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المركز الإقليمي للطاقة المتجددة وكفاءة الطاقة

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On behalf of: Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety of the Federal Republic of Germany

Energy Efficiency and Renewable Energy for Food and Water Security in the Arab Region

- Cairo Water Week 2019 -

Water-Energy-Food Nexus:
State of the Art

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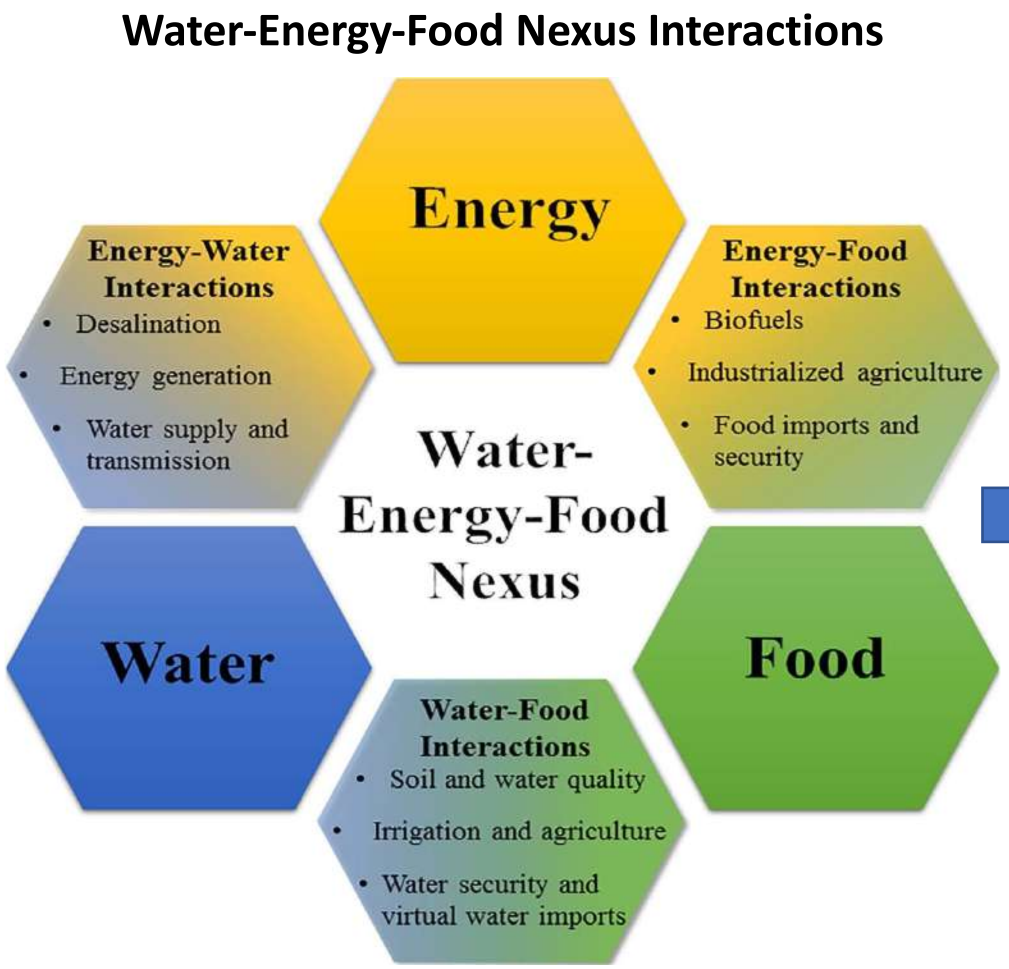
Introduction

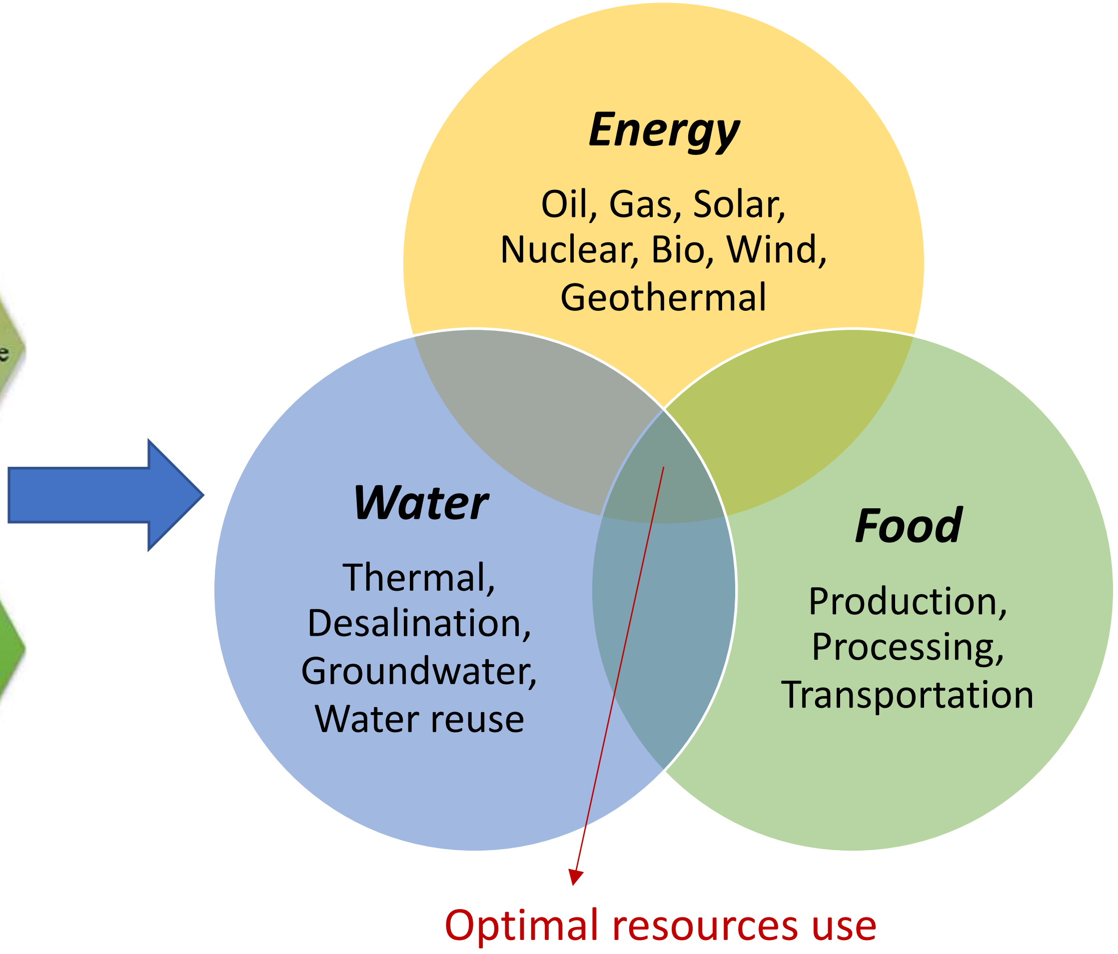
- ***Food, Energy, and Water*** (FEW) have been described as 'the pillars on which global security, prosperity, and equity stand' and all three show up in the United Nations Sustainable Development Goals.
- The **security** of water, energy and food is becoming a very high concern due to **future uncertainties**. The global demand for water, energy and food is driven by rapid ***population growth, urbanization and climate change*** which requires the development of sustainable and resilient water, energy and food systems

Introduction

- The synergies and trade-offs between the water, energy, and food sectors are represented by the ***Water-Energy-Food Nexus***. The Nexus Approach is an integrated decision making practice that can be used by policy makers to optimize these synergies and manage trade-offs.
- The Nexus Approach aims to provide decision makers with better or convoluted information, as opposed to more information, in the nexus areas for more efficient policy- and decision-making in an effort to transition to a ***Green Economy*** which aims **at resource efficiency** and mutually reinforcing policies.

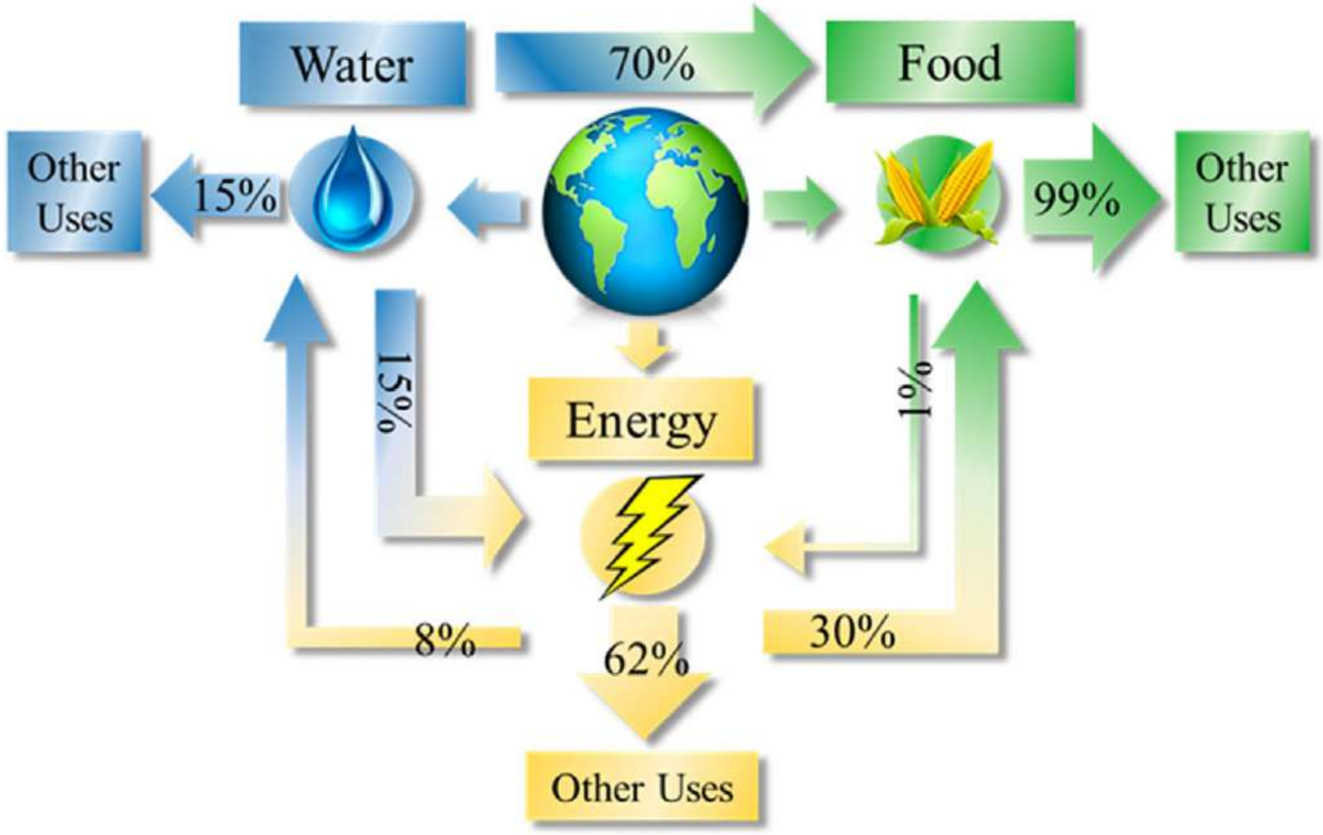
Introduction





Source: Kaddoura, S., & El Khatib, S. (2017). Review of water-energy-food Nexus tools to improve the Nexus modelling approach for integrated policy making. Environmental Science & Policy, 77, 114-121.

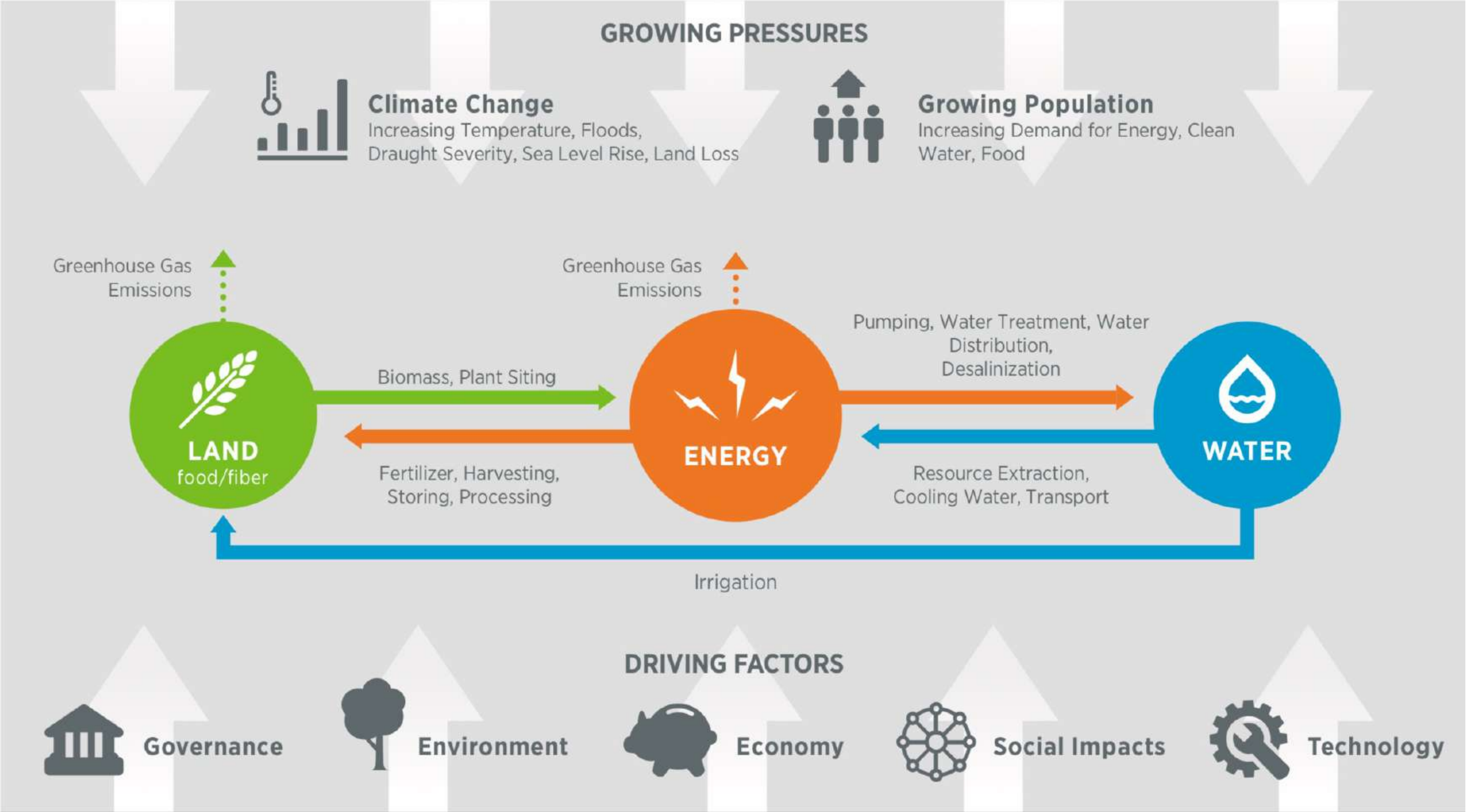
Introduction



Globally:

- water -> 15% for energy purposes, 70% for agriculture and 15% for all other purposes
- Energy -> 8% for water pumping and treatment, 30% for food production and supply chain
- Food -> 1% for energy

Source: Garcia, D. and You, F., (2016) The water-Energy-Food nexus and process system engineering: a new focus, Computers and Chemical Engineering 91,49-67



National Renewable Energy Laboratories (NERL), Connecting the dots, 2014

History of Water-Energy-Food Nexus

- The popularity of nexus is dated back to the ***World Economic Forum 2008*** where the global challenges related to economic development were recognized from the water-energy-food nexus perspective.
- The view of the Nexus has evolved from it being perceived as a ***network of global risks***, into a decision making philosophy utilizing ***systems thinking*** that optimizes policies and regulation in a way that will allow for capitalizing on the synergies between water, energy, and food, while reducing their trade-offs.
- In recent years, other pressing factors have been added to the water, energy and food nexus such as ***climate change***.

Definitions of Water-Energy-Food Nexus

- There is no consensus on the nexus definitions , it has varying interpretations in different sectors and contexts and by different researchers.
- In general, there are <u>two categories of definitions</u>:

1

This category focuses on the representation of interactions between different sectors, aiming at grasping the overall characteristics of the complex system by its <u>**components' interlinkages**</u>. As the **security issues** of these three sectors become severe, the term emphasizes that failures in one sector may exert pressures on the other two sectors, requiring **a holistic management among these sectors.**

Source: Zhang, C., Chen, X., Li, Y., Ding, W., & Fu, G. (2018). Water-energy-food nexus: Concepts, questions and methodologies. Journal of cleaner production, 195, 625-639.

Definitions of Water-Energy-Food Nexus

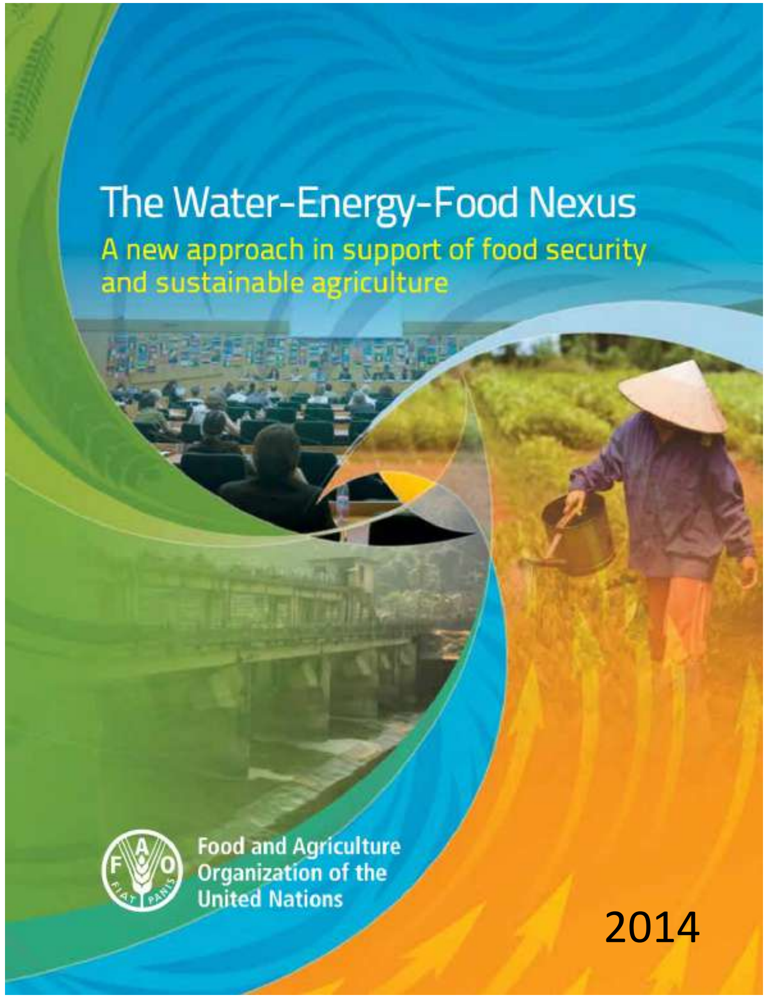
2

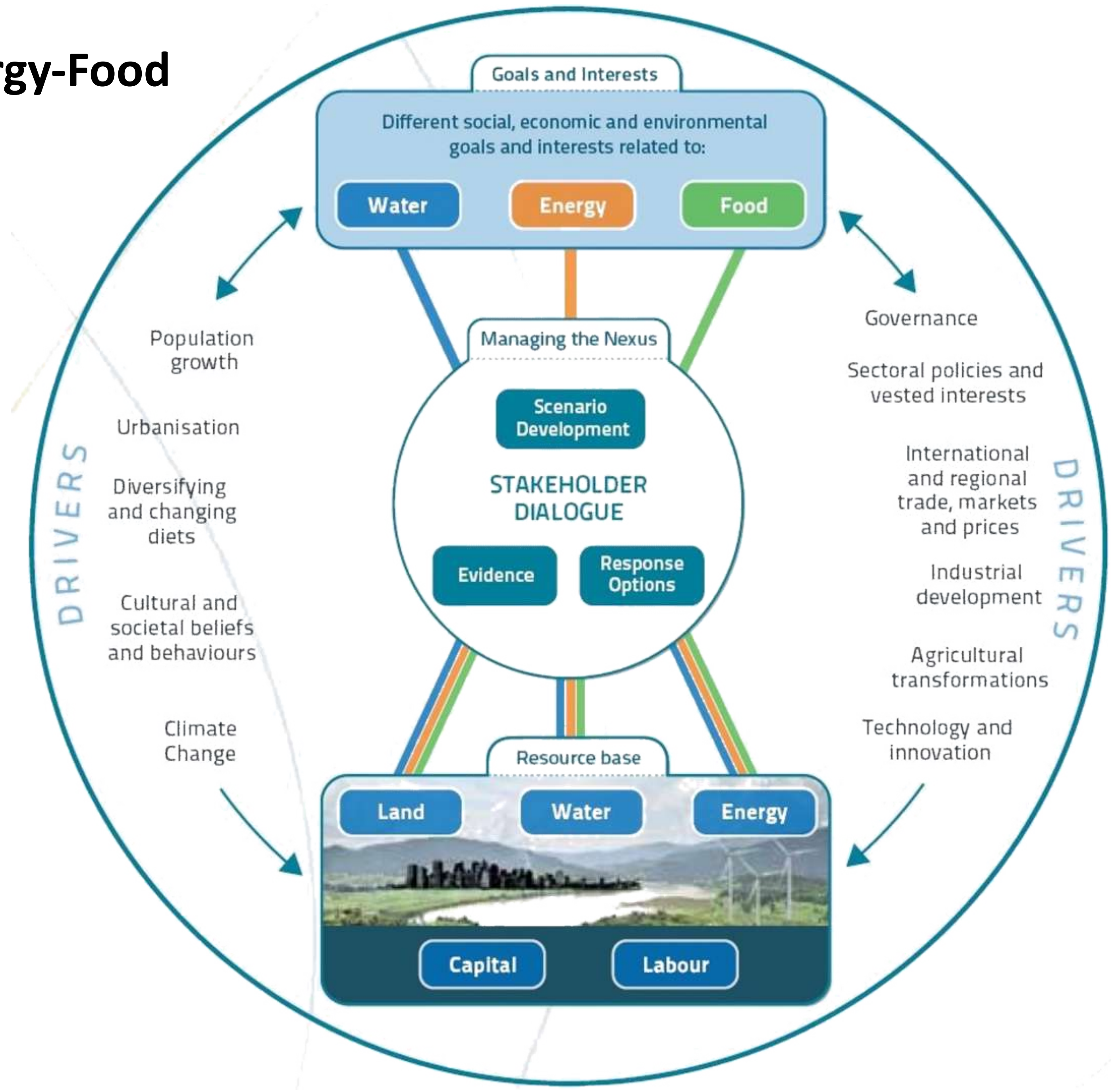
The nexus is presented as **an analysis approach to quantify the links between the nexus nodes** (i.e., water, energy and food). There are many interpretations about this emerging approach such as:

- ***The Food and Agriculture Organization*** of the United Nations highlighted that the functions of the nexus approach was to systematically analyze the coupled human-nature system, and to produce an integrated management of natural resources across different sectors and scales by building synergies and managing trade-offs.
- ***Smajgl et al. (2015)*** deepened the understanding of this approach to a continuously evolving system, arguing that the interactions among nexus nodes **ought to be dynamically addressed**.
- Therefore, they preferred to define it from three aspects, including an analytical method, **governance tool** and an emerging discipline, which complemented one another.

Source: Zhang, C., Chen, X., Li, Y., Ding, W., & Fu, G. (2018). Water-energy-food nexus: Concepts, questions and methodologies. Journal of cleaner production, 195, 625-639.

The FAO approach to the Water-Energy-Food Nexus





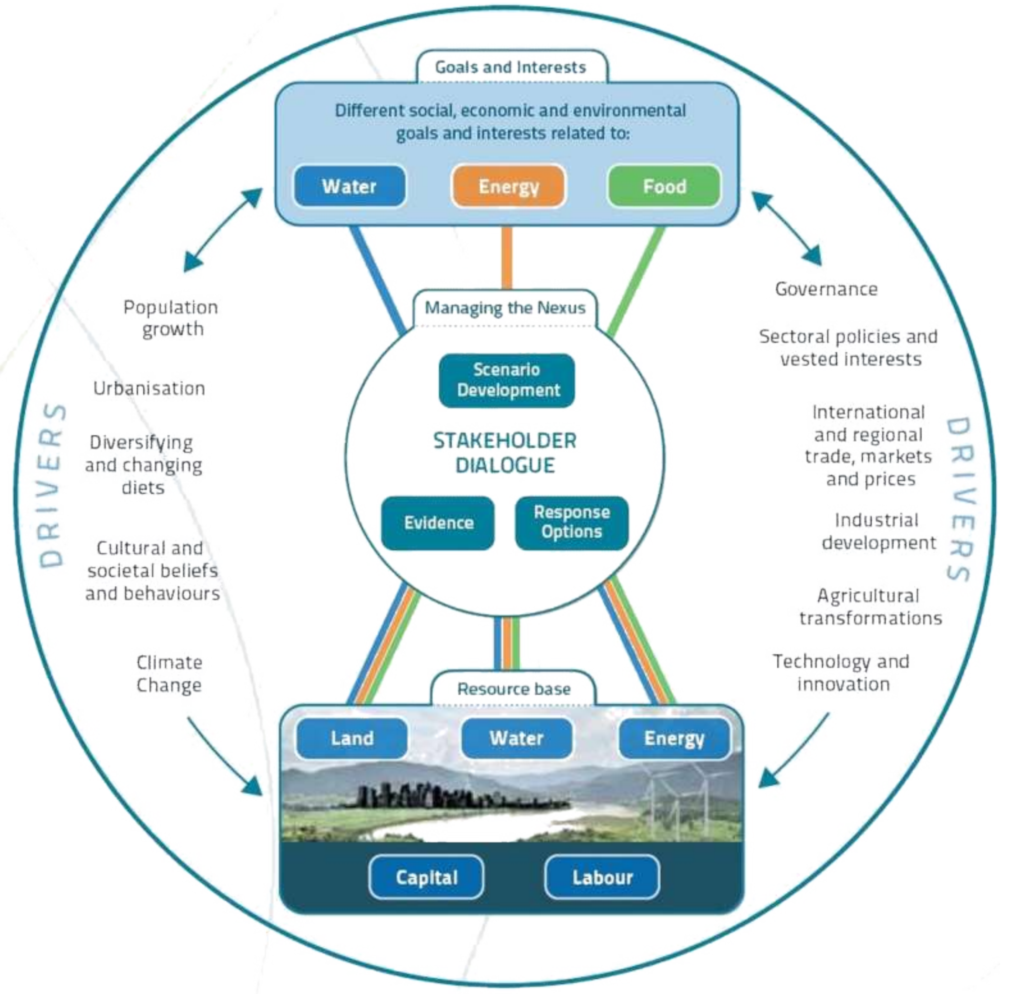
The FAO approach to the Water-Energy-Food Nexus

The resource base: natural and socio-economic resources, on which we depend to achieve different goals and interests pertaining to water, energy and food.

Nexus interactions: are about how we use and manage resource systems, describing interdependencies (depending on each other), constraints (imposing conditions or trade-offs) and synergies (mutually reinforcing or having shared benefits).

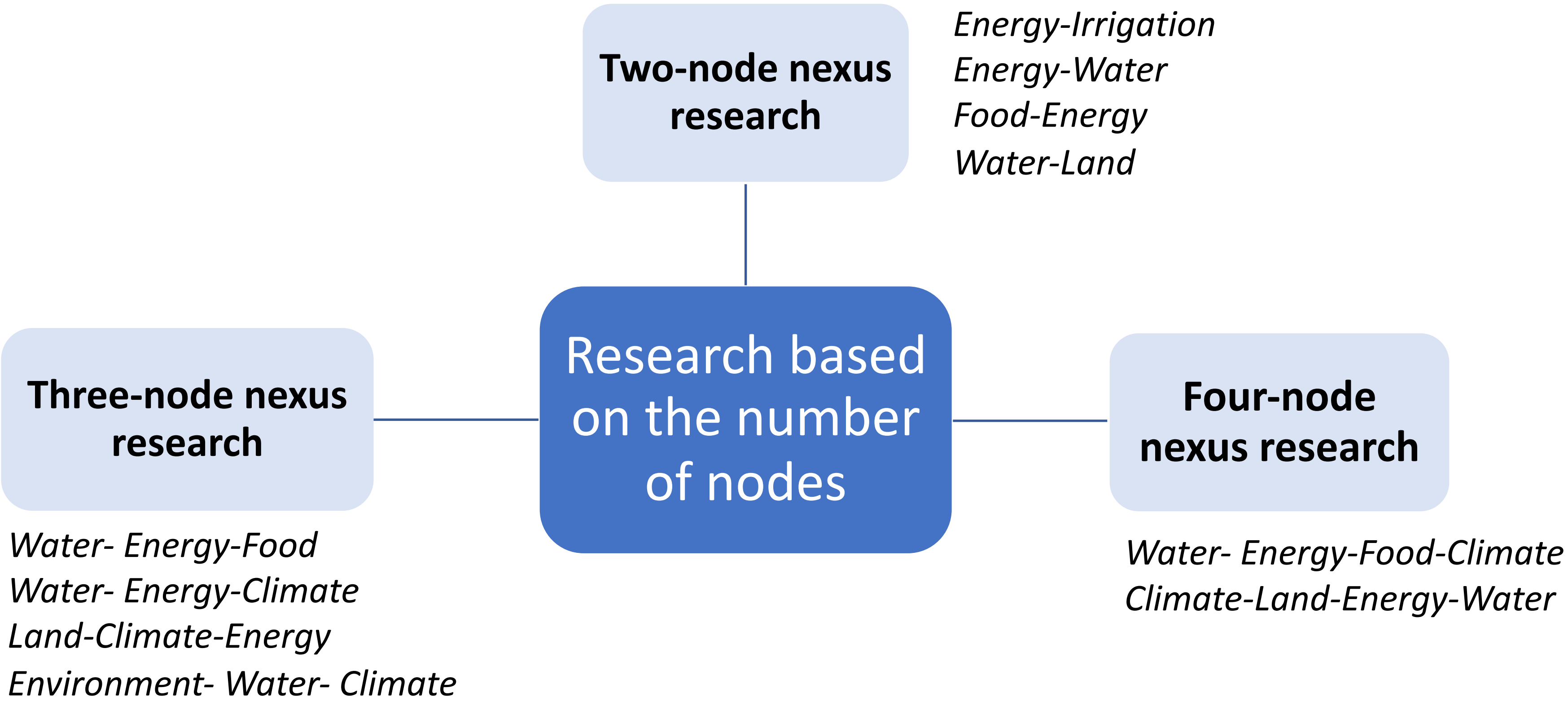
Drivers: such as demographic changes, urbanization, industrial development, agricultural modernization, international and regional trade, markets and prices, technological advancements, diversification, and climate change as well as more context-specific drivers, like governance structures and processes, cultural and societal beliefs and behaviors

Impacts: these drivers often have a strong impact on the resources base, causing environmental degradation and resource scarcity, but they also affect and are affected by different social, economic and environmental goals and interests.



Themes of Nexus Research

Nexus research can be divided into three categories based on the number of nodes:



Nexus Research Questions

Nexus research questions can be classified into three categories based on the connections between different sectors as well as the descriptions of coupled system performance:

Internal Relationship Analysis

- Captures interactions between different sectors
- The interactions between sectors can be ***one way impact*** (how changes in one specific sector affects associated sectors) or ***interactive impact*** analysis (describes the characteristics of the nexus more comprehensively and reveal mutual interrelationships between different sectors)

External Impact Analysis

- Deals with external environment changes/threats affecting the performance of the nexus system by shaping the production and use of water, energy and food.
- External threats are impacts of outside force, entity or actor such as: climate change, pollution incidents, population growth, politics,..etc). They can be social or physical, acute or chronic.

Evaluation of the coupled System

- Involves analysis and assessment of the entire nexus system performance with respect to concepts such as sustainability and resilience.
- It also explores the impacts of policy changes on the resilience and sustainability of a nexus system.

Source: Zhang, C., Chen, X., Li, Y., Ding, W., & Fu, G. (2018). Water-energy-food nexus: Concepts, questions and methodologies. Journal of cleaner production, 195, 625-639.

Nexus Research Methodologies

Summary of Nexus research methods and their applications:

Research scale	Interdependency	Research priorities	Research methods
Global scale	• Water-energy • Food-energy-water • Climate-food-economy • Climate-water-energy-food	• Investigating impacts of consumption patterns (e.g. dietary shifts) and economic activities (e.g. trade) • Improving food/energy/water security given water-energy-food nexus • Climate change impacts and mitigation policy assessment and design • Ecosystem or sustainability valuation to help decision making • Development of integrated system modelling tools	• Investigation and mathematical statistics • Computable general equilibrium model • Econometric analysis • Ecological network analysis • Integrated Index
National scale	• Water-energy • Food-water • Food -energy-water • Climate-energy-water • Climate-water-food • Climate-energy-water-land	• Investigating trade-offs underlying supply chains of water, energy, and food • Improving food/energy/water security given water-energy-food nexus • Climate change impacts and mitigation policy assessment and design • Demonstrating impacts of consumption patterns (e.g. dietary shifts) and economic activities (e.g. trade) • Promoting coherence in policy-making • Development of integrated system modelling tools	• Investigation and mathematical statistics • Computable general equilibrium model • Econometric analysis • Life-cycle analysis • System dynamics model
Basin scale	• Water-energy • Energy-food • Energy-water-food • Climate-water-energy-food	• Manifesting nexus issues caused by resources allocation and promoting policy integration (e.g. expansion of bioenergy, water resource allocation between upstream and downstream countries, etc.) • Investigating trade-offs underlying supply chains of water, energy, and food • Improving resource use efficiency by resources recycle and novel technologies • Achieving long-term sustainability by managing trade-offs between water, energy, and food • Development of integrated system modelling tools	• Investigation and mathematical statistics • Life-cycle analysis • Agent-based model
City scale (or community scale)	• Water-energy • Water-energy-food •Climate-food-energy-water	• Manifesting nexus issues inherent in urban metabolism • Revealing impacts of household uses (or end-use) • Identification of eco-friendly pathways to sustained economic growth • Improving resource use efficiency through resources recycle and novel technologies (e.g., renewable energy technologies, novel technologies in desalination and wastewater treatment, etc.) • Development of integrated system modelling tools	• Investigation and mathematical statistics • Ecological network analysis • System dynamics model • Integrated Index • Physically based models

Source: Zhang, C., Chen, X., Li, Y., Ding, W., & Fu, G. (2018). Water-energy-food nexus: Concepts, questions and methodologies. Journal of cleaner production, 195, 625-639.

Examples of Nexus modelling tools

<u>CLIMATE, LAND-USE, ENERGY, WATER (CLEW)</u>

- The CLEW framework is developed by the International Atomic Energy Agency (IAEA) with the purpose of illustrating synergies and trade-offs within the CLEW areas for **decision making** related to achieving development goals. The synergies are represented using a toolkit made up of existing independent planning tools: Long-Range Energy Alternatives Planning System (LEAP), and Global Agro-Ecological Zoning Model (GAEZ).
- The CLEW framework is a prime example of applying a systems thinking approach to the WEF Nexus.

<u>Applications:</u>

- Evaluate trade-offs and synergies to optimize policy making recommendations.
- Assessment of policies and technologies to determine if they advance multiple objectives at once which is important for integrated policy making.
- Minimize synergistic inefficiencies by harmonizing conflicting policies.
- Understanding the implications of different policies and their effect on future development goals, which is the fundamental purpose of the WEF Nexus.

Source: Kaddoura, S., & El Khatib, S. (2017). Review of water-energy-food Nexus tools to improve the Nexus modelling approach for integrated policy making. Environmental Science & Policy, 77, 114-121.

Examples of Nexus modelling tools

WATER, ENERGY, FOOD NEXUS TOOL 2.0

- The Water, Energy, Food Nexus Tool 2.0 was developed at Texas A & M University. It is a web-based tool accessible to the public online. A case study testing the tool was completed on Qatar and managed to provide some notable insights on the synergies within the hyper-arid country.
- The tool provides the following seven outputs based on user defined scenarios:
    1. Total water requirement (m3)
    2. Total land requirement (ha)
    3. Local energy requirement (kJ)
    4. Local carbon footprint (ton CO2)
    5. Financial cost (US $)
    6. Energy consumed through import (kJ)
    7. Carbon emissions through import (ton CO2)

Applications:

These outputs are used to calculate an overall sustainability index which is a decision making indicator that allows for an absolute comparison between various development scenarios. For example, a scenario requiring less water could be more energy intensive. However, a scenario that utilizes renewable energy might be more financially demanding. The sustainability index allows the user to compare these two alternatives.

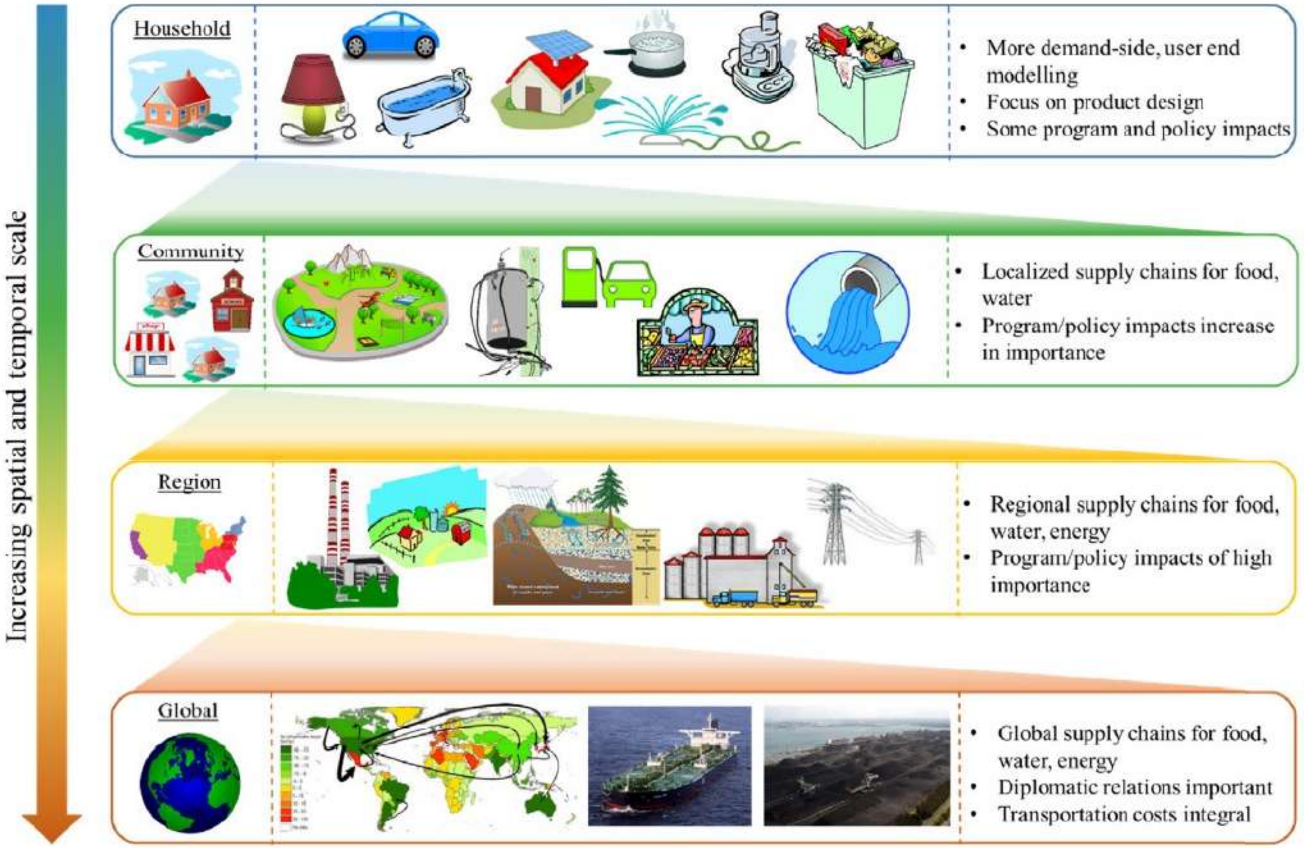
Source: Kaddoura, S., & El Khatib, S. (2017). Review of water-energy-food Nexus tools to improve the Nexus modelling approach for integrated policy making. Environmental Science & Policy, 77, 114-121.

Nexus Research Challenges

There are three major challenge areas for modeling the water-energy-food nexus:

1. <u>Multi-scale challenges</u>

- There are multiple spatial and temporal scales within the nexus, and any changes or in one scale will have far-reaching consequences in other scales.
- There are multi-scale uncertainties which are present at all temporal and spatial scales, which will affect decisions made at each scale differently. For example, extreme events that could occur due to climate change, such as droughts, are another type of uncertainty that affect multiple scales simultaneously but indifferent ways.



Multiple scales of water-energy-food nexus

Source: Garcia, D. J., & You, F. (2016). The water-energy-food nexus and process systems engineering: A new focus. Computers & Chemical Engineering, 91, 49-67.

Nexus Research Challenges

2. <u>Challenges with appropriate system boundary definitions:</u>

An appropriate system boundary is an elementary consideration in WEF Nexus studies. Considerable effort must be directed towards developing system boundaries that harmonise with both the system under study and any economic, environmental, or social impacts to be optimized.

3. <u>Challenges in modelling the importance of of multiple stakeholders and their objectives:</u>

Multiple stakeholders and their differing (and often competing) objectives define one of the central challenges of effectively modeling and optimizing the WEF nexus. Industrial and supply chain stakeholders and their objectives are usually well-defined. However, the objectives of other stakeholders, such as consumers or households, do not receive as much attention. Consumers and households are important stakeholders in the WEFN as they demand the goods and services that necessitate industries and supply chains of the WEF nexus. Thus, their objectives must be considered. Regulators and policymakers play key roles by regulating sectors within the WEFN, and their objectives should also be modeled.

Source: Garcia, D. J., & You, F. (2016). The water-energy-food nexus and process systems engineering: A new focus. Computers & Chemical Engineering, 91, 49-67.

Future Research Directions

Limitations in current nexus studies and challenges (explained in the previous slide) suggest new directions for future research which include four main aspects:

1. **System Boundary**:
   Defining the system boundary is important in nexus analysis as different system boundary definitions result in different results.

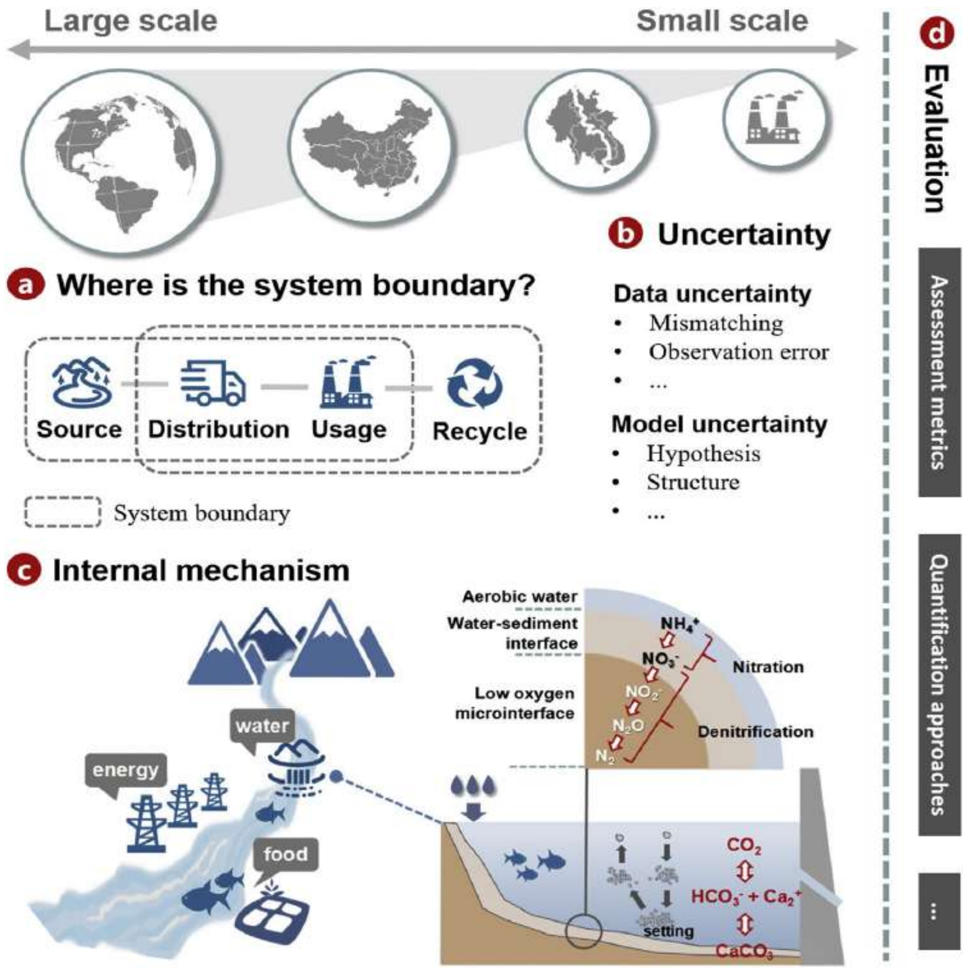
2. **Data and Modelling Uncertainty:**
   Different research problems have different data requirements, the larger the system scale is the more concern about social and economic data. Data is of variable quality and availability and released by different sectors for different purposes without consistent reporting standards.

3. **The Underlying Mechanism of Nexus:**
   Future research needs to characterize the interlinkages between nexus sectors with a focus on understanding the underlying mechanism of the nexus. Studies focus more on the supply chains and resource use efficiencies of nexus sector, than on physical, biophysical and chemical processes affecting the nexus system.

4. **Coupled Nexus Systems Evaluation:**
   The assessment metrics and approaches designed for individual systems may be no longer applicable to the nexus system as a whole.

Source: Zhang, C., Chen, X., Li, Y., Ding, W., & Fu, G. (2018). Water-energy-food nexus: Concepts, questions and methodologies. Journal of cleaner production, 195, 625-639.

Future Research Directions



Summary of future nexus research directions

Source: Zhang, C., Chen, X., Li, Y., Ding, W., & Fu, G. (2018). Water-energy-food nexus: Concepts, questions and methodologies. Journal of cleaner production, 195, 625-639.

Food–Energy–Water and Conflict Nexus

- There is growing evidence of a strong linkage or 'nexus' between ***conflict*** — both domestic and international — and food, energy, and water (FEW) resources and services.
- For example, with the connection between fresh water and food production, the increase in droughts is associated with an increase in food prices, and in turn, both will increase the frequency of conflict.
- There is a positive, significant correlation between ***FEW security*** and ***political and social stability***. FEW insecurity and political instability influence each other and may also be influenced by external factors such as poor governance or changing environmental stressors.
- The Nexus approach is needed to reduce the conflicts arising from rapidly growing demand for resources.

Source: Abbott, M., Bazilian, M., Egel, D., & Willis, H. H. (2017). Examining the food–energy–water and conflict nexus. Current Opinion in Chemical Engineering, 18, 55-60.

Illustrative examples of nexus applications

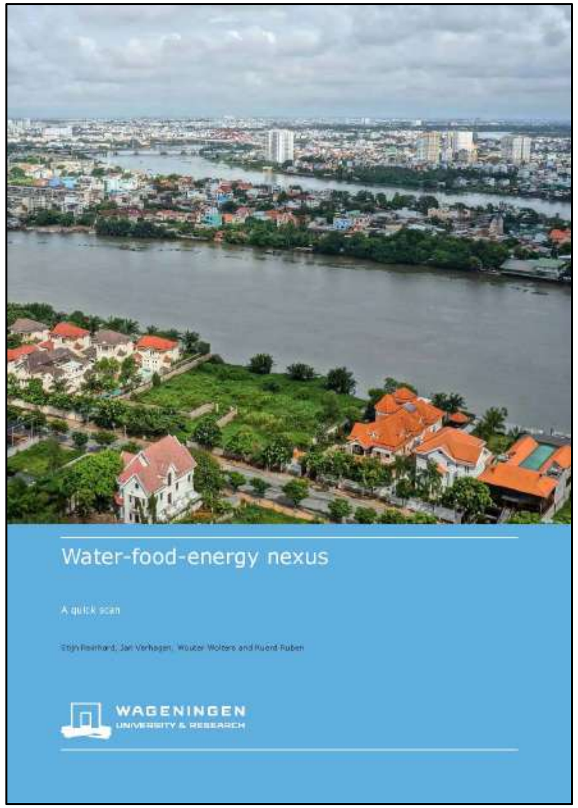
Egypt – Case Study

A study was carried out by Wageningen Economic Research and financed by the Dutch Ministry of Economic Affairs to answer the following two questions:

1. Is the nexus concept sufficiently developed to be used for evidence-based analyses to support the water-related policy of the Dutch Ministry of Economic Affairs, where the main focus is on food policy?
2. What are the essential elements of water, food security and energy to optimise the nexus system?

To exemplify the nexus approach and its results, three case studies were presented one of which was Egypt where the fast-growing population needs to be fed, while the only source of fresh water is the Nile with a lot of competing claims. The nexus approach in the study consisted of three key elements:

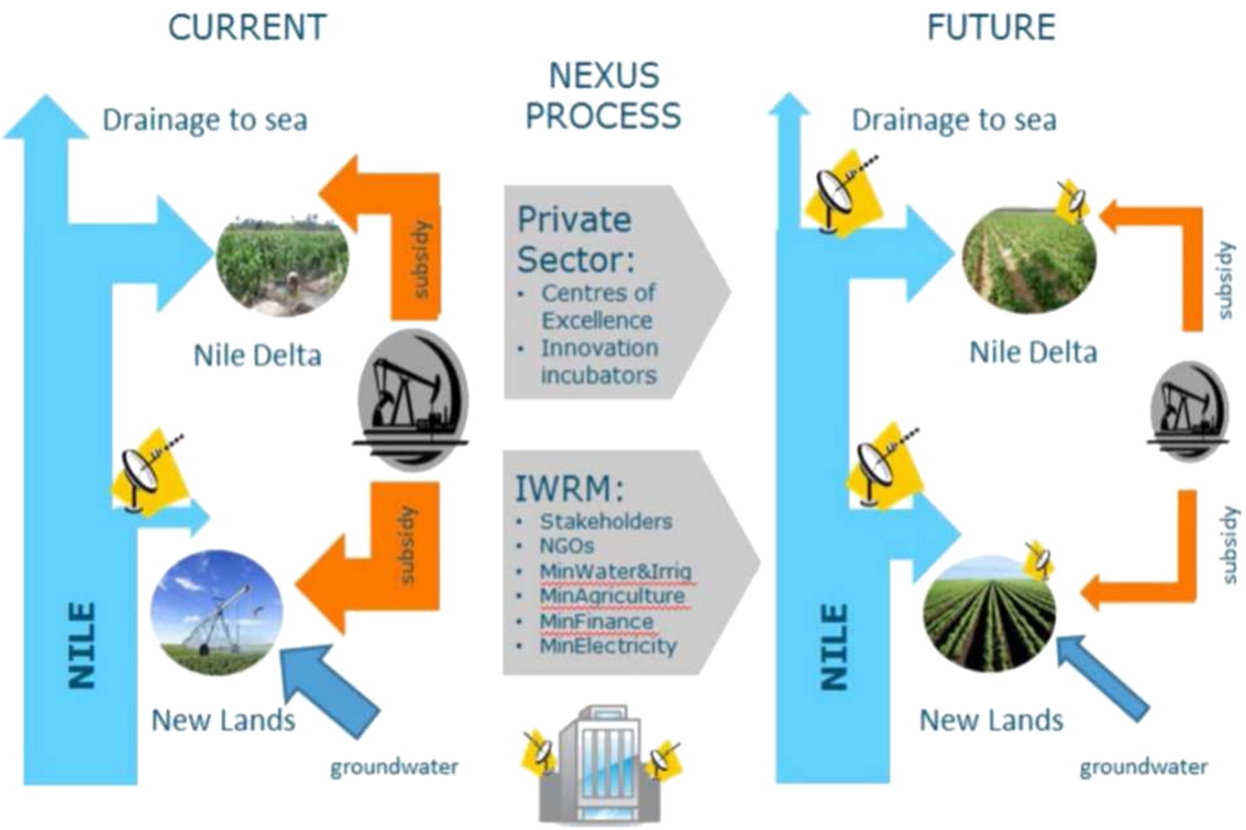
- Defining goals, the relevant system and integration issues
- Identifying which of these issues are handled with the nexus approach
- Developing a coherent plan with nexus approach



Illustrative examples of nexus applications

Conclusions of the Egypt Case Study:

"There is an urgent need for application of the nexus approach in Egypt. Too often the sectoral policies (and even national goals) are created separately from other sectors. The main issues in the nexus in Egypt are not so much 'technical'; they are largely institutional. For the water sector, the need for 'integration of policies' has been advocated for about ten years now and there is governmental recognition that it should be done and some steps towards improvement have been taken. However, reality sometimes seems unruly."



Overview of an Egyptian Nexus Process

Illustrative examples of nexus applications

<u>Ethiopia – Case Study</u>

The Dutch Climate Solutions research programme developed an analytical and modelling approach that allows for the quantification of trade-offs between the water, energy and food nexus at different scales; allowing to go from national analysis of nexus stress by identifying and quantifying key inter-sectoral claims and trade-offs, up to a more detailed and even local specific analysis of the trade-offs. This framework was applied to Ethiopia as a case study as follows:

Step 1: Problem definition

Step 2: Forecasting and Management of Climate Uncertainty

Step 3: Analysis of trade-offs and synergies

Step 4: Formulating Climate Smart Strategies

- Modelling results and quantification of trade-offs
- Economic analysis of water-energy trade-offs
- Trade-offs in the water-energy-food nexus

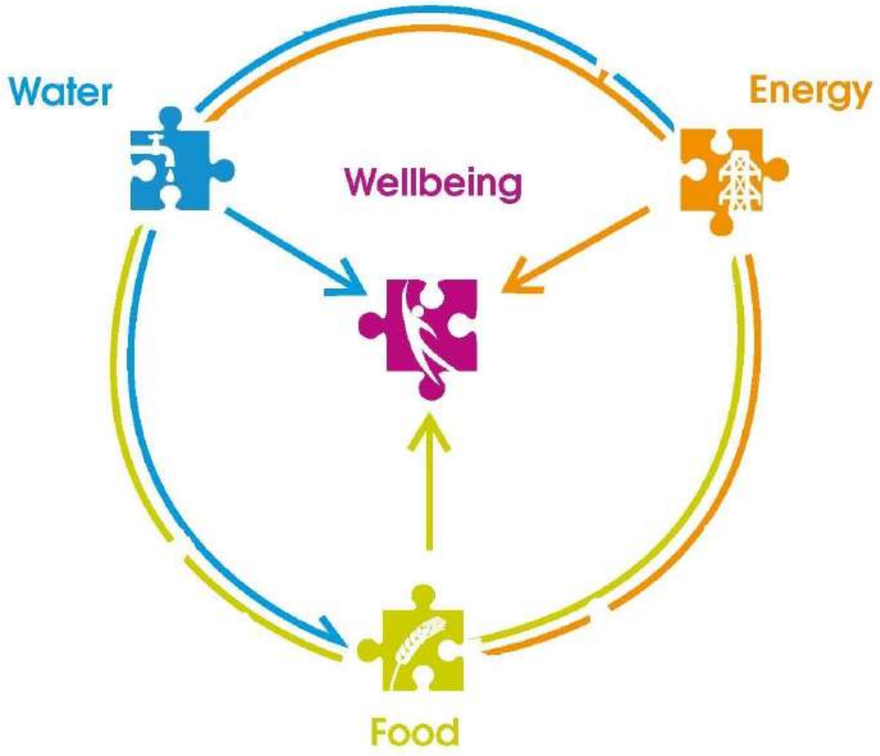
Illustrative examples of nexus applications

<u>IChemE</u>

An IChemE Green Paper presents some case studies highlighting examples where the application of a systems thinking approach from a chemical engineering perspective has improved our understanding of Nexus.

Chemical engineers have a central role to play in shaping the understanding of the connections between water, energy and food – and, more importantly, in devising practical solutions to address this dilemma through:

- Applying life cycle analysis (LCA)
- Working across Nexus boundaries
- Thinking globally but acting locally



Source: IChemE (2015). Getting to grips with thewater-energy-food Nexus?

Illustrative examples of nexus applications

IChemE Green Paper Case Studies:

Case Study – Water for Energy

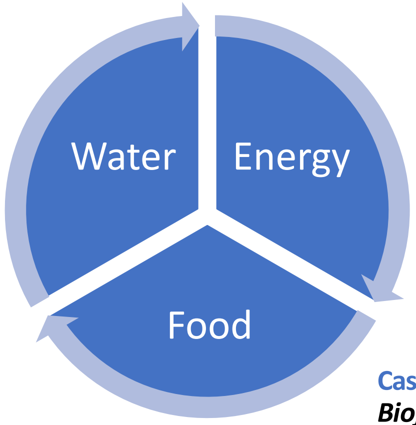
Hydraulic fracturing for shale oil and gas in the UK

Hydraulic fracturing (fracking) requires large amounts of water which can be drawn from local aquifers or, in waterscarce areas, trucked in with the concomitant increase in traffic movements. This water, with the chemicals added to aid the fracking process, is returned with the produced oil and gas. It can be treated and recycled to minimize freshwater use and although not universally practised, this will be mandatory in the UK.

Case Study – Water for Food

Banana production in Ecuador

The environmental impact of food production varies with its economic importance. The banana is of key economic importance in Ecuador, representing 2.5% of GDP and one third of global banana production. For such an economically important crop, water supply is essential but it takes 330 L of water to produce 1 kg of bananas. Value chain analysis indicates that agricultural methods used can reduce the amount of water required, for example by reducing fertiliser use or through more efficient washing processes.



Case Study 2 – Energy for Water

Water production in the Middle East and North Africa

Extracting, producing, delivering, purifying and disposing of water requires energy. However, it is essential in some waterscarce regions to use energetically costly processes to ensure a supply of freshwater. Countries in the Middle East and North Africa use an estimated 5-12% of their total electricity consumption for pumping ground water and desalination. Integrated assessment suggests that this could be reduced by greater reuse and recycling of water supplies.

Case Study – Food for Water

Food as a global transporter of water

When a country imports a water-intensive product, it imports virtual water23. Real water trading between water-rich and water-poor countries is limited, but trading water through virtual water products is significant. The development of the water footprint concept has been an important step in understanding the importance of freshwater. Existing methodologies mainly assess the quantity of water used in food production and processing rather than the related impacts.

Case Study – Food for Energy

Biofuel production from cereal crops

The production of bioethanol from corn and wheat for blending with or as a replacement for gasoline has increased dramatically as a result of government targets in several countries, in an attempt to reduce carbon emissions. There is an immediate conflict with the production of food, and increasing biofuel production from these feedstocks has driven up food prices. Additionally, if land use change is taken into account, the ability of these first generation biofuels to contribute to carbon emissions reduction becomes doubtful.

Source: IChemE (2015). Getting to grips with thewater-energy-food Nexus?

Conclusions and recommendations

- The W-F-F nexus is put forward to call for an integrated management of the three sectors by cross-sector coordination in order to reduce unexpected sectoral trade-offs and promote the sustainable development of each sector. In this regard, it differs from conventional decision-making practices that are previously considered within separate disciplines.

- WE need this approach to tackle the problems we are facing in managing our resources.

- I recommend to establish a high-level multidisciplinary research group with the mandate to develop a research plan, get connected to similar groups world-wide.
- Required resources to support this group shall be made available.

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