MINES PARIS | PSL | TTI.5° The Transition Institute

SYNTHESIS

Summary of the Water-Food-Energy Nexus seminar

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SEMINAR SYNTHESIS WRITTEN BY CLAIRE CAUMEL AND LEWISIA TOLEDO--PONCET

TTI.5 PUBLIC SEMINAR - SESSION 1

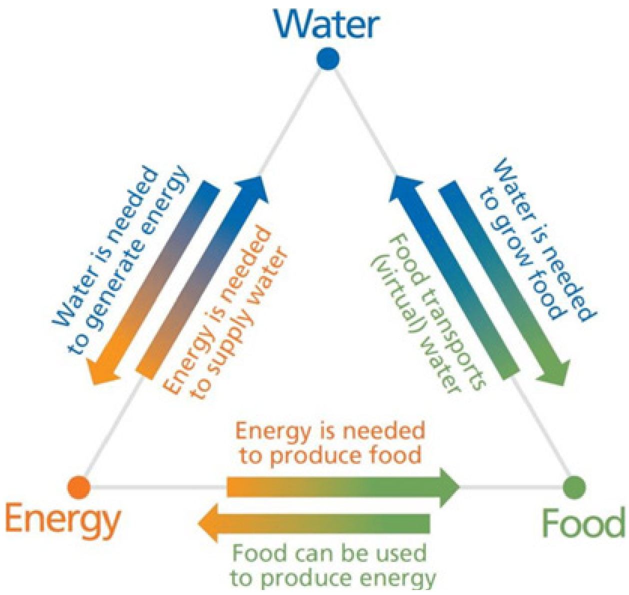

Figure 1: Interdependence of water, energy and food (IWA, 2018)

Introduction to the Water-Food-Energy Nexus

Daniel Florentin – ISIGE and research associate at CSI (Mines Paris – PSL)

To start with, it is important to point out that this nexus is based on the observation of an interdependence between water, food and energy issues (Figure 1). For example, energy is required to produce water and vice versa.

The reflection on a nexus stems from an analysis of the question in terms of making flows secure, integrating the different areas in line with each other to avoid potential shortages. This reflection, which was mainly developed by the chief scientific adviser to the UK government, John Beddington, is part of a political agenda that dates back a decade.

Beddington warned public actors that food shortages, scarce water and insufficient energy were leading to a "perfect storm" involving a multifaceted crisis by 2030. This analysis drew attention to the systemic character of crises and led to a shift from looking at the issue in terms of interdependence to considering vulnerability. In order to act on vulnerability, research has underlined the need to understand the nature of interdependence and its intensity between sectors.

This nexus is now part of the agenda for policy, science, and all disciplinary fields. For example, reflections on the water-food-energy nexus have led to rethinking forms of public action (cf. Artioli et al., 2017; Monstadt and Coutard, 2019). In most research on local public action, some studies show for example that considering the nexus is an invitation to re-politicize integration questions. The problems involved are not in fact purely technical, but it is necessary to understand the institutional and sociotechnical set-ups at the heart of the nexus question.

Put simply, the nexus can be tackled in several different ways, the three main ones being:

1. An approach through functional and technical interdependencies, referred to as homeostatic (i.e. approaching flows in the form of quantification), which can be used to measure interdependencies.

2. An approach through organizational interdependencies: based more on management.

3. An approach through the governance of flows: economic and political ecology approaches that are often based on quantification studies and attempt to analyze the systems for regulating and managing these flows.

Nevertheless, while discussions on the nexus attempt to demonstrate the existence of a significant circulation of flows (energy, water, etc.), in general the second biggest flow in terms of tonnage is left out of these analyses, i.e. building materials.

Water resources in a changing environment

Nicolas Flipo – Géosciences (Mines Paris – PSL)

The first part of this presentation mentions the main challenges facing water resources subject to climate change. The second part focuses on evaluating changes at the scale of regional water basins taking the example of the Seine River.

Main challenges facing water resources subject to climate change

The future of water in a changing environment is a subject that concerns climate change, but it is also a subject that questions how we take into account various land use developments due to societal practices, with a view to anticipating the impacts of these changes.

Water is a renewable resource. Out of the 46,000 km3 of water that flow into the oceans every year, 4,500 km3 are withdrawn, of which 2,200 km3 are consumed.

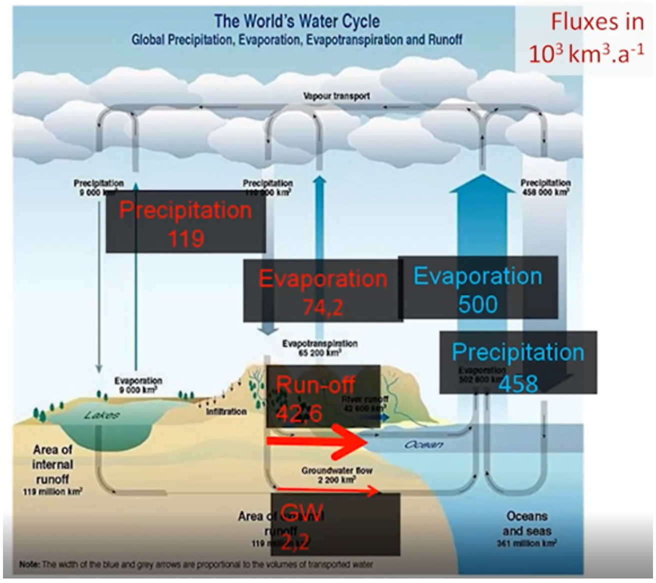

Figure 2: World water cycle by Shiklomanov, 1994

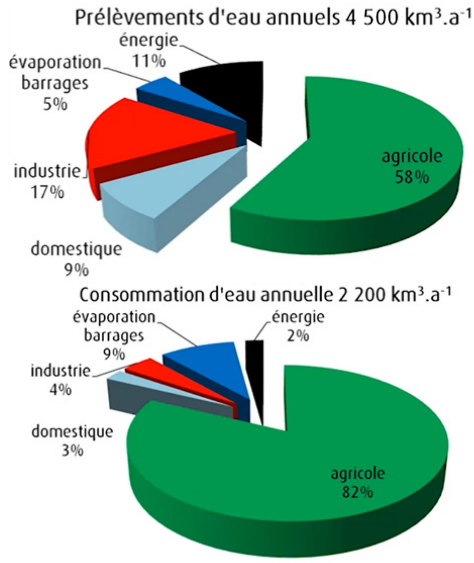

Figure 3 by Marsily, G. 2008

Looking at the above graph, we can see that agriculture is the sector subject to the highest amount of water withdrawals and also the biggest consumer. The third part of this nexus, energy production, also requires large quantities of water, in particular to cool down power stations (primarily nuclear but also gas and coal). The interdependence between these two water usages is also apparent in the water-food-energy nexus.

Based on consumption and hydrological balances, an estimated four billion people undergo severe water[1] stress during at least one month a year, and 500 million do so permanently. The trend is rising, with dry places becoming drier and wet zones even wetter, doubly reinforcing "extreme" events with significant flow losses during summertime and greater flows during flood-risk periods.

In a projection where the global temperature increases by 1.5°C at the end of the century, the average number of people subject to water stress is likely to double (i.e. 1 billion individuals in 2100).

[1] A situation is defined as severe water stress when demand represents over 50% of the recharge of water systems.

Evaluation of changes at regional water basin scale taking the example of the Seine River

In this research, we set out to evaluate water changes at the scale of a regional water basin, in this case the Seine.

The Seine river basin, which has the unusual characteristic of sharing three types of area: agricultural, forest and urban (with more than 17 million inhabitants), features 28,000 km of rivers and is the biggest underground water reservoir in Europe within a geological structure (known as "pile d'assiettes", or stacked plates). The natural water regime is also regulated in the basin, through dam-reservoirs installed in clay areas that can retain over 840,000,000 m3 water, helping it to maintain low-water flows. However, the basin is under pressure: the population withdraws about three billion m3 of water per year (surface water and aquifer).

To understand how the basin works required developing a model. The Geoscience Center therefore developed CaWaQS, a generic tool for modeling surface and ground waters applied to the Seine river basin. The model represents the Seine basin's spatiality and the different water flows, employing geological, meteorological, land usage data, etc. A piezometric map can be used to visualize (by measuring the water pressure) the different flows of surface waters and aquifers (groundwater). This tool can also be employed to determine the contribution from groundwater (aquifers) to surface water and the dependencies of the latter.

In the future, the modeling tool could be used to reconstitute hydrological trajectories. Recently, it was coupled with SARAN reanalysis reconstituting precipitation data in the basin since the 19th century. The model should be able to make a historical reconstitution and carry out prospective exercises to anticipate the future of water resources in the basin in the context of climate change. Scenarios are used that are based on the territorialization of scenarios from the previous IPCC exercise projected with the MIROC5 model: a median scenario and a business as usual scenario (RPC8.5: 8.5C° by the end of the century).

The results of this exercise are astonishing: in the case of the RCP8.5, the prognostic is an extremely serious period in 2050 with a piezometric collapse that could reach 7 or 8 meters (i.e. the water network would disappear in some central areas of the basin). By the end of the century, low-water flows in the east of the basin would be 10% lower than current levels, and winter flows would significantly increase all over the basin.

To conclude, the projections calculated using the MIROC5 model indicate that, while in mid-century the situation would require adapting to extreme drought, by 2100, it would call for large-scale flood management plans.

Impact of agricultural practices on groundwater quality in the Seine River basin

Nicolas Gallois – Geosciences (Mines Paris – PSL)

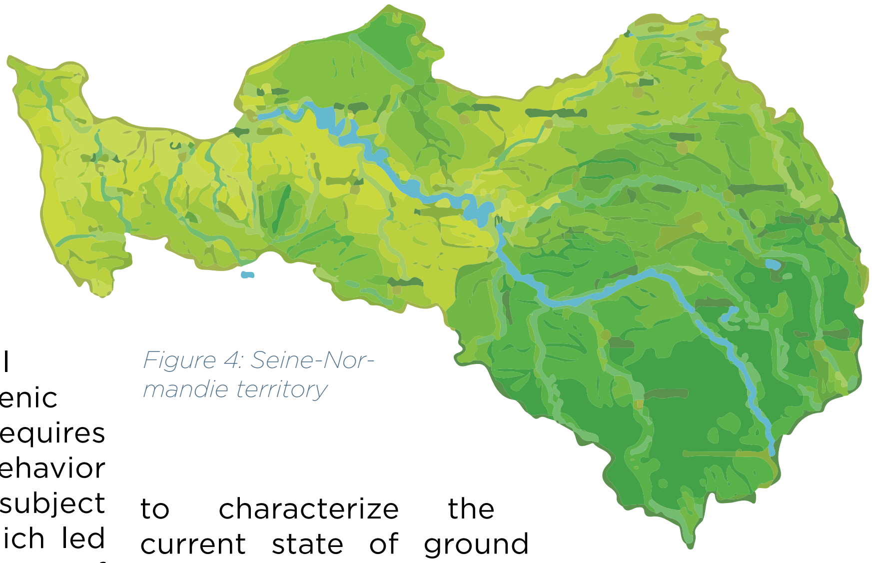

Figure 4: Seine-Normandie territory

For more than two decades, some of the researchers at the Geoscience Center (Mines Paris – PSL) have been looking closely at the quantified evolution of water resources in the Seine-Normandy area and its vulnerability to both global changes and high anthropogenic pressure. This complex question requires a close understanding of the behavior of the regional water system, subject to a changing environment, which led to the conception and development of several mathematical models.

To comprehend the current state of the quality of water in the area vis-à-vis the nitrogen loads resulting from farming, a multidisciplinary modeling platform was implemented mobilizing the hydrologic-hydrogeologic model CaWaQS (Geoscience Center, Mines Paris - PSL), the spatialized agronomic model STICS (INRAE / Geoscience Center) and the biogeochemical model pyNUTS-RIVERSTRAHLER (Sorbonne University), which can be used to simulate the transportation of nitrogen loads in all compartments of the basin (soil, aquifer system and hydrographic network). In addition, the tool is interfaced with a database that details the evolution of crop systems in the area (ARSeiNE base, INRAE) to consider the actual production of this pollution

As part of the basin management stock-taking exercise required by the Water Framework Directive, the results of its regional application are summarized to characterize the current state of ground and surface water bodies. The platform has also led to an initial characterization of long-term evolution trajectories of the state of these water bodies subject to different regionalized prospective agro-climatic scenarios (continued specialization and intensification of agriculture in the basin, progressive introduction of agroecological practices).

The digital tools on this evolving platform require continuous updating in order to both hone their representations of all or part of the system studied, and to extend their scope of application. As a result, the tool is currently the object of studies centered on modeling energy/temperature flows, a crucial issue in a context of climate change.

Analyzing the Applicability of Random Forest-Based Models for the Forecast of Run-of-River Hydropower Generation.

Valentina Sessa – CMA (Mines Paris – PSL)

This talk presents the paper (Sessa, 2021), and provides an analysis of the practicability of a machine learning technique used for forecast hydropower generation.

This work was conducted as part of the Clim2Power project, which is a European research project developed by several research centers from different countries. The main goal of the project is to promote the integration of climate variability in investment decisions related to the European power system. Indeed, the European energy sector is already affected by climate change but most models do not take climate variability into consideration. As a result, Clim2Power analyzes different climate scenarios.

In order to do so, two main tasks needed to be completed:

- Translate climate data into hydro, PV, and wind power generation, and electricity demand.
- Use these values to feed energy models in order to compute the reduction in terms of cost and CO_2 emissions whenever renewable resources are integrated into the existing power system.

The paper, which was published as part of this project, focuses mainly on hydropower production, which is the largest renewable energy source in the world. More specifically, the paper focuses on run-of-river (Hror) hydropower (electricity is generated according to river flow).

In particular, the task was to translate time series of daily climate data (air temperatures and precipitation) into time series of daily hydropower capacity factor at country level for all of Europe. To do so, we opted to use Machine Learning (ML).

Machine Learning involves two main phases: a training phase, and a prediction phase. In the training phase, we use part of historical data for learning, and then use the rest of the historical data to check the accuracy of the model. In the learning phase of the model, the main task is to choose an appropriate algorithm and input to introduce into the model.

Several regression methods were compared, and the one that performed best was the Random Forest method. This algorithm creates a forest of decorrelated trees by performing a random bootstrap of the training data set and then randomly subsampling among the features (Figure 5).

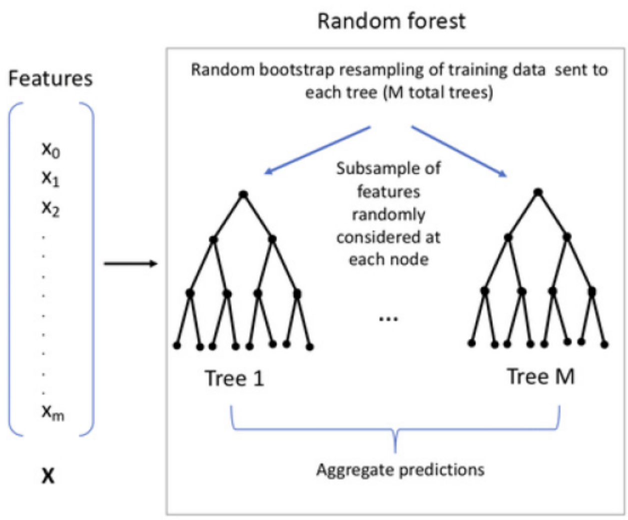

Figure 5: Illustration of the Random Forest method

[3] Capacity factor is defined as the percentage of hydropower generated over installed capacity

Predictors	M1 (avg)	M2 (NUTS2)	M3 (avg+NUTS2)
Temperature			
sync	✓	✓	✓
lagged (opt)	✓	✓	✓
Precipitation			
sync	✓	✓	✓
lagged (opt)	✓	✓	✓
accum (opt)	✓	✓	✓

Figure 6: Model definition via predictors selection. "Avg" is a country mean average values, NUTSS2: regional mean values.

At the end of the process, the predicted output will be the sample mean of the responses given by each tree.

After choosing the regression algorithm, the analysis focused on the input features (temperature and precipitation data). The aim was to determine which form of the input can improve the accuracy of the underlying models. The main choice was between an average at country level (Ho & al. 2020) and/or a finer spatial resolution.

The numerical experiments showed that the M3 model, which combined the two choices of input data forms, performed best.

It should be noted that this model showed good results for some countries, but not for all of them. Some country-related issues emerged. For example, the model could not predict hydropower generation at the end of 2019 with high accuracy because this period was exceptional in terms of precipitation.

To conclude, machine learning is a very important tool to provide information about variations in hydropower production. Although the model is not particularly accurate, now that the methodology has been established, it will naturally improve over time as more data feed into the ML algorithm. It is important to bear in mind that having an accurate model for predicting the energy produced by renewable resources is essential to promote their integration in the existing power system.

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