General Overview on the Water–Energy–Food Nexus

Anas Tallou, Khalid Aziz, Karim Sbihi, Mounir El Achaby, Lhoucine Gebrati, Francisco Pedrero Salcedo, and Faissal Aziz

Abstract In this world, water, energy, and food are extremely important for life, human safety, and sustainable development consideration of our natural resources. Water is used to produce food, where 70% of the available water on earth and 30% of energy are used in agriculture. In addition, the rising population in all over the world (9 billion estimated in 2050) implies the increasing demand for water, energy, and food. From this, it has been noticed that there is a need for a new concept of water, energy, and food in international and national governance. In the last 10 years, this

A. Tallou
Polydisciplinary Laboratory for Polyvalent Research and Development, Biology and Geology department (Fp), Faculty of Sciences and techniques, Sultan Moulay Slimane University of Beni Mellal, Beni Mellal, Morocco

K. Aziz
Materials, Catalysis and Valorization of Natural Resources, Faculty of Sciences, University Ibn Zohr, Agadir, Morocco

K. Sbihi
Laboratoire de Biotechnologie, Matériaux et Environnement, Equipe de recherche : Substances naturelles & Environnement, Faculté Polydisciplinaire, Taroudant, Université Ibn Zohr, Agadir, Morocco

M. El Achaby
Materials Science and Nano-engineering (MSN) Department, Mohammed VI Polytechnic University (UM 6 P), Ben Guerir, Morocco

L. Gebrati
Materials, Process, Environment and Quality Laboratory, Ecole Nationale des Sciences Appliquées de Safi (ENSAS), University Cadi Ayyad, Marrakech, Morocco

F. P. Salcedo
Department of Irrigation, CEBAS-CSIC, Campus Universitario de Espinardo, Murcia, Spain

F. Aziz (✉)
Laboratory of Water, Biodiversity and Climate Change, Semlalia Faculty of Sciences, University Cadi Ayyad, Marrakech, Morocco

National Centre for Research and Study on Water and Energy (CNEREE), University Cadi Ayyad, Marrakech, Morocco
e-mail: f.aziz@uca.ma

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concept becomes very interesting to scientists and policymakers. They must work together in order to change our behaviours against water, energy, and food consumption. Therefore, new morphological methods and metrics are elaborated in order to accelerate sustainable development goals. Measurement, assessment, and new approaches were considered in different countries in order to evaluate the water–energy–food (WEF) nexus. Even with this progress in the global world thinking, the risks and threats to WEF nexus still present and affect the effectiveness of this concept.

Keywords Water · Food · Energy · Sustainable development · Circular economy

1 Introduction

Nowadays, humanity starts to face strong environmental challenges due to different human activities. New sources of environmental, eco-friendly, and renewable energy are now on global demand (Li et al. 2018; Haouas et al. 2022; Tallou et al. 2020a, b). The main goal today is to reach circular economy concept, which is one of the objectives of the sustainable development goals (SDGs). This system must protect our environment, insure human life, and strengthen the economic and industrial growth (Winans et al. 2017). Articulating demand for further human resource appropriation, sustaining the resource base, and redistributing power and benefit are the three major groups that exist among the sustainable development goals (SDGs) (Tallou et al. 2021; Si et al. 2019).

The term water–energy–food (WEF) nexus gained importance during the World Economic Forum 2008 and then officially in *Bonn* conference in 2011 'The Water, Energy and Food Security Nexus – Solutions for the Green Economy'. Afterwards, the WEF nexus started to attract European policymaking in their official documents. Nexus new thinking is a global call to all countries in the world to consider sustainable use of the Earth's natural resources. For that reason, the water–energy–food nexus means to consider the pressures and stress created by agriculture, water consumption, and energy production (Hoolohan et al. 2019).

Nexus research activates discussions and debate on how to face positively global environmental change that is now threatening human safety (Zhang et al. 2019). Complexity and uncertainty that characterize the nexus term need more researches and work to gather knowledge and experience from different perspectives and scale. The focal point is to try understanding how metrics in policymaking affect and influence the nexus governance. Considering that metrics can play an important role in stabilizing or challenging how policymakers are representing the world, 'Nexus' thinking needs updated metrics in order to face new challenges (Hoolohan et al. 2019). Three main questions can rise in this consideration:

- What are the new approaches of the nexus concept and how it is related to governance?
- How the WEF nexus can be elaborated on national scale?
- What are the risks and threats to the water, energy, and food nexus?

2 New Morphological Methods to Activate Sustainable Change

Scenario analysis is one of those methods to enhance and accelerate sustainable development. It is already used in different fields of global change and governance, but it is still limited in nexus researches. It also provides many exploring possibilities for future conditions that control and affect the process (Hoolohan et al. 2019). Stepping Up evaluates how to enhance and accelerate the effectiveness of new approaches and innovations that could influence positively the water–energy–food nexus. This method has an objective of understanding the involvement of technological, social, and climatic developments and findings for the nexus innovation concept. The understanding of this concept might accelerate the water–energy–food nexus in order to face the new challenges (Garza 2018).

This method combines the multidimensional changes through the water–energy–food nexus and the different researches in different field studies to produce new scenarios that could help in clarifying the complexity of rapid changes (Zhang et al. 2019). In addition, these scenarios could help to understand how the nexus thinking and decision-making can be enhanced by the water–energy–food research (Garza 2018; Gevelt 2020). In order to reach the effectiveness of decision-making in the water–energy–food nexus concept, it needs deep thinking and the ability to detect the interference between drivers and factors. Therefore, there is a need to build capacities across the different disciplines in order to develop the understanding of the new challenges (Garza 2018; Gevelt 2020).

It is expected in the near future that the integration of water–energy–food (WEF) in the global thinking will enhance the interdisciplinary discussion during the policy development process (Zhang et al. 2018). Comprehensive assessment could help to better understand and provide data about the water–energy–food nexus (Lin et al. 2019). The most important and effective method to evaluate the inter-linkages between water, energy, and food is the life cycle assessment (LCA) method. It can imply the consumption or needs of the natural resources and can estimate the potential changes of WEF in the present and future (Ghodsvali et al. 2019). The second important tool to evaluate and illustrate the practicality of the WEF concept is the GIS-based Regional Environmental Assessment Tool *(GREAT-FEW)*. It was developed by combining a solid model conception, calculation methods, and database. The usefulness of this tool was elaborated in Taiwanese study, where the result showed that the Scenario 1 refers to non-nuclear homeland policy that caused the lowest environmental damage when compared to Scenario 0, which is the baseline, and Scenario 2, which is non-nuclear homeland policy with National Spatial Plan. This result is a consequence of better water consumption, energy structure, and good management of agricultural fields. Therefore, it is obvious that when selecting indicators, the results were affected. We should mention that additional designed indicators are required for each case study (Lin et al. 2019). *GREAT-FEW* allows the users to work on different scenarios for agricultural land use, food needs, energy production, and for sure water demand and consumption. This tool cannot only be used to quantify the environmental influence using the LCA method but also spatial–temporal illustration via a GIS tool interface. The tool will provide policymakers and scientists with both positive and negative results in order to develop new investments and to create new policies for the future (Lin et al. 2019).

Nowadays, there is an important attention to the challenges in developed and developing countries and their transition from unsustainable to sustainable practices. The connection between these three crucial resources offers a conceptual tool for achieving sustainable development. It has become strongly important to understand the interdependencies and interrelationships between the WEF nexus. Looking for new strategies to manage the nexus could contribute significantly to achieving the Global Sustainable Development Goals (SDGs). The WEF nexus, when applied as an analytical tool, becomes important in evaluating progress towards Sustainable Development Goals (SDGs), especially Goal 2 (zero hunger), Goal 3 (good health and wellbeing), Goal 6 (clean water and sanitation), and Goal 7 (affordable and clean energy) (Nhamo et al. 2020) (Fig. 1).

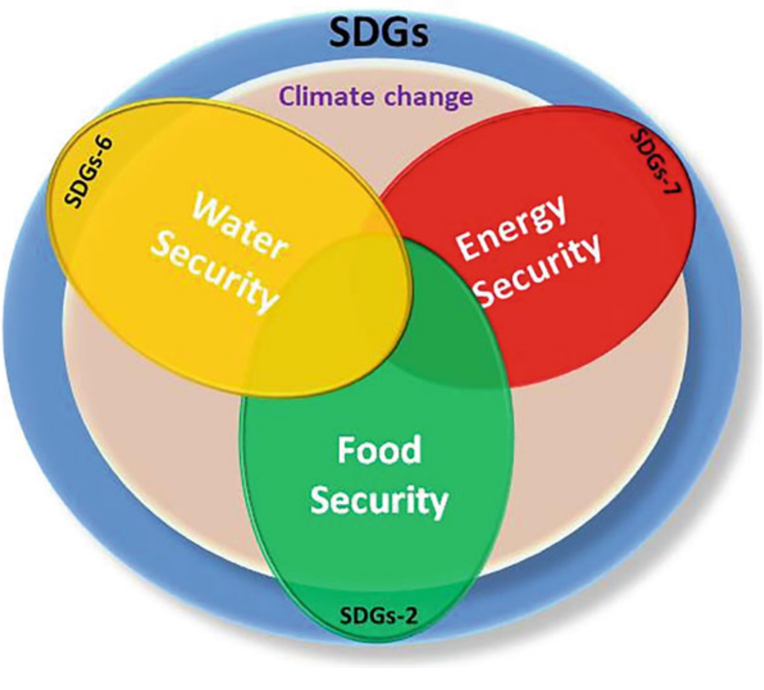

Fig. 1 WEF nexus security and the Sustainable Development Goals

3 The Importance of Metrics in the Water–Energy–Food Nexus Thinking Within the European Commission

The discussion in the European Commission tries to explore the relationship between governance, metrics, and the nexus of WEF *(*Märker et al. 2018*)*. In order to change policy decisions, the metrics must be updated regarding the new interdisciplinary thinking (Gevelt, 2020). It has been indicated that the processes of production and the elaboration of new metrics depend on the institutional practices and will influence the policymakers (Voelker et al. 2019). In doing so, a critical analysis must be done in order to evaluate the role of metrics in environmental governance. It has been highlighted that focusing on the institutional parameters in the way they are elaborated and used, the question of relationship between metrics and WEF nexus, needs more exploration regarding the policy makers' objectives in Europe (Lima et al. 2018, 2019). In the literature, it had been declared that we need to link the multidimensional (institutional, political, and cultural) policymaking to the WEF nexus needs. In this understanding, the biggest challenge is to understand the complexity and the interference between sustainability and the actual modes of consumption and production (Hoolohan et al. 2019; Li et al. 2018).

The majority of studies worked on epistemological problems or conceptual challenges, but only few ones presented the institutional metrics and mechanisms that could limit the consideration of the new nexus thinking and governance (Voelker et al. 2019). Therefore, the nexus complexity could be visible and clear if we use institutional vision that makes environmental challenges relevant. Metrics could build new governance legality and effectiveness. The water–energy–food nexus needs to be considered as a problem of legitimate policy objective if we want to be more precise and broadly within the institutional culture of the European Commission and policymaking. Therefore, it is important to know that the WEF nexus is not only a technical tool, but it is new thinking controlled by exact metrics (Voelker et al. 2019).

4 Measuring the Water–Energy–Food Nexus for Specific Country or Region

Usually, water–energy–food performance of a specific country can be evaluated separately. There are a number of indicators and metrics for each country controlled by the World Bank and United Nations. However, the indicators cannot provide an exact view of any sector because of the presence of different parameters and drivers that interact and affect the general understanding of the nexus. The evaluation of the three sectors of WEF is done according to the available data that are important to understand the ongoing sustainable development of a specific country (Mabrey and Vittorio 2018). Recently, a new approach proposed by the two authors *Simpson* and *Berchner* in 2017 uses an index that involves sustainability level of each country regarding WEF and population (Garza 2018). Three main indicators have been proposed per each sector, which are access, availability, and stability. Those indicators help to obtain a clear understanding and vision about the WEF nexus, and it is possible to notice the status of each sector regarding the available resources. In addition, the sustainable development progress in a specific country or region can be evaluated and measured using these indicators (Garza 2018).

Spatiotemporal disaggregated simulation model was elaborated in *Gavkhuni Basin (central Iran)* using water–energy–food (WEF) nexus concept in order to evaluate water and food supply security considering sustainable environment. This model was used for the first time in *Iran*, where the main contents of it are water, agriculture, population, and energy metrics. This model was developed using the System Dynamics (SD) tool and was used to evaluate the effectiveness of each sector, industrial, domestic, and agricultural water, energy consumption, and environmental safety in enhancing ecosystem-provisioning services in the near future. Results indicated that the combined policies available in the agriculture and environment sectors were the most influencing in changing the WEF system and meeting the *Gavkhuni* environmental requirements (Ravar et al. 2020). The combination policies and instructions (controlling groundwater withdrawal, changing crop pattern, implementation of technology, etc.) increase surface water availability and groundwater security by 5%. In addition, it reduced water used for food production by 18% and energy for water demand by 26%. Policies of the energy sector did not increase the ecosystem-provisioning services. These results have summarized that the food sector was the most influencing and important for the security of water supply and status of the energy system in the *Gavkhuni Basin*. The results also showed the high performance of the WEF (Water, Energy and Food) model in terms of policy impacts of water, energy, and food sectors (Ravar et al. 2020).

Another case study was treated in *Pakistan* using a Life Cycle Approach (LCA) production of molasses-based bioethanol and was interesting in terms of producing food and energy materials related to water–energy–food consumption (Mannan et al. 2018). The water–energy–food nexus for bioethanol in *Pakistan* was described. This Life Cycle Approach (LCA) was used in order to evaluate the four footprint groups (carbon, ecology, water scarcity, and energy production) at the same time with an energetic analysis of bioethanol (Silalertruksa and Gheewala 2019). When comparing bioethanol to gasoline, bioethanol could have better performance regarding greenhouse gas emissions, high-level energetic performance, and safe use in agricultural lands. In contrast, water scarcity will increase because of its high impacts and expenses. Therefore, effective management is required for the best use of this natural resource, which can be insured by new WEF nexus metrics to avoid the risks (Silalertruksa and Gheewala 2019).

In the twenty-first century, deterioration of water runoff in the *Yellow River* region decreased, which results in a clear bad utilization of the available water. The authors of this study identified the most important component from water–energy–food nexus vision. They also established a WEF nexus model for *Upper Yellow River Basin* (UYRB) using the water supplies to the lower and the middle regions that feed the Yellow River, energy production, and food growth in this region (Si et al. 2019). The Multi-start Solver of *LINGO* and the ε constraint method were elaborated in order to reveal the complexity in the WEF nexus concept. This method was used in order to guarantee the general benefits in *Long yang xia* Reservoir that should maintain a high water level in the Yellow River region (Si et al. 2019).

5 Risks and Threats to the Water, Energy, and Food (WEF) Nexus

The complexity of understanding the water–energy–food nexus rises from the diversity and the interaction between many parameters and drivers. The capacity for governing nexus challenges on regional or national scales could be limited by global interdependencies. In their analysis of global production networks, Franz et al. (2018) analysed the global production networks and highlighted the important role of socioenvironmental risks if regions are globally integrated. A fair and equitable consideration of the risks and benefits between sectors and across regions is one of the governance challenges (Raza et al. 2019). Numerous risks threat water–energy–food nexus because of complexity of this concept and due to global environmental change processes, as well as rapid urbanization, climate change, and pollution. Romero-Lankao et al. (2018) worked on the urban side and showed that these kinds of interdependencies increased the risks and threats in the water–energy–food nexus (Sukhwani et al. 2019). It has been illustrated that a precise and clear understanding of these interdependencies is the major key to avoiding the risks and threats between WEF nexus sectors (Arthur et al. 2019). The authors of this work examined how WEF nexus infrastructural systems serve and boost the risks of climate change to urban water–energy–food security system (Namany et al. 2019). The most dangerous risk that threatens the water–energy–food nexus is the wrong understanding and the blur vision of the interferences between the nexus components, and can unfortunately lead to extreme natural damage in those sectors and consequently the human safety (Pahl-wostl et al. 2018).

6 New Strategies to Reduce Water and Energy Consumption in Food Production

In order to reduce water consumption in agriculture and to increase water efficiency, new technical and non-technical strategies and methods were elaborated. These options are soil mulching, deficit irrigation, and drip irrigation. In northwest *China*, the effect of mulching was evaluated regarding soil water storage improvement and soil properties and fertility in maize rotation system. Mulches showed positive effect, and water storage was improved and resulted in warmer soils. In contrast, organic C and total N content of these soils decreased in long term. Therefore, this technique reveals some disadvantages and cannot be considered sustainable (Scardigno 2019). The combination of different techniques and options can be elaborated and can reach the system balance. In northern Greece, different irrigation techniques and technologies were evaluated on cotton. Compared to the sprinkler method, drip technology showed a reduction in water footprint by 5%, and the deficit irrigation there needs about 12% lesser than full irrigation system. In Lebanon, some authors evaluated the effects of mixing mulching with drip irrigation and organic material. Results indicated positive impact of this combination when the water footprint was reduced by 5%. The same results were confirmed also by an Indian study where water productivity was improved after combining drip irrigation and mulching (Scardigno 2019).

Nowadays, irrigation management in agriculture must consider the tempo-spatial variability of plants growth and soil, without affecting the environment, water availability, and food production. Different strategies and solutions were identified in energy optimization in agriculture for water and food production. Some authors proposed new performed tools for energy measurement and control (Scardigno 2019). These techniques identified the weak points in water distribution network and presented the actions that improve the irrigation system. This technique called revised Supply Energy Efficiency uses indicators and data from different distribution network points and the designs using more than one water-feeding source. This method facilitates the decision and data collection in order to improve irrigation efficiency and to reduce water consumption by detecting leak points (García et al. 2017).

Another new method for energy optimization was developed by combining optimization of a pumping station for irrigation and network management using a semi-arranged demand model (Voelker et al. 2019; Winans et al. 2017). This model was elaborated in southern Spain where water scarcity is facing this region. The results showed energy-saving between 5.6% and 25.8% with critical hydrants between 14.5% and 7.8%, respectively (Arthur et al. 2019; Zhang et al. 2018). These strategies must take into consideration the crop requirements and then should not affect the optimal energy and water consumption. Lima et al. proposed a new model called centralized management of collective irrigable areas on demand that reduces and minimizes the energy consumption at farm level. Fixed and variable pressure heads are the two techniques used in this research paper. It has been highlighted that the energy consumed for water distribution can be reduced by 30%. Farmers, in order to control and manage the energy and water consumption in agriculture, should adopt these techniques (Arthur et al. 2019; Zhang et al. 2018).

7 Conclusion

The water–energy–food nexus attracted many scientists and policymakers in recent years. The main objective of working on this nexus concept is to improve the efficiency of natural resource management and to reach the circular economy concept that produces goods, protects the environment, and enhances the human life quality. At the same time, this system must avoid the risks threatening the nexus sectors. In order to reach this global system, new thinking, approaches, and strategies must be established and considered from both the institutional and policy systems. Sustainable Development Goals and circular economy concept are the frameworks of the water–energy–food nexus, but this concept cannot be fruitful without implementation of new metrics and parameters that guide to a better understanding of the complexity of the WEF nexus. Population growth, water scarcity, and limited natural resources increased the pressure on water, energy, and food resources. Therefore, smart management that provides societal goods, protects the environment, and enhances the economy is now an obligation for sustainable development. The complexity and multiplicity of the drivers and interactions between the water–energy–food nexus require mobilization of governance, thinking renovation, and building new capacities to be able to understand the WEF nexus vision and to act exactly in a sustainable way.

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