Machine learning for water-energy-food-ecosystems nexus policy

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Dr Janez Sušnik, from the IHE Delft Institute for Water Education and NEXOGENESIS Coordinator, guides us through the use of machine learning for improving policy advice in the water-energy-food-ecosystems nexus

Water, energy, and food (WEF) form a coherent interconnected system often referred to as the WEF nexus (Hoff, 2011). The WEF nexus interacts strongly with ecosystems, forming the wider WEFE nexus.

Ecosystems provide the 'base' of the WEFE nexus, helping ensure the quantity, quality, timing, and accessibility of WEF resources, for example, by providing services including water purification, contributing freshwater provisioning, pollution reduction and control; maintaining healthy landscapes, contributing towards crop growth for food and energy crops; biodiversity providing pollinating insects for crop production and; forest and floodplain ecosystems provide biomass that as act as a global carbon sink and oxygen supply (Bell et al. 2016; Martinez- Hernandez et al. 2017).

The complex water, energy, and food nexus

The WEFE nexus is extraordinarily complex, with each sector interacting with the other sectors and being affected by 'externalities', such as the impacts of climate change and socio-economic developments which modulate resource demand, consumption, and exploitation, as well as degrading ecosystems.

WEF interactions include: water needed for irrigated agriculture; agricultural activities impacting water quality; water is required for energy generation in thermal power plant cooling and hydropower plants; energy being used in the production of water (pumping, treatment), for heating and cooling of water, and the treatment, disposal, and re-use of wastewater; food and crop residues are used in energy production through biomass burning and the production of biofuels and; energy is used for agriculture in mechanisation, the food value chain, and for the production of synthetic fertilisers.

Therefore, in our modern hyperconnected society, when considering the WEF sectors, we cannot think about each in isolation without considering its impacts on the other sectors. As alluded to above, the interaction with and from ecosystems and their services complicates the WEFE system further.

The WEFE nexus does not exist in isolation; instead, it is framed within a more extensive system comprising climate and socio-economic-political factors that both modulate resource demand, use, extraction, and pressures on ecosystems (which are already

overexploited; Richardson et al., 2023) and are themselves affected by the availability of high-quality WEFE resources in sufficient quantities at the time they are required. Managing such a complex system demands a holistic, integrated perspective accounting for interactions across sectors.

A single-sector, silo approach to natural resource management is insufficient. However, attaining cross-sectoral harmonisation (i.e. achieving policy goals while not causing detrimental impacts to other sectors) in policy formulation is hard enough when considering even just the nexus-wide implications of one policy accounting for various climate and socio-economic futures.

This situation is made considerably more complex when multiple interacting policies are considered. As an example, if we consider ten hypothetical policies across nexus sectors, all with their own goals that could be implemented either one at a time or in any combination with other policies as a set of policy suites, there are approximately 3.6 million unique ways to combine these ten policies.

This raises questions such as: which combinations are most feasible? Which achieves the most objectives whilst minimising negative impacts in other sectors? (it is noted here that in most cases, not everyone can “win” – there are always trade-offs. The question is how to minimise these trade-offs). Obviously, it is not possible to explore all options manually. This is where machine learning comes in.

WEFE nexus system research

The European Commission Horizon 2020 research project, “Facilitating the next generation of effective and intelligent water-related policies utilising artificial intelligence and reinforcement learning to assess the water-energy-food-ecosystem (WEFE) nexus” (NEXOGENESIS), is researching the WEFE nexus system in five diverse studies, including one from South Africa, and how the nexus may evolve to 2050 under a set of climate and socio-economic futures.

NEXOGENESIS explores the potential impacts of multiple policies being implemented across WEFE sectors to achieve multiple, sometimes conflicting, goals. Through the use of machine learning technologies, vast policy combinations and their impacts on WEFE resource pathways can be assessed against many objectives and within different climatic and socio- economic futures (not all policies will perform the same under different conditions).

WEFE nexus system policy

The WEFE models and the policy suggestions are developed in close collaboration with local case study partners and broad stakeholder groups. One key aim of NEXOGENESIS is to offer a set of potential ‘policy packages’ that achieve multiple objectives across sectors as well as possible whilst minimising negative trade-offs. Policies may have become more robust under an uncertain future. The packages will be recommended to local policy experts so they can investigate further and narrow them down.

In this way, millions of potential options are narrowed to a few feasible packages. A deeper, local-level investigation can then focus on the feasibility, cost, (social) acceptance, etc., of the suggested policy packages to help achieve WEFE resources security in the case studies. The hope is that policies may be redesigned to account for the complex nature of the interacting WEFE nexus and for the fact that policy performance will differ in different futures.

Through intense and novel stakeholder co-creation activities, governance assessment, WEFE systems modelling, and machine learning integration, NEXOGENESIS is well-placed to deliver actionable policy recommendations to the five project case studies. It also provides a framework and template that can be adopted in other regions to contribute towards more integrated and streamlined policy formulation for holistic natural resources management.

References

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NEXOGENESIS Project: IHE Delft Institute for Water Education

IHE Delft Institute for Water Education is the largest international graduate water education facility in the world. Based in Delft, the Netherlands, IHE Delft confers fully accredited MSc degrees and PhD degrees in collaboration with Dutch partner universities The Institute conducts research and supports capacity development to address the world's water challenges. Since the start […]