ii) Energy:* A critical resource with regard to security associated with fossil fuels and their key role in climate change and a low-carbon economy, as well as affordability issues. The interlinkages of energy with other resources are considered, mainly through pumping and hydropower (requiring water and land), energy crops (requiring land and water and polluting the latter), extracted energy (renewable or not scarce and requiring land, be it from wind mills or mines), irrigation for agriculture and food/feed production (water-energy-food). A large part of industrial water use is for power station cooling for energy generation, while the combustion of fossil fuels commonly releases GHGs and affects climate. Finally, large quantities of water are required for nuclear power generation, while radioactive waste treatment and disposal is also water demanding and seriously affects water resources (especially groundwater) in multiple ways.

(iii) Land: Cultivable land increases as either forests are cleared, or marginal lands and deserts are made cultivable by irrigation and fertilization. Since available land is limited, competition among uses can be high: urban, grazing of livestock, crops for food, biofuel, fuel wood and large infrastructure (dams, roads, etc.). As land use changes, significant amounts of carbon can be either sequestered or released to the atmosphere. Different amounts of land are required and offer different yields depending on crop type, rainfall (climate), fertilization, irrigation, etc., with consequences for other sectors and associated emissions. *iv) Food:* Increased population exerts pressure on food demand and requires higher productivity leading to higher demand for water, energy and land use. While increase in agricultural productivity lags behind increase in food demand, further expansion in land use for agricultural production leads to substantial pollution and water quality degradation from fertilizer use, as well as loss of nature, biodiversity and associated ecosystem services are realized.

(v) Climate: Major pressure on all resources is exerted through climate change, creating negative synergies such as an increased energy demand for heating or cooling, which produces higher GHG quantities and intensifies climate change, while carbon sequestration is at its highest with forest. A linkage with desertification (land), water scarcity and agriculture (food) is apparent. In some cases climate change might also lead to development opportunities that can contribute to the achievement of wider policy goals – if adequately seized within a Nexus compliant integrated policy framework.

Resource efficiency is one of the core elements of multi-sectoral strategies The fact that resource efficiency requires

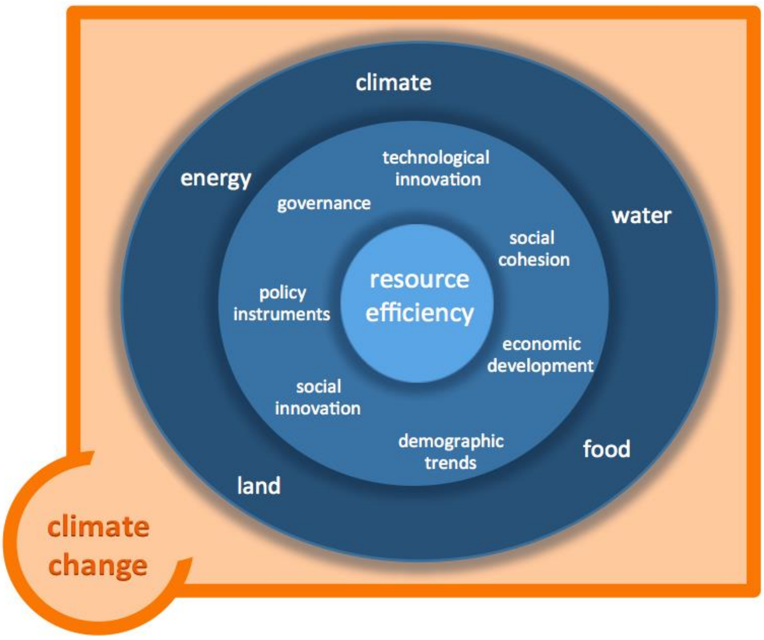

Figure 2. The Vision of NEXUS Concept

action in such a broad range of areas means that modeling is particularly complex. Existing models focus on specific policy areas and sectors such as energy and economics, or climate and water. They cannot fully capture the impact of resource use on ecosystems, the economy and society as a whole, or the interdependence of policy measures. SIM4NEXUS proposes to predict society-wide impacts of resource use and relevant policies on sectors such as agriculture, water, biodiversity and ecosystem services through a model-based analysis of the Nexus via the scientific integration of results of leading (already developed) thematic models, covering components of the Nexus, using a combination of advanced complexity science methodologies. SIM4NEXUS will address the barriers of achieving a low-carbon economy, such as contradictory policies and market signals and will assess the impact of various proposed and implemented climate change adaptation and mitigation measures. This will be achieved by increasing the understanding of the complex web of interactions among all Nexus components, under the influence of a series of drivers, such as economic development, demographic trends, technological and social innovations, policy instruments, governance and social cohesion.

A number of well-known, existing thematic knowledge models will provide detailed outputs for specific aspects of the Nexus. The set includes operational climate-energy economic water and land-use models, with most of them considering the interdependencies of only a few sectors and no single one taking into account all five components of the Nexus. Each of these models has been used to support policy-making institutions (e.g. European Commission, Organisation for Economic Cooperation and Development (OECD) and the World Bank). SIM4NEXUS will use model outputs as a feeder for the Complexity Science integration methodologies to produce a coherent holistic output that will support the Serious Game.

3. Investigating the Nexus in Practice

SIM4NEXUS will carry out research activities in case studies that represent contrasting biophysical, socio-economic and policy features of the Nexus. The case studies draw on transdisciplinary research methods, with knowledge partners working with end-users (policy makers and managers in charge of the Nexus components), SMEs and civil society organisations within participatory approaches.

The case studies will serve as test-beds for the models, the integration methodologies and the Serious Game. In all the case studies, the Nexus trade-offs and the impact of different policies for the future will be assessed. In all regional and national case studies, local stakeholders and decision makers (actors) for the development and testing of the strategies, the policies, and the Serious Game will be engaged. The case studies are classified under four different categories/levels: regional, national, continental and global, so as to enable us to examine and test the Nexus methodologies and approaches adopted in varying detail, and degree of integration. Two case studies are transboundary, so as to give SIM4NEXUS the opportunity to mobilize and include actors from different countries in the same case study stakeholder panel. In all the regional and national case studies local partners participate in the SIM4NEXUS consortium to:

(a) ensure access to local stakeholders, decision makers, data and information,

(b) organise events at local level, and

(c) liaise with local media/institutions for project communication /dissemination purposes.

The level of detail, obviously will differ, according to the case study, i.e. national studies will be examined at higher level than regional ones, enabling SIM4NEXUS to define the type and level of detail most suitable for the Serious Game at each level for further exploitation after the end of the project. The regional and national case studies are mapped in Figure 3. SIM4NEXUS comprises three regional, five national, two transboundary, one continental (European) and one global Case Study (total number 12).

4. Conclusions

The overall scope of SIM4NEXUS is the development of knowledge (about the Nexus, the methodologies of integration, the impact of policies) leading to improved decisions for resource efficiency, related to the Nexus based on:

- Strong science about the Nexus;
- Appropriate and innovative tools and methodologies for integration;
- Participatory procedures based on real case studied at different scales and
- Compliance of the local stakeholders and end-users in order to develop, test and validate proposed approaches, methodologies and tools.
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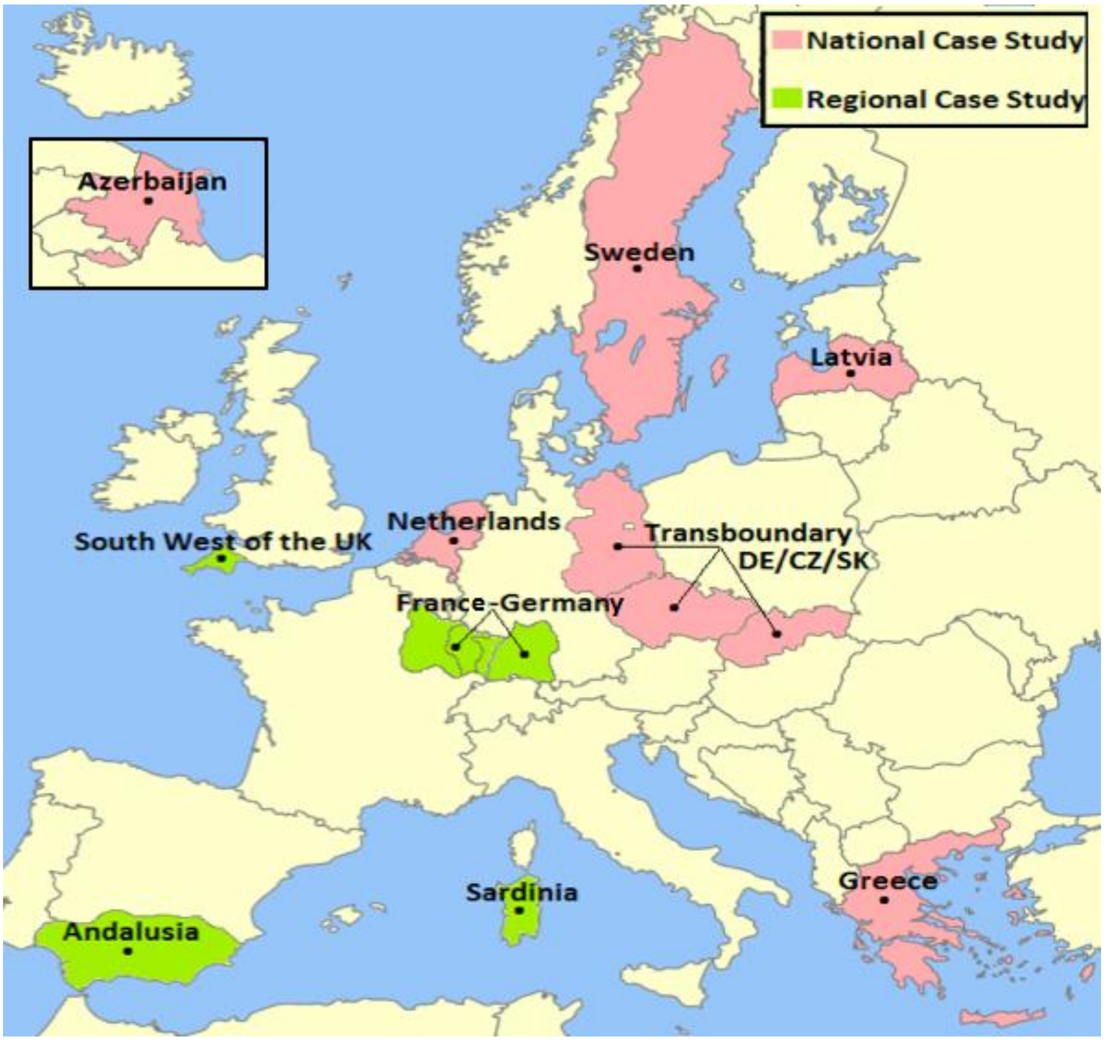

Figure 3. A map of SIM4NEXUS Case Studies

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