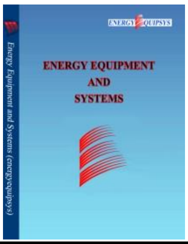
Energy Equip. Sys./ Vol. 8/No. 2/June 2020/ 179-201

ENERGY EQUIPSYS

Energy Equipment and Systems

http://energyequipsys.ut.ac.ir
www.energyequipsys.com



The food-energy-water nexus: A framework for sustainable development modeling

Authors

Behnaz Rezaie [a*]
Marc. A. Rosen [b]

[a] Applied Energy Research Laboratory (AERL), Department of Mechanical Engineering, College of Engineering, University of Idaho, 875 Perimeter Dr., Moscow, ID 83844-0902, USA

[b] Faculty of Engineering and Applied Science, University of Ontario Institute of Technology 2000 Simcoe St. N., Oshawa, ON, L1G 0C5, Canada

Article history:

Received : 14 December 2019
Accepted : 8 February 2020

ABSTRACT

Energy, water, and food are facing present and future challenges triggered by climate change, population growth, human behavior, and economics. Management strategies for energy, water, and food are possible through policies, technology, and related education. However, the links between resources (energy, water, and food) and impacting factors (population increase, human behavior, economics, and global warming) need to be developed. Holistic modeling is needed to supply and demand energy, water, and food. That type of modeling explores the energy-water-food nexus. The framework for such modeling is described in this study, and previous frameworks are reviewed. Recommendations for addressing energy, water, and food challenges, before and after completing the energy-water-food nexus modeling, involve the following: modifying processes, modifying products, innovative processes, and innovative products. With an energy water-food-nexus model, the impact of any changes on resources can be measured and quantified.

Keywords: Energy-Food-Water Nexus; FEW Nexus Modeling; Climate Change; Sustainable Development; Technical Innovation.

1. Introduction

For a human, regardless of time, technology, country, race, or gender, the first needs are food and water. Energy is embedded in food and water since food must be prepared, and water must be delivered. Food, water and air, being the basic needs for survival of humans, is clearly depicted by Maslow in his hierarchy of needs [1]. Finding food for early humans was difficult due to the lack of technology. By improving technology and knowledge over the centuries, humanity helped resolve some challenges, but also created new ones. However, this time challenges are due to failures of technology and overuse of resources.

Moreover, population inflation (growth), modern lifestyles and increasing demands for all types of resources magnify the problem drastically. Energy, water, and food are more interrelated in the modern world, and the modeling of their use is much more complicated than in previous centuries. In the modern era, the complex links between energy, water, and food, under the influence of economics and climate change, are becoming increasingly complicated. Developing a model to capture most of the interrelated linkages between energy, water,

* Corresponding author: Behnaz Rezaie
Applied Energy Research Laboratory (AERL), Department of Mechanical Engineering, College of Engineering, University of Idaho, 875 Perimeter Dr., Moscow, ID 83844-0902, USA Email: Rezaie@uidaho.edu

and food is a great challenge for the present generation, if it is to leave a positive legacy for future generations if there is any. The phrase "if there is any" is based on the Paris agreement 2015, which describes the risk of losing the planet and life over global warming.

More precisely, the global population is expected to reach 8.5 billion to 9.7 billion by 2030 and 2050, respectively [2]. The growing population increases the demand for energy, water, and food. Adding technological advancements to population growth translates into further increases in demand for energy and water. Correspondingly, it is predicted that energy demand will increase by 56% from 2010 to 2040 [3], and that the need for water will increase by 40 million cubic meters in 2030 compared with 2015 [4]. The demand for food is also expected to escalate accordingly. Using more resources to satisfy population demands generates more pollution and environmental impact, contributing to climate change. The average global temperature increased by 0.7°C over the last century and is expected to increase between 1.8°C to 4°C by the end of this century [5]. Shifting climate, in turn, affects human economic behavior regarding the use of resources. The dilemma is how to satisfy increasing demands for energy, water, and food and while addressing urgent requirements to reduce environmental pollution, or how humanity can be better stewards of the Earth's resources and have a less environmental impact. Multi-disciplinary collaboration and problem-solving are needed to mitigate this tension.

Researchers and other stakeholders need to map FEW security by clarifying three key statuses: time and location of FEW security; interacting parameters with FEW systems; the supporting team and people who benefit from the FEW system [6]. The FEW nexus demands a transdisciplinary approach, which is defined as a multi-disciplinary investigation including natural sciences, social sciences, humanities, engineering, and law with the close collaboration of stakeholders, investors, governmental agencies, policymakers, development organizations, industry, and media [7].

In this paper, the authors present a new framework for a sustainable FEW nexus. First, the status of energy, water, and food are assessed. Then some linkages between energy-water, water-food, and energy-food are presented to provide an overview of the FEW nexus. The main impacting factors, including population, human behavior, economy, and climate change, on the FEW nexus are described, focusing on their influences on FEW resources. Then controlling tools including education, technology, and policy for adjusting the influence of the main impacting factors on FEW linkages are elaborated. The FEW linkages and interactions between the controlling factors on FEW linkages in mathematical modeling to support sustainable development is the backbone of the proposed FEW nexus framework. Based on the model and sub-models, FEW security can be mapped and provides guidelines for policymakers and government agencies to establish proper strategies to manage FEW sustainability.

2. Methodology

Numerous studies have approached modeling of the FEW nexus from different or similar aspects. Other studies have defined a framework for FEW nexus. They all seek to define boundaries for such undefined problems and/or to identify correlations among the parameters involved in modeling of the FEW nexus. These studies are placing together various pieces of the puzzle of the energy, FEW nexus. Nonetheless, researchers are focusing on defining boundaries of the broader question, "What is the energy, water, and food nexus?" The solution demands a comprehensive interdisciplinary approach, which is very complicated. The present authors propose a new approach here for modeling and evaluating the FEW nexus based on goals and type of modeling to establish a proper framework.

2.1. Goal

The goal set by various national and international institutions for population and the demands for energy, water, and food by 2030 are estimated and considered as a goal for countries [8][9][10]. However, the demand for resources in the future is the objective of every study.

2.2. Model

Modeling energy, water, and food usage have attracted much attention from a security point of view. Several of these models have been presented collectively [5][7]. However, there are other schools of thought regarding modeling the linkages between energy, water, and food. The present approach is a holistic view of modeling resources altogether.

3. Review of frameworks

There is a demand for more FEW frameworks to provide methods to organize and map the FEW interlinkages and issues at different levels [11]. They are a great requirement for integration and cross-thinking regarding energy, water, and food [12], which is why a framework needs to be defined for the nexus. Researchers have proposed various frameworks for FEW studies, so as to define the depth and boundaries of projects. The most common ones are as follows:

- The FEW security nexus of the Stockholm Environment Institute, 2011 [13]
- Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM), 2013 [14]
- Climate, land-use, energy and water strategies (CLEWS), 2013 [15]
- The FEW nexus, 2014 [16]
- Environmental Livelihood Security (ELS), 2015 [17]
- Nexus framework of climate in southern Africa, 2015 [18]
- FEW nexus with trans-boundary for Delhi, India, 2017 [19]

Each framework has measurable targets, some of which are partially common with other frameworks and some of which are unique. These frameworks have various limitations and capabilities for defining FEW relationships. The advantages and disadvantages are described in detail elsewhere [17].

Sustainable development requires that climate change issues be adequately addressed, and it often starts with investigating resources [20][21]. The following nine areas demand "sustained action, political and economic leadership, and intelligent use of technology" [21]:

- Financial/economic organizations
- Environmental issues
- Food and health issues
- Energy issues
- Educational issues
- Political democratic change around the globe
- Transformative government in the globe
- Equity and security in the globe
- Technology, innovation, entrepreneurship as motive core in societies

A non-linear quintuple helix model has been proposed that combines knowledge, know-how, and natural environment system together into one homogenous, interdisciplinary framework that assists in advancing sustainable development [22].

Ringler et al. [16] proposed an extended framework for the water, energy, and food nexus by adding land as a parameter. They conclude that connections in this water, energy, land, and food (WELF) approach are important and affect humans as well as the environment. The following recommendations describe alternative approaches to boost and/or stretch resources [23]:

- Propose an assisting environment to improve access to natural resources
- Offer proper information and tools for addressing the nexus
- Enhance technology efficiencies to improve Sustainability
- Decrease distortionary subsidies
- Optimize free market and trade strategies

Another approach for establishing a framework is premised on the idea of starting locally and then expanding globally [24]. The original framework is more manageable at the local level and can be expanded to national and international scales. Other studies also suggest an expansion of the view from regional to global for resolving energy-water issues [25]. The idea is the logical expansion of four case studies in which energy-water resources are managed in four parts of the U.S. The impact of each case study extended further than the original regions [25]. From another perspective, researchers explain the breakdown of global problems to quantify at the community level of nexus resources [26]. The authors suggest that localized regions can better implement strategies than larger districts [26]. Multiple scales of food, water, and energy at four levels (household, community, region, and global) are also suggested to address the issues affecting each level [27]. According to a study in the U.K. using an interdisciplinary approach for all of the stakeholders noted above, four themes of barriers and opportunities in the U.K. energy-food-water nexus were identified [28]:

- Communication and collaboration,
- Decision-making processes,
- Social and cultural dimensions,
- Nature of responses to shock.

Also, research in Germany has defined three pillars for nexus discussions [12]:

- Demand for resources and increasing scarcities,
- Current supply emergencies for resources,
- Failures of field-focus management policies.

Clearly, many studies have been conducted in different nations and focusing on various aspects to build a framework for investigating the energy-water-food nexus. Most are unique and valuable in the sense of adding a new perspective to the nexus. Nonetheless, not all premises of the topic have yet been investigated.

4. Sustainable framework

The present authors believe a sustainable approach to the energy-water-food nexus can enhance the framework. This belief does not suggest that previously proposed frameworks are inadequate or that the present work constitutes the ultimate nexus framework. Rather, the authors believe a sustainable framework provides a new and advanced perspective for the nexus, which improves its level of comprehensiveness. Sustainability, as explained through various definitions, must address the sustainable development, modern lifestyles, and security of resources. Sustainable development is facilitated and possible via a resources nexus approach. Defining a FEW nexus framework is important for sustainable development. A significant part of the above definition is "meeting present and future generations need". In other words, people's demands now and in the future, must be satisfied continually.

To start modeling the framework, one must define demands and resources. Resource demands and supply resources for energy, water, and food are presented in Fig. 1. The ultimate goal is to achieve a balance between

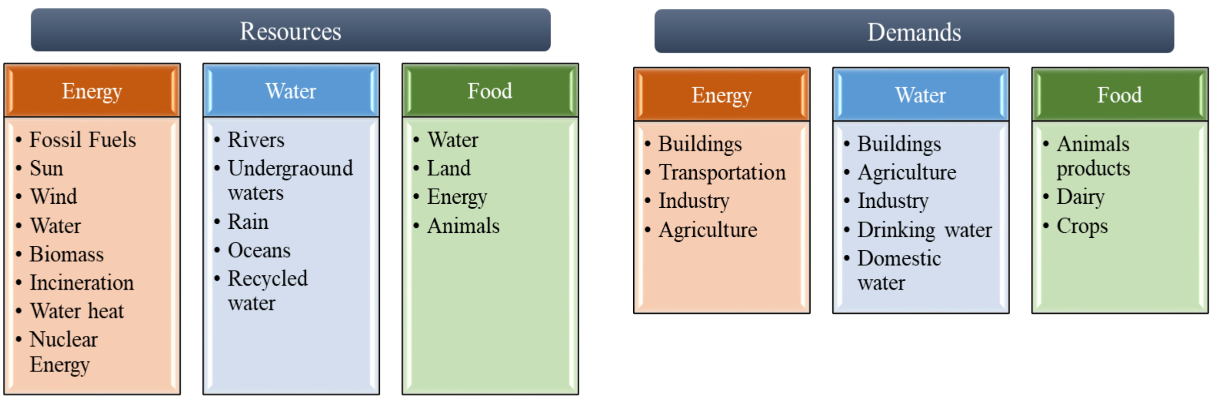


Fig. 1. Selected energy, water, and food resources and demands

supply and demand for energy, water, and food. Many studies have been performed to balance each of energy, water, and food independently, with some extent of success. By considering the fact that energy, water, and food are interconnected at many levels, some studies were initiated to explore the relationships between these resources.

By knowing the relationships (interlinkages) between energy, water, and food, the impact of each resource on the others can be better monitored. Additionally, the impact of balancing one resource on the others by simulating the outcomes of balancing the supply and demand of one resource, even though that does not necessarily balance the overall system. For that reason, some studies take a more holistic approach toward balancing resources. In the following subsections, some outcomes of previous studies are presented, some of which focus only on resources independently and some of which consider at least two resources and their connections.

4.1. Energy

Respecting the environment when developing energy generation technology is not only beneficial for nature but is also necessary for energy sources to be sustainable [29]. Insights on the Sustainability of energy resources are obtainable by conducting research on renewable energy technologies and resources includes solar thermal, solar electricity, biogas, biomass, wind energy, hydro and geothermal, as well as on the energy flexibility of systems including thermal and electrical energy storage [30]. Research to improve the performance of energy technologies is being carried out on a wide range of topics [30]:

- sustainable combustion technology,
- energy-efficient technology,
- sustainable buildings and communities,
- renewable energy and technologies and resources,
- energy flexibility and energy storage.

Besides, on the above topics, investigations of energy consumption reduction are necessary.

China and surrounding countries are examining the potential of renewable energy resources to satisfy their energy demands [31].

Energy research topics with unique system boundaries that are suitable for examining the energy, water, food nexus, which demand more focus for the future are [32]:

- Energy access and deforestation,
- Biofuels,
- Irrigation and food security,
- Hydropower,
- Desalination.

A narrow disciplinary focus on energy is necessary for exploring the status of many energy issues, but it is not sufficient for addressing energy problems in general. Additionally, exploring the social aspects of energy studies provides a more comprehensive approach [33]. For securing a sustainable energy future, not only are modified infrastructures and technologies are needed, but so is social acceptance [34]. That is one reason why the American Academy of Arts and Sciences recommended that the U.S. Department of Energy (DOE) added a unit on social science. It also explains why the Department of Energy and Climate Change in the U.K. has the Customer Insight Team [33]. The great majority of recent energy research appears to have been carried out in western countries with similar schools of thought, based on a study of 9545 energy studies from 1999 to 2013 that showed that 83% of researchers are male, 87% of researchers are from Europe or North America, 67% of research is in engineering, physical sciences, economics and statistics while 20% is on social sciences including law, business and public policy [35]. Various areas are underrepresented or neglected in energy research, such as the following:

- What are the energy issues (including accessibility and application topics) in other parts of the world with much greater populations?
- What are practical approaches for nations with differing socio-economics, geographies and governments for solving their energy challenges?

4.2. Water

Water scarcity reflects problems with water quality and quantity, and it occurs when water demand for drinking, domestic use, agriculture, and the industry is higher than freshwater reserves. Water scarcity especially affects domestic water consumption as well as agriculture [36]. Correct management of water resources can help reduce water scarcity [37], and primary measures for water management include water recycling, conserving water resources, increasing irrigation efficiency, and increasing energy production efficiency [37]. Irrigation and climate change both have negative impacts on water resources, and climate change increases the complexity of satisfying water and food demands [36].

Water management, including balancing water supply and demand, is necessary for water sustainability. Increase the efficiency of urban and agricultural water provision on the supply side helps reduce the differences between supply and demand [38]. Improvement options on the demand side include decreasing food waste [39], reducing the consumption of water-intensive food production [40], and increasing urban water efficiency [41]. Switching to healthier diets reduces the water footprint, according to a study of urban residents in Holland, and is thus aligned with global water sustainability [42].

Water issues include population increase, overuse of freshwater, and changing climate [43]. Holistic measures are often more effective for managing water resources for highly populated areas like China and India [24]. To further examine this idea, two approaches to managing agricultural water in India and China have been compared [24]. That investigation showed that China with centralized control could manage water issues, while India could not do so; due to the lack of centralized control and direction. An investigation for Asia demonstrated that, for conserving water resources, it is beneficial to use dams, not only decreasing flooding but also for managing flows to downstream energy plants [29].

4.3. Food

Irrigation efficiency has a direct impact not only on water consumption but also on energy usage [37]. Improving irrigation systems is an effective approach to reducing water scarcity [36]. The more efficient a region becomes in irrigation, the less water needs to be transported and used on crops, and the less energy is consumed to produce a fixed amount of food [29]. Increasing meat consumption over the last few decades in developed countries has increased their water consumption [42].

Urban areas tend to be major threats to agriculture water supplies since populated cities overuse water [36]. Parameters impacting food supplies are [36]:

- Water issues,
- Climate change,
- Energy cost,
- Credit issues.

The following measures can help address food scarcity through policies [36]:

- Mitigating climate change,
- Conserving energy and water resources,
- Proposing robust varieties of food and developing farming systems which demand less water and energy,
- Remodeling agricultural investment,
- Promoting domestic food supplies,
- Restructuring global food trade,
- Expanding the vision beyond regular farming.

Food waste impacts food security and needs to be considered as a waste of energy and water as well.

4.4. Energy-Water

Energy and water are strongly connected. Energy is needed to collect, treat, desalinate, and distribute water. Similarly, water is needed for generating electricity in hydroelectric plants, cooling reactors and running turbines, and as working fluids in power plants [43]. The vulnerability of water supply to global warming has an impact on energy demand [44].

Recommendations to promote wise consumption of water [29]:

- Not using freshwater for generating electricity
- Not using freshwater for irrigation

Some have examined the analytical correlation between access to sanitation, access to food and energy consumption. This examination suggests that more energy is generated by a region, the higher the percentage of the population that have access to sanitation and food [23].

Another study suggests an option to reduce water scarcity is the large-scale implementation of dams in the mountains [45]. Dams are beneficial for both energy production and water management [29]. Hydroelectric dams capture the energy of moving water through turbines [46], which reduce the use of fossil fuels for electricity production, helping to mitigate climate change and related issues [29]. Some suggest that the best solution to reduce water consumption in energy plants would be the building of energy plants with high-efficiency gas-based combined cycles, as they consume less water than conventional fossil fuel power plants [29]. Using seawater for power plants close to the sea is an option for plants in regions with shortages of water [47]. In south Florida, seawater is already used in energy plants, and this idea has the potential to be used worldwide [29].

The energy and water nexus is observed strongly in thermoelectric power plants, although reductions in their consumption of water can help improve the nexus [48]. This observance can also be achieved by using natural gas instead of coal, which reduces water consumption by 37%, and replacing closed-loop with open-loop cycles for cooling the power plants, which can reduce water consumption by 32% [48]. Another study suggests using wind turbines instead of fossil fuel power plants to reduce CO_2 emissions and water consumption [49]. Hydroelectric power is another connection between water and energy. Although using dam technology in one of the cleanest electricity generation methods, its use has been observed to affect the ecosystem around the basin. This change has an impact on the agriculture of the region, due to holding the water behind the dams. As a consequence, the downriver areas do not receive proper water supplies when needed for agricultural practices. Advances in cooling systems offer significant potential for reducing electricity and water demands in the future [50].

Four steps for reaching sustainable energy and water security have been reported [51]:

I. Study the region to assess the status of energy and water,
II. Find goals for energy and water for the future,
III. Identify policies not supporting energy and water nexus,
IV. Encourage policies that support the energy and water nexus now and in the future.

The significance of the relations between energy and water is expected to increase in the future as demand increases for both [52]. There are two main methods to manage the situation: reducing the coupling between energy and water or improving the correlation between them. In the latter option, optimizing one resource through a well-established algorithm also optimizes the other resource [52]. With this idea, an integrated engineering system model for water, electricity, and wastewater is developed based on electricity and water demand [53], which is useful for improving the energy and water nexus. Another energy-water model has been developed to determine the tangible effects of structural and technological advances in water consumption on the energy demand of a region [37].

4.5. Water-Food

Like energy and water, water and food are strongly linked at different levels. 70% of global water consumption is related to food production [45]. To have flourishing plants and people, one can make some changes to one's advantage, like improving water consumption, modernizing the irrigation infrastructure, and reforming how food is processed along with waste [54]. New designs of irrigation are needed to avoid water scarcity [36].

A study of Dutch cities shows that water utilization in Amsterdam and Rotterdam is 3245 l/cap/day, which is higher than for other urbanized cities (3126 l/cap/day), mainly because of greater consumption of meat and cereals and less of potatoes [42]. It was shown that people in Holland could reduce water use by 29 to 32% by shifting to a healthier diet and reducing consumption of animal products, sugar and crop oil [42]. Switching to a vegetarian diet or a pesco-vegetarian diet can reduce water use 40-42% and 36-39%, respectively [42].

4.6. Food-Energy

Globally, 30% of total energy use supports food production, while 1% of crops are converted to energy products [50]. Some researchers suggest that food prices are correlated to demand, available technology, and resource constraints, which in turn directly affect water, energy, and land resources [23]. Another detail from this idea is the strong price correlation between the price of oil and food [23]. Figure 2 illustrates this idea, demonstrating that the price of crude oil and the food index exhibit the same trend.

5. Impacting factors

The complexity of the energy, water, and food nexus lies not only in exploring the interconnections among these resources, but also the sophistication of understanding their increases, by knowing that there are factors that have a great impact on the complex relationships between energy, water, and food. The complex relationships between energy, water, and food are greatly dependent on people. Accounting for the behaviors of people makes mathematical modeling difficult and, in many instances, almost impossible. However, it is necessary to account for the impact of people on the energy-water-food nexus because human behavior regarding resources is a major cause of climate change and because a human must adapt appropriately to cope with the effects of climate change [57] and its impact on resources including energy, water, and food. The major factors are population increase, human behavior, economy and climate change. Each of these factors influences the energy, water, and food nexus significantly. Climate change integrated with socioeconomic development greatly impacts the interdependencies in the food-energy-water nexus [18]. Figure 6 illustrates the impacting factors, which suggests that the study about the framework for the energy-water-food nexus should be expanded to reflect the multi-disciplinary of the problem, which requires collaboration among engineers, economists, environmentalists, psychologists, sociologists and others. In the following subsections, selected studies focusing on the impacting factors are described.

5.1. Population Increase

Demand for energy, water, food is a function of population, which is rising significantly. The global population expected to reach 8.5 billion and 9.7 billion by 2030 and 2050,

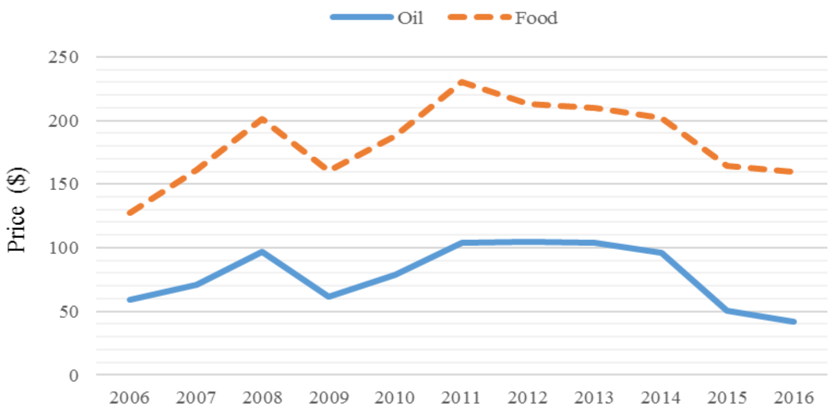


Fig. 2. World oil and food price (in U.S. dollars) from 2006 to 2016 [55][56]

respectively [2]. Figure 3 shows population growth predictions by continent from 2015 to 2050. Based on this graph, Africa will be in great demand for food, followed by Oceania and Latin America and the Caribbean, mainly because the population grows drastically in those continents. Although North America and Asia have less population growth in comparison to Africa, Oceania, Latin America and the Caribbean, they still have a population increase, and demand for food will increase. Accounting for the diets of people in different regions (an aspect of human behavior) is needed to determine the growth in food demand. Similarly, demand for energy will increase with the growth of the population, while human behavior (lifestyle) also influences the growth of energy demand. These considerations affect water demand growth similarly.

5.2. Human Behaviour

Demand models depend significantly on human behavior. Human behavior varies by country and community and depends on culture, religion, and marketing policy of that region. Figure 4 shows one aspect of human dietary behavior in selected countries and regions. Australia and the U.S. rely notably on animal products, which require more water and energy to produce than other countries. Similarly, people in India and Indonesia typically have diets low in animal products.

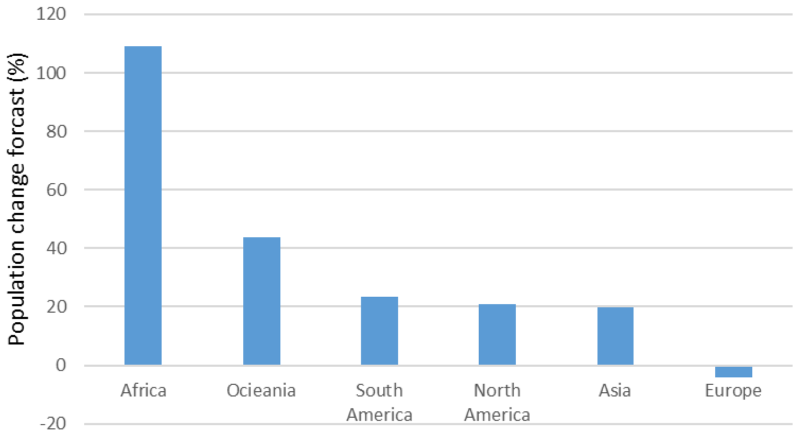


Fig. 3. Global and continental population increase predictions, 2015-2050 [58]

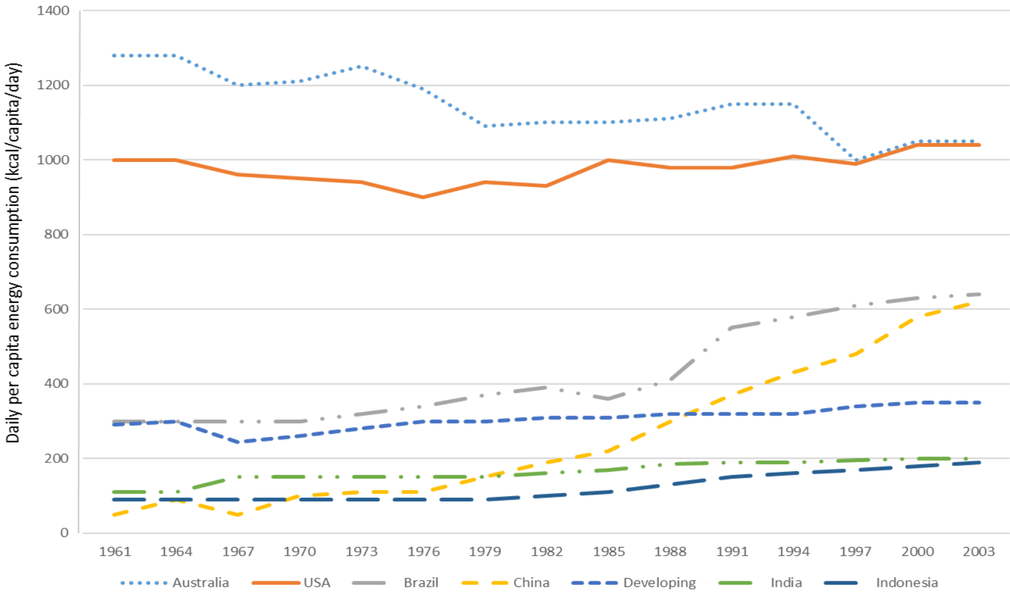


Fig. 4. Breakdown by country of daily per capita energy consumption from animal products for 1961-2003 [59]

Wasting food is another behavior of people that is dependent on culture and availability of resources. Food waste indirectly implies a waste of water and energy. Meat, poultry, and fish are the highest energy-intensive food product categories, and they account for 16% of the annual waste in the U.S. Similarly, dairy and vegetable wastes constitute 32% and 25.3% of the U.S. waste, respectively [60].

Psychological aspects of human behavior toward consumption of resources and its impact on the environment have attracted much interest. Psychological barriers delay human behavior that would facilitate mitigation consumption of resources, adaptation to new lifestyles, and environmentally sustainable behavior. Psychological barriers to human behavioral changes include [61]:

- limited understanding of the issue,
- ideological views,
- sunk costs and behavioral drive,
- lack of trust toward experts and authorities,
- apparent risks of change, and
- insufficient behavior transformation.

Psychologists need to collaborate with other scientists, technical experts, and policymakers to remove these psychological barriers [61].

A psychological study of the relationship between human behavior and global climate change determined that human behavior is the cause of global climate change and that humanity needs to respond to that properly [57]. The study examined three major areas:

- Defining human opinions of climate change,
- Understanding and correcting individual and community behaviors toward climate change,
- Evaluating the human impact on the environment and ultimately on the global climate and impacts of human adjustments.

The study considered cognitive, physiological, affective and interpersonal processes, as well as biophysical, cultural, social and engineered environments of individuals[57]. According to this study, the opinions of people about climate change are the result of intellectual and emotional biases based on trust and interpretive frameworks, which are established by mass media as well as direct or indirect experiences with the effects of climate change [57]. One outcome of that study indicates that effective communication about adjusting behaviors so as to achieve positive impacts on the environment requires consideration of the intellectual abilities, biases, beliefs, values, identities, social relationships, and political views of individuals, as it is necessary to incorporate these factors into a modified understanding of human dealings with a changing climate [57]. Another study examined Norwegian understanding and behavior toward climate change based on cultural resources and governmental organization trust [62]. The results indicated that a low level of trust was supported by the belief that climate change is a natural occurrence, while a high level of trust corresponded to the idea of anthropogenic factors being the cause of climate change [62]. The impact of cultures and professional orientations on perceptions about science have been examined in other studies [63].

5.3. Economy

The economy has a strong influence on the use of resources (energy, water, and food). Also, the economy has a strong interaction with altering the supply and demand of the resources. Figure 3 shows the direct relationship between food and energy. Not only is there a two-sided impact between resources and economy, but also there is a similar impact between the economy and other major factors, including population increase, human behavior, and global warming. Countries with a higher gross domestic product (GDP) typically have lower rates of population increase. One study shows that the economy is a function of temperature increase, for up to 2°C, which causes GDP increases [43]. Also, countries with lower GDP usually are moderate consumers of resources and have less impact on global warming. Global warming changes the consumption patterns in a different part of the world and, consequently, the economic patterns of that region also change. This change influences the consumption of market products in that region subsequently. The economy also is affected by climate change, via increasing morbidity and mortality, which affect labor productivity and demand for health care [64]. Some markets are particularly influenced by climate change [65], including agriculture, tourism, and coastal area business. Human health, a non-market area, is also influenced by natural disasters and climate change [65].

Figure 5 shows the evolution over time of renewable energy markets, globally and by type of country. Renewable energy investments encourage researchers and industries to focus on developing renewable energy technologies, which is another way that the economy influences energy sustainability.

5.4. Climate Change

Climate change is caused by the activities of civilization [67][68]. Climate affects life on Earth [69] by impacting ecosystems over both short and long terms. However, many people think climate change is far off in the future and will not have any immediate impact [35]. Unfortunately, poorer countries that contribute less to climate change are generally the most affected by it [70]. Global warming directly affects human health through five major diseases: cardiovascular, respiratory disorders, diarrheal disorders, malaria, dengue fever, and schistosomiasis [64]. This observation stems from and is supported by two original studies of the relationship between global warming and malaria, which suggests the relationship is linear [71][72]. The general equilibrium model developed within the Global Trade Analysis Project can be used to predict the number of additional deaths, the additional years of life illness, and the additional cost of illnesses by the aforementioned diseases [64].

Climate change harms agriculture, particularly notably, as it normally demands large quantities of water [73]. Climate change increases demands for crop irrigation. Population shifts also affect water demand and supply, and these changes directly impact energy systems [44]. Climate change also has an impact on food and water-borne illnesses [64]. Food production, water resources, migration, and economic development are

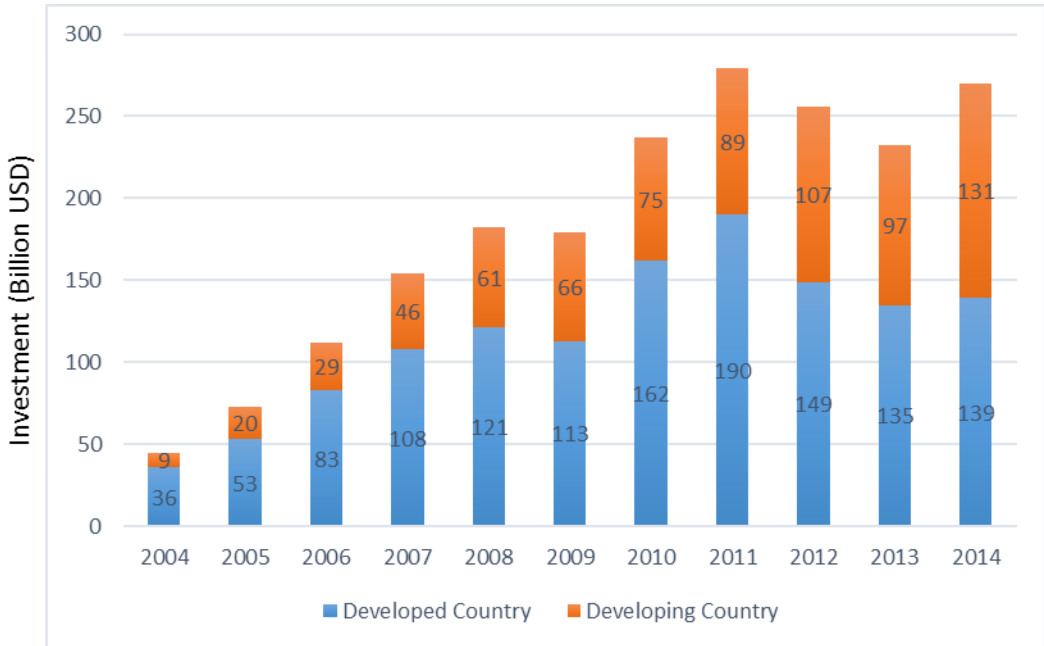


Fig. 5: Annual new investment in renewable energy and fuels, globally and broken down by developed and developing countries [66]

also affected by climate change [20]. Climate policy is a tool for water use reduction as are bioenergy irrigation policies as well as technologies for less water-intensive electricity generation and less water-intensive cooling [50].

Some researchers modeled the effects of climate on shared socio-economic pathways (SSPs) to evaluate various scenarios in the development of society and ecosystems over a century, with and without climate change [21].

6. Controlling tools

Energy, water, and food are interconnected and are influenced by population increase, human behavior, economy, and global warming. Various controlling tools exist for directing resources and major impacting factors. Policy, technology, and education are strong tools for managing the practical aspects of energy, water, and food in different circumstances. Policies and regulations at various government levels are useful for promoting sustainable development and discouraging environmental impacting technology and behaviors. Policies are usually developed based on outcomes of related studies in order to advance technology and/or behavior that support sustainable development in society. Technology is the major technical component in controlling tools to modify practically the present situation. Technology is also the backbone of innovative new ways of harvesting and using energy, water, and food to promote sustainable development. Finally, education is a controlling tool that is focused on people. Humanity is the center of all research, directly or indirectly, and ıs in this critical situation from an environmental vıewpoint because of human behavior in terms of unreasonable consumption of not only energy, water, and food but also other resources. Human behavior is changeable by providing general awareness and training for people and consumers and a more in-depth level of awareness and better training of community leaders, designers, engineers, decision-makers, teachers, students, etc.
Figure 6 demonstrates the interaction between controlling tools and resources (energy,

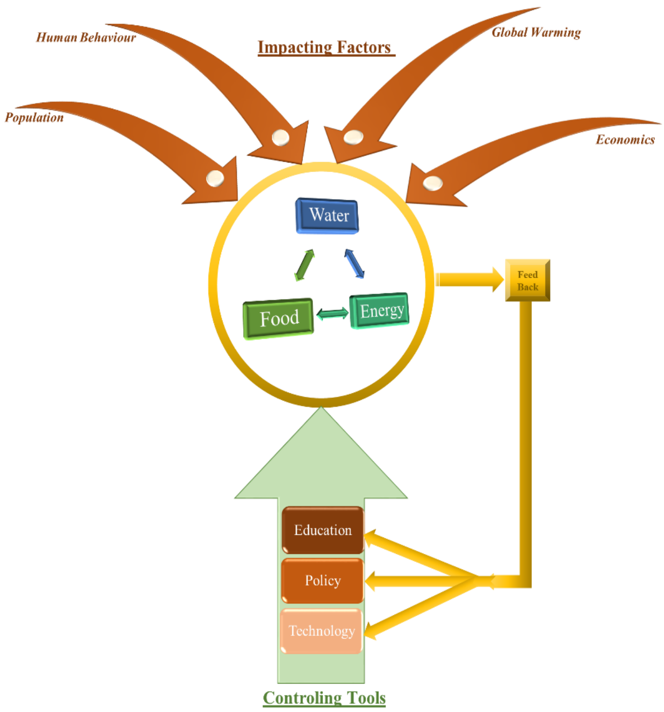


Fig. 6. Interactions between resources (energy, water, food) and major impacting factors (population increase, human behavior, economy, and global warming) and controlling tools (policy, technology, and education)

water, food) and major impacting factors (population increase, human behavior, economy, and global warming). In the following sub-sections, selected related research regarding controlling tools is presented.

6.1. Policy

Policies are needed to support decision making regarding the nexus of energy, water and food. Availability of energy, water and food in terms of quality and quantity have a great impact on the economy, and correspondingly the economic climate directly impacts consumption patterns of energy, water, food and other resources. However, because of the inadequacy of governmental policies in some cases, engineers and scientists in private and public sectors have responsibilities to help inform or be involved in policymaking [22]. There is a demand for cost-effective policies that cover several resources across the FEW nexus [11]. Effective policies and leadership are needed to address the energy-water-food nexus [32]. Before developing policies, it is essential to establish a conceptual framework that contains two sub-nexuses: the water-food-trade nexus and the energy-climate change nexus [22]. Policies and regulations frequently send sub-optimal signals regarding economics, national security and environmental concern [32]. Changing the set of policies for a given issue often leads to different outcomes. For example, consider water management in China and India. Water was successfully managed in China through strong controls and policies, while a different policy approach in India was not successful [24].

A supportive technological policy is an important tool for replacing or upgrading old technologies [48]. Many current policies need to be reviewed and, in many instances, replaced with policies that promote water and energy security, now and in the future [51]. Policymakers need to analytically evaluate the consequences of decisions regarding energy and water, especially since they are interconnected at a variety of levels. Thus, a decision on one has an impact on others. For any policy development, the nexus of water and energy needs to be considered, rather than evaluating the two separately [25]. For a transition to emission-free energy, new policies are needed to incorporate renewable energy technologies into the industry and to replace fossil fuels [74]. That is not an easy transition, but proper policies can play a great role in this evolution. Providing and protecting FEW resources for people through sudden harsh weather events (like floods) leads to regulations with support of innovation and Sustainability [6]. Recognition of co-dependencies and interrelationships for regions with high climate impacts (like South Africa) is necessary for considering emerging strategies [18]. Determining people and places at risk is crucial for planning the infrastructure and regulations for social practice [6]. A study considered implications of governance for FEW nexus in Phoenix, Arizona by identifying stakeholders first, and then by obtaining their help in preparing the interlinks between energy-water, energy-food, and water-food for Phoenix, as the backbone for FEW nexus framework [75]. Policy, in general, is a powerful means of preventing many uncontrollable situations before they occur. Considering climate change and its impact suggest that there is much work needed by policymakers. Climate change ultimately impacts world food security, and policymakers may be able to prevent that by regulating food and ensuring food security [73]. One study shows that efforts to increase support for climate change policies provide method means for raising social awareness and communicating the uncertainties and risks [76]. However, a better understanding of the social basis for rejecting or supporting climate change is necessary to develop policies that communicate mitigation and adaption needs effectively, since behavior change is associated with culture, beliefs and concerns about the future [62].

6.2. Technology

Technology is a large player in the effective use of energy, water and food resources. For that reason, improving technology is a key research focus. One of the most common areas of technology research is increasing efficiency. However, innovative and creative technology needs to receive attention if it is to become an option for balancing the supply and demand for energy, water.

Renewable energy resources and fossil fuel technologies have attracted much attention since climate change and sustainable development became prominent topics. Table 1 shows the annual growth rates of renewable energy for the period 2009 to 2014 and the year 2014. It can be seen that the use of renewable energy technology increased significantly in 2014. In Table 1, energy forms are shown that are used for electricity generation (geothermal, hydro, solar P.V., CSP, wind), transportation (ethanol and biodiesel), and heating (solar).

More specifically, Figs. 7 and 8 depict the growth of solar energy via P.V. technology and via solar water heating technology, respectively, from 2004 to 2014. It can be seen that P.V. technology has received much attention during these years, in large part because the economics of P.V. panels have improved notably, and the technology is more compatible in the market. The role of some policy and incentives during these years in some areas has had an impact on the growth of P.V. use. Solar water heating collectors are more efficient and need lower maintenance, and have been more commonly used by consumers globally, as seen in Fig. 7.

Global growth in the use of wind turbine technology from 2004 to 2014 has been significant, as depicted in Fig.8. Wind power capacity is growing based on technology advances and price decreases, combined with and growing demand for this technology. Consequently, there is a high demand for more wind turbines, which results in the growth of electricity generation from wind.

Table 1: Average annual growth rates (in %) of renewable energy capacity, end-2009–2014 [66]

Period	Geothermal	Hydro	Solar PV	Wind	Solar Heating	Ethanol Production	Biodiesel Production
2014	5.3	3.6	30	16	9	7.1	13
End 2009 through 2014	3.6	3.5	50	18	17	5.2	11

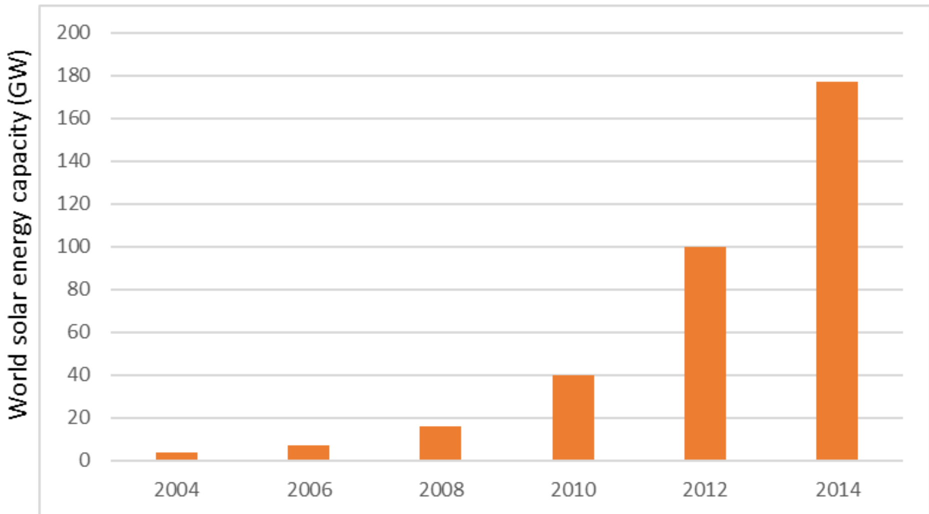


Fig. 7. Solar PV global capacity, 2004-2014 [46]

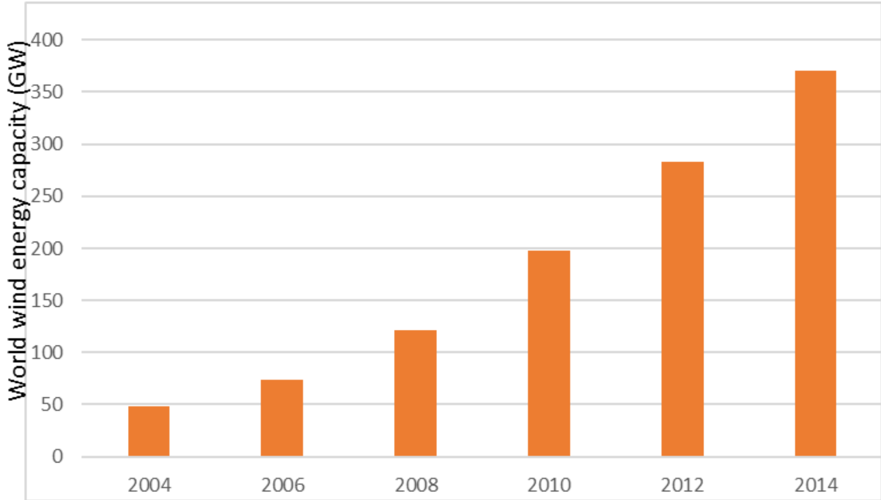


Fig. 8. Solar water heating collectors global capacity, 2004-2014 [66]

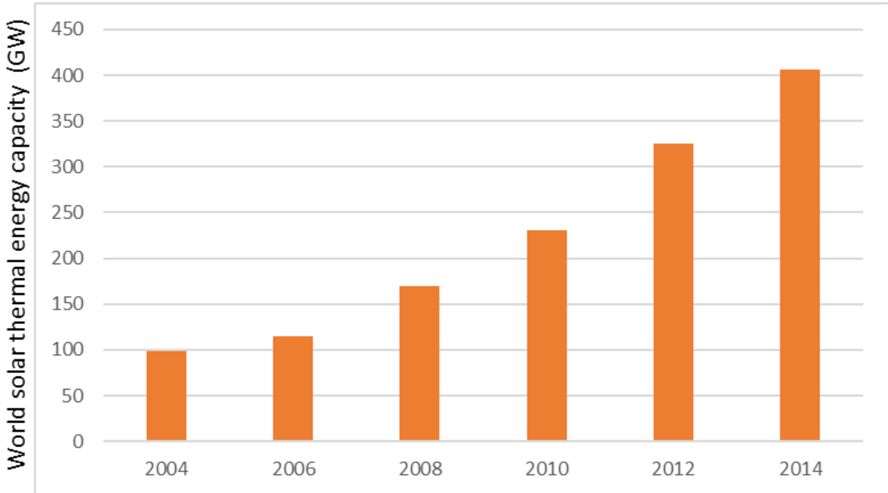


Fig. 9. Wind power global capacity, 2004-2014 [66]

Although higher efficiency technologies and renewable energy technology are of great benefit for mitigating climate change, they are not adequate for resolving the problem. Innovation for new technologies is greatly needed to combat global warming. There is a demand for technology innovation that explores the interlinkages between the FEW nexus [11].

6.3. Education

Many believe climate change and Sustainability pose a major problem and challenge. However, few global citizens are engaged in solving environmental problems [61], which is, in large part, due to a lack of awareness that can be offset by educating people. Educating global citizens about global warming can be done in educational institutions as well as through newspapers, media, and the internet. People need to process information selectively and detect and avoid bias linked to political or corporate aims [77]. Global warming beliefs have an impact on changes in local climate conditions, which is one reason why some people do not accept the reality of experiences regarding warmer summers in past years [57]. Hence, investigations of the sources of beliefs and attitudes towards climate change are necessary [57] for providing effective climate change education. Knowledge improvement is essential for providing an understanding of various professions of the social basis for climate change actions in the future [62].

Climate change education in the Next Generation Science Standards is a need for professional development [78]. Previous studies presented the complex nature of climate change and the curricular challenges associated with teaching the subject; the need for professional development can be implemented by practical courses for teacher education and professional development [78]. The approach to teacher professional development about climate change education needs to cover the following areas to be effective [78]:

- the requirement for quality curricular resources to support climate change instruction,
- the potential of regional case observations for learning so as to make climate change personally relevant to students; and
- the value of research-based professional development and teacher education for advancing climate change education.

The impact of cultural beliefs, cognitive upbringing, and positions of power on people's understanding about climate change consequences in the future, as supported by sociological and psychological research [62], which suggests that early life experiences and cultural orientation must be considered more carefully in perceptions of future climate change effects [62].

7. FEW nexus framework implementation

The method of applying the proposed FEW framework in Fig.10 is explained step by step. Implementation of that model is much more complex than depicted by the simple schematic and requires considerable financial resources to support multi-disciplinary investigations and collective management. The steps for applying the proposed FEW framework are as follows:

I. Choosing a region for implementing the FEW nexus model and customizing it. This implementation is necessary since impacting factors and types of consuming food, energy and water resources are different for various areas and communities.

II. Developing interlinks between energy-water, energy-food, and water-food for that region. Finding interlinks between food, water, and energy are involved and time-consuming and usually requires a group of specialists to form the regional FEW framework. At least several hundred interlinks are expected to be defined.

III. Investigating the effects of four impacting factors (population, human behavior, global warming, and economics) on the developed interlinks. This stage demands significant collaboration among stakeholders and various interdisciplinary collaborations to formulate interactions of each impact factor on each interlink and, consequently, on the FEW nexus of that region. The rough estimations for the number of interactions are four times the number of interlinks.

IV. Studying the interactions to find how they can be controlled by the transdisciplinary approach is the next stage. The outcomes include identifying the shortcomings of this complicated system, which are the guidelines for governing institutions regulating the controlling tools (educations, policy, and technology) of the proposed FEW nexus in Fig. 10.

V. Defining the educational plans at different levels by considering the available budgets and resources to facilitate FEW security is one part of this stage.

Planning for the proper technology to support sustainable FEW for the region by considering the resources and social potential is the other part of this stage.

Developing the policies, regulations, and laws by considering the competences and interests of stakeholders regarding FEW security is another complex part of this stage. While these three parts are usually developed in parallel through different specialists and policymakers, they greatly influence each other. Therefore, the policymaker teams have to work closely.

VI. Implementing control tools on the boundary of the FEW nexus, which involves a new complex multilevel multi-disciplinary system. Therefore, controlling the performance and debugging the system are crucial tasks at this stage. The outcomes are modifying the control tools, some focusing on short and some on long terms, as well as preparing comprehensive reports on the performance of the control tools.

VII. Modifying the control tools based on the feedback reports is a continuous task to keep up with new criteria of the FEW status and to adjust to fluctuations in the impacting factors. Multi-disciplinary research teams and stakeholders always are engaged in this stage.

With comprehensive and complete models of supply and demand for energy, water, and food, it is easier to manage and modify processes and products, because the impact of any change on resources would be measurable. Setting strategies and policies for sustainable development is more realistic when holistic models for supply and demand for energy, water, and food are available. Figure 10 lists selected challenges and resolutions for the FEW nexus framework.

As suggested in Fig. 10, the modeling of the FEW linkages and interactions with controlling factors is an extensive and complex mathematical study that integrates actual information on relationships with other important parameters, separately and holistically. Simplifying processes is a useful strategy for determining sustainable relationships with resources (food, water, and energy). Re-thinking, re-defining, and inventing processes is a useful approach to resolving the issues.

8. Conclusion

Frameworks supported by previous research have been reviewed to identify their strengths and unique perspectives regarding the FEW nexus. This study is complementary to previous framework studies and focuses on a new perception of the FEW nexus, which is Sustainability. Here, a sustainable framework for modeling the FEW nexus is proposed. The strategy used involves modeling the supply and demand for energy, water and food. To facilitate such modeling, one should explain the connections between resources and the major impacting factors that affect resources. It was observed that researchers are focusing on exploring and defining these relationships. However, the work is not yet complete, and there exist many complex relationships at various levels that have not yet been explored. Mathematical model developments are needed for accounting for details and a large number of relationships and utilizing relevant data. In addition, controlling factors (policy,

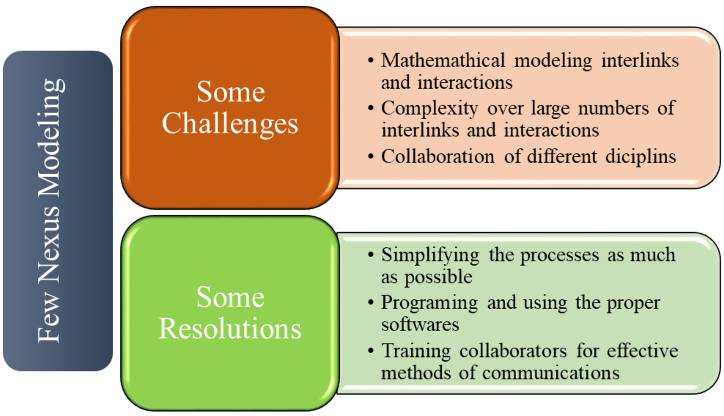


Fig. 10. Summary of selected challenges and resolutions for the energy-water-food nexus

technology, education) require modeling to develop a better understanding of their interactions with the supply and demand model. Educational models are expected to have a high impact on demand-models through human behavior, but the exact nature of the impact on the demand model remains unclear. This impact also suggests the need to develop both models of demand and education. Consequently, changing demand influences supply and understanding that requires a mathematical model of supply and demand for quantifying the magnitudes of the effects of demand variations.

To explore the FEW nexus model, one must study impacting factors, including population increase, human behavior, economics, and climate change. Their significant influence on energy, water, and food is discussed here, based on previous studies. The controlling tools, policy, technology, and education help manage the overall systems, including resources. Perhaps technology is adaptable with some modifications for different regions. However, policy and education are often not adaptable with minor changes in various countries because of diverse socio-economics, cultures, governments, and interests. Policy and education require local attention of sociologists, economists, policymakers, educators, environmentalists, engineers, and lawyers to develop customized and effective policies and education for citizens of the region. The role of each tool is based on the relevant literature, which was cited and is studied as well.

The pressure to define the FEW nexus pushes researchers towards innovations for sustainable development, which requires transdisciplinary, multi-disciplinary, and multicultural studies of the topic that account for the diverse perspectives of different societies and the approaches of various research disciplines if a comprehensive and practical approach applicable to various nations is to be developed. Perhaps these efforts on such a large problem will encourage humanity at all levels to review its activities to improve or, in some cases, re-invent technology and society.

References

[1] A. H. Maslow, "Maslow's Hierarchy of Needs : Research History," Psychological Review, 50, 370-396, 1943. Available: http://www.researchhistory.org/2012/06/16/maslows-hierarchy-of-needs/. [Accessed: 27-Jan-2019].

[2] "U.N. projects world population to reach 8.5 billion by 2030, driven by growth in developing countries," United Nations News, 29 July 2015.

[3] U. E. I. Administration, "EIA projects world energy consumption will increase by 56% by 2040," U.S. Energy Information Administration, 25 July 2013. Available: http://www.eia.gov/todayinenergy/detail.cfm?id=12251#. [Accessed: 1-July-2010].

[4] J.-D. Rinaudo, "Long-Term Water Demand Forecasting," Chapter 11 in Understanding and Managing Urban Water in Transition, Springer Netherlands, 2015, pp. 239–268.

[5] Parry, M.L., Canzani, O.P., Palutikof, J.P. et al., eds., Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change (IPCC). Cambridge: Cambridge University Press, 2007.

[6] P. Romero-Lankao, T. McPhearson, and D. J. Davidson, "The food-energy-water nexus and urban complexity," Nature Climate Change, 7, 233-235, 2017.

[7] A. Endo, I. Tsurita, K. Burnett, and P. M. Orencio, "A review of the current state of research on the water, energy, and food nexus," J. Hydrol. Reg. Stud., 11, 20-30, 2017, doi: 10.1016/j.ejrh.2015.11.010.

[8] World Economic Forum, An initiative of the Risk Response Network "Global Risk 2011" Sixth Edition, Geneva, January 2011.

[9] The World Economic Forum Water Initiative, "Water Security: The water-Food-Energy-Climate Nexus," Washington, 2011. http://www3.weforum.org/docs/WEF_W

I_WaterSecurity_WaterFoodEnergyClimateNexus_2011.pdf [accessed: Sep 14, 2019]

[10] N. Weitz, M. Nilsson, and M. Davis, "A Nexus Approach to the Post- 2015 Agenda: Formulating Integrated Water, Energy, and Food SDGs," SAIS Rev., vol. XXXIV, no. 2, pp. 37–50, 2014.

[11] S. Shannak, D. Mabrey, and M. Vittorio, "Moving from theory to practice in the water–energy–food nexus: An evaluation of existing models and frameworks," Water-Energy Nexus, vol. 1, no. 1, pp. 17–25, Jun. 2018, doi: 10.1016/j.wen.2018.04.001.

[12] M. Al-Saidi, N. A. Elagib, and D. Barcelo, "Towards understanding the integrative approach of the water, energy and food nexus," Sci. Total Environ., vol. 574, pp. 1131–1139, 2017, doi: 10.1016/j.scitotenv.2016.09.046.

[13] H. Hoof, "Understanding the nexus. Background paper for the Bonn2011 Conference: the water, energy and food security nexus," in Stockholm Environment Institute, 2011.

[14] M. Giampietro, R. J Aspinall; S.G.F. Bukkens; J. Cadillo Benalcazar;F. Díaz maurín; A. Flammini; T. Gomiero; Z. Kovacic; C. Madrid; J. Ramos Martín; T. Serrano Tovar "An innovative accounting framework for the food-energy - water nexus: Application of the MuSIASEM approach to three case studies" Roma, Italy, 2013.

[15] M. Howells, S. Hermann, M. Welsch, M. Bazilian, R. Segerström, T. Alfstad, D. Gielen, H. Rogner, G. Fischer, H. Velthuizen, D. Wiberg, C. Young, R. A. Roehrl, A. Mueller, P. Steduto & I Ramma "Integrated analysis of climate change, land-use, energy and water strategies," Nat. Clim. Chang, vol. 3, no. 7, pp. 621–626, Jun. 2013, doi: 10.1038/nclimate1789.

[16] FAO, "The Water-Energy-Food Nexus A new approach in support of food security and sustainable agriculture," Roma, 2014.

[17] E. M. Biggs, E. Bruce, B. Boruff, JMA. Duncan, J. Horsley, N. Pauli, K. McNeill, A. Neef, F.V. Ogtrop, J. Curnow, B. Haworth, S. Duce, Y. Imanari, "Sustainable development and the water–energy–food nexus: A perspective on livelihoods," Environ. Sci. Policy, vol. 54, pp. 389–397, 2015, doi: 10.1016/j.envsci.2015.08.002.

[18] D. Conway, E.A. van Garderen, D. Deryng, S. Dorling, T. Krueger, W. Landman, B. Lankford, K. Lebek, T. Osborn, C. Ringler, J. Thurlow, T. Zhu, C. Dalin, "Climate and southern Africa's water-energy-food nexus, Nat Clim Change, 5 (2015), pp. 837-846, doi: 10.1038/NCLIMATE2735.

[19] E. Mohareb et al., "Environmental Research Letters LETTER, OPEN ACCESS Related content Considerations for reducing food system energy demand while scaling up urban agriculture Tracking urban carbon footprints from production and consumption perspectives," Environ. Res. Lett., 2017, doi: 10.1088/1748-9326/aa5556.

[20] S. Bunyavanich, C. P. Landrigan, A. J. McMichael, and P. R. Epstein, "The Impact of Climate Change on Child Health," Ambul. Pediatr., vol. 3, no. 1, 2003.

[21] B.C. O'Neill, E. Kriegler, K. Riahi, K.L. Ebi, S. Hallegatte, T.R. Carter, R. Mathur, D.P. van Vuuren, "A new scenario framework for climate change research: the concept of shared socioeconomic pathways," Clim. Change, vol. 122, no. 3, pp. 387–400, Feb. 2014, doi: 10.1007/s10584-013-0905-2.

[22] W. E. Allan Tony, Keulertz Martin, "The water–food–energy nexus: an introduction to nexus concepts and some conceptual and operational problems," Int. J. Water Resour. Dev., vol. 31, no. 3, pp. 301–311, 2015, doi: 10.1080/07900627.2015.1029118.

[23] C. Ringler, A. Bhaduri, and R. Lawford, "The nexus across water, energy, land and food (WELF): potential for improved resource use efficiency," Curr. Opin. Environ. Sustain., vol. 5, pp. 617–624, 2013, doi: 10.1016/j.cosust.2013.11.002.

[24] U. Lele, M. Klousia-Marquis, and S. Goswami, "Good Governance for Food, Water and Energy Security," Aquat.

Procedia, vol. 1, pp. 44–63, 2013, doi: 10.1016/j.aqpro.2013.07.005.

[25] C. A. Scott, S. A. Pierce, M. J. Pasqualetti, A. L. Jones, B. E. Montz, and J. H. Hoover, "Policy and institutional dimensions of the water–energy nexus," Energy Policy, vol. 39, pp. 6622–6630, 2011, doi: 10.1016/j.enpol.2011.08.013.

[26] D. Perrone, J. Murphy, and G. M. Hornberger, "Gaining Perspective on the WaterÀEnergy Nexus at the Community Scale," Environ. Sci. Technol, vol. 45, pp. 4228–4234, 2011, doi: 10.1021/es103230n.

[27] D. J. Garcia and F. You, "The water-energy-food nexus and process systems engineering: A new focus-food nexus Modeling and optimization of multiple spatial and temporal scales Life cycle optimization Multi-scale modeling Modeling of multiple stakeholders," Comput. Chem. Eng., vol. 91, pp. 49–67, 2016, doi: 10.1016/j.compchemeng.2016.03.003.

[28] C. Howarth and I. Monasterolo, "Understanding barriers to decision making in the U.K. energy-food -water nexus: The added value of interdisciplinary approaches," Environ. Sci. Policy, vol. 61, pp. 53–60, 2016, doi: 10.1016/j.envsci.2016.03.014.

[29] Kaufui Vincent Wong, "Energy–Water–Food Nexus and Recommendations for Security," J. Energy Resour. Technol., vol. 137, no. May, pp. 034701-1-034701–4, 2015.

[30] G. Krajačić, N. Duić, M. Vujanović, Ş. Kılkış, M. A. Rosen, and M. A. Al-Nimr, "Sustainable development of energy, water and environment systems for future energy technologies and concepts," Energy Conversion and Management. 2016, doi: 10.1016/j.enconman.2016.08.050.

[31] K. Singh, Baljinder; Kaur, Jagdeep; Singh, "Production of Biodiesel from Used Mustard Oil and Its Performance Analysis in Internal Combustion Engine," ASME, J. Energy Resour. Technol., no. September, pp. 031001-1-031001–4, 2010.

[32] M. Bazilian H. Rogner, M. Howells, S. Hermann, D. Arent, D. Gielen, P. Steduto, A. Mueller, P. Komor, S. Tol, K. Yumkella, "Considering the energy, water and food nexus: Towards an integrated modeling approach," Energy Policy, vol. 39, pp. 7896–7906, 2011, doi: 10.1016/j.enpol.2011.09.039.

[33] D. S. B.K. Sovacool, S.E. Ryan, P.C. Stern, K. Janda, G. Rochline and L. L. M.J. Pasqualetti, H. Wilhite, "Integrating social science in energy research," Energy Res. Soc. Sci., vol. 6, pp. 95–99, 2015.

[34] M. J. Pasqualetti and M. A. Brown, "Ancient discipline, modern concern: Geographers in the field of energy and society," Energy Res. Soc. Sci., vol. 1, pp. 122–133, 2014, doi: 10.1016/j.erss.2014.03.016.

[35] B. K. Sovacool, "What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda," Energy Res. Soc. Sci., vol. 1, pp. 1–29, 2014, doi: 10.1016/j.erss.2014.02.003.

[36] M. A. Hanjra and M. Ejaz Qureshi, "Global water crisis and future food security in an era of climate change," Food Policy, vol. 35, pp. 365–377, 2010, doi: 10.1016/j.foodpol.2010.05.006.

[37] A. Dubreuil, E. Assoumou, S. Bouckaert, S. Selosse, and N. Ma, "Water modeling in an energy optimization framework â€ "The water-scarce middle east context," Appl. Energy, vol. 101, pp. 268–279, 2013, doi: 10.1016/j.apenergy.2012.06.032.

[38] P. Grassini, J. Wolf, P. Tittonell, and Z. Hochman, "Yield gap analysis with local to global relevance—A review," F. Crop. Res., vol. 143, pp. 4–17, 2013, doi: 10.1016/j.fcr.2012.09.009.

[39] D. Vanham, F. Bouraoui, A. Leip, B. Grizzetti, and G. Bidoglio, "Lost water and nitrogen resources due to E.U. consumer food waste," Environ. Res. Lett., vol. 10, no. 8, p. 084008, Aug. 2015, doi: 10.1088/1748-9326/10/8/084008.

[40] A. Y. Hoekstra, "Water for animal products: a blind spot in water policy," Environ. Res. Lett., vol. 9, no. 9, p.

091003, Sep. 2014, doi: 10.1088/1748-9326/9/9/091003.

[41] C. J. Koop, S. H. A.; van Leeuwen, “The challenges of water, waste and climate change in cities,” Env. Dev Sustain, no. 19, pp. 385–418, 2017, doi: 10.1007/s10668-016-9760-4.

[42] D. Vanham, T. N. Mak, and B. M. Gawlik, "Urban food consumption and associated water resources: The example of Dutch cities," Sci. Total Environ., vol. 565, pp. 232–239, 2016, doi: 10.1016/j.scitotenv.2016.04.172.

[43] G. Gold and M. Webber, "The Energy-Water Nexus: An Analysis and Comparison of Various Configurations Integrating Desalination with Renewable Power," Resources, vol. 4, no. 2, pp. 227–276, Apr. 2015, doi: 10.3390/resources4020227.

[44] R. Schaeffer , A.S. Szklo, A.F.P. de Lucena, B.S.M.C. Borba, L.P.P. Nogueira, F.P. Fleming, "Energy sector vulnerability to climate change: A review," Energy, vol. 38, pp. 1–12, 2012, doi: 10.1016/j.energy.2011.11.056.

[45] Vidal. John, "China and India' water grab' dams put ecology of Himalayas in danger," Obs., 2013.

[46] A. Wong, Kaufui V.; Paddon, Andrew; Jimenez, "Review of World Urban Heat Islands: Many Linked to Increased Mortality," ASME J. Energy Resour. Technol., vol. 135, pp. 022101-1-022101–11, June 2013.

[47] K. V. Wong, "The Second Law of Thermodynamics and Heat release to the Global Environment by Human Activities," in ASME Proceedings IMECE, 2010.

[48] Tyler A. DeNooyer a, Joshua M. Peschel a, Zhenxing Zhang b, and Ashlynn S. Stillwell, "Integrating water resources and power generation: The energy-water nexus in Illinois," Appl. Energy, vol. 162, pp. 363–371, 2016.

[49] X. Li, K. Feng, Y. L. Siu, and K. Hubacek, "Energy-water nexus of wind power in China: The balancing act between CO_2 emissions and water consumption," Energy Policy, no. 45, pp. 440–448, 2012, doi: 10.1016/j.enpol.2012.02.054.

[50] L. B. Ioanna Mouratiadou, Anne Biewald, Michaja Pehl, Markus Bonsch and E. K. David Klein, Alexander Popp, Gunnar Luderer, "The impact of climate change mitigation on water demand for energy and food: An integrated analysis based on the Shared Socioeconomic Pathways," Environ. Sci. Policy, vol. 64, pp. 48–58, 2016.

[51] K. Hussey and J. Pittock, "Guest Editorial, part of a Special Feature on The Energy-Water Nexus the Energy-Water Nexus : Managing the Links between Energy and Water for a Sustainable Future," Ecol. Soc., vol. 17, no. 1, 2012.

[52] A. Santhosh, A. M. Farid, and K. Youcef-Toumi, "Real-time economic dispatch for the supply side of the energy-water nexus," Appl. Energy, vol. 122, pp. 42–52, 2014, doi: 10.1016/j.apenergy.2014.01.062.

[53] W. N. Lubega and A. M. Farid, "Quantitative engineering systems modeling and analysis of the energyâ€ "water nexus," Appl. Energy, vol. 135, pp. 142–157, 2014, doi: 10.1016/j.apenergy.2014.07.101.

[54] M. Falkenmark and D. Molden, "Wake Up to Realities of River Basin Closure," Int. J. Water Resour. Dev., vol. 24, no. 2, pp. 201–215, 2008, doi: 10.1080/07900620701723570.

[55] World Bank, “Crude Oil (petroleum) - Monthly Price - Commodity Prices - Price Charts, Data, and News - IndexMundi.” Available: http://www.indexmundi.com/commodities/?commodity=crude-oil&months=120. [Accessed: 17-Nov-2019].

[56] FAO, "FAO Food Price Index | FAO | Food and Agriculture Organization of the United Nations." Available: http://www.fao.org/worldfoodsituation/foodpricesindex/en/. [Accessed: 17-Nov-2019].

[57] S. Clayton et al., "Psychological research and global climate change," Nat. Clim. Chang., vol. 5, pp. 640–646, 2015, doi: 10.1038/NCLIMATE2622.

[58] The data Team, “Global population forecasts,” The Economist, 2016. Available: http://www.economist.com/blogs/graphicdetail/2015/08/daily-chart-growth-areas. [Accessed: 30-Nov-2019].

[59] FAO, "Food Outlook: Global Market Analysis," Roma, 2008.

[60] A. D. Cue�llar and M. E. Webber, "Wasted Food, Wasted Energy: The Embedded Energy in Food Waste in the United States," Environ. Sci. Technol., vol. 44, no. 16, pp. 6464–6469, Aug. 2010, doi: 10.1021/es100310d.

[61] R. Gifford and Robert, "The dragons of inaction: Psychological barriers that limit climate change mitigation and adaptation." Am. Psychol., vol. 66, no. 4, pp. 290–302, 2011, doi: 10.1037/a0023566.

[62] Bjørn P. Kaltenborn, Olve Krange, and Torvald Tangeland, "Cultural resources and public trust shape attitudes toward climate change and preferred futures—A case study among the Norwegian public," Futures, vol. 89, pp. 1–13, 2017.

[63] G. Gauchat, "The cultural authority of science: Public trust and acceptance of organized science," Public Underst. Sci., vol. 20, no. 6, pp. 751–770, Nov. 2011, doi: 10.1177/0963662510365246.

[64] F. Bosello, R. Roson, and R. S. J. Tol, "Economy-wide estimates of the implications of climate change: Human health," Ecol. Econ., vol. 58, pp. 579–591, 2006, doi: 10.1016/j.ecolecon.2005.07.032.

[65] J.-C. Ciscar A. Iglesias, L. Feyen, L. Szabó, D. Van Regemorter, B. Amelung, R. Nicholls, P. Watkiss, O.B. Christensen, R. Dankers, L. Garrote, C.M. Goodess, A. Hunt, A. Moreno, J. Richards, A. Soria, "Physical and economic consequences of climate change in Europe.," Proc. Natl. Acad. Sci. U. S. A., vol. 108, no. 7, pp. 2678–83, Feb. 2011, doi: 10.1073/pnas.1011612108.

[66] REN21, "RENEWABLES 2015 GLOBAL STATUS REPORT," Paris, 2015.

[67] IPPC, "Climate Change 2007, the Physical Science Basis," 2007.

[68] T. L. Friedman, Hot, Flat, and Crowded: Why We Need a Green Revolution--and How It Can Renew America. London: Penguin, 2009.

[69] R. S. J. Tol, "The Economic Effects of Climate Change," J. Econ. Perspect., vol. 23, no. Spring, pp. 29–51, 2009.

[70] M. Yohe, G; Schlesinger, "The economic geography of the impacts of climate change," J. Econ. Geogr., vol. 2, no. 3, pp. 311–341, 2002.

[71] M. G. Martin, P.H.; Lefebvre, “Malaria and climate: sensitivity of malaria potential transmission to climate,” Ambio, vol. 24, pp. 200–207, 1995.

[72] Y. Matsuoka, T. Morita, and M. Kainuma, "Integrated Assessment Model of Climate Change: The AIM Approach," in Present and Future of Modeling Global Environmental Change: Toward Integrated Modeling, T. Matsuno; H. Kida, Ed. TERRAPUB, 1994, pp. 339–361.

[73] T. Wheeler and J. von Braun, "Climate Change Impacts on Global Food Security," Science, vol. 341, no. 6145, pp. 508–513, 2013.

[74] D. J. Arent, A. Wise, and R. Gelman, "The status and prospects of renewable energy for combating global warming," Energy Econ., vol. 33, pp. 584–593, 2011, doi: 10.1016/j.eneco.2010.11.003.

[75] D. White, J. Jones, R. Maciejewski, R. Aggarwal, and G. Mascaro, "Stakeholder Analysis for the Food-Energy-Water Nexus in Phoenix, Arizona: Implications for Nexus Governance," Sustainability, vol. 9, no. 12, p. 2204, Nov. 2017, doi: 10.3390/su9122204.

[76] N. Pidgeon and B. Fischhoff, "The role of social and decision sciences in communicating uncertain climate risks," Nat. Publ. Gr., vol. 1, pp. 35–41, 2011, doi: 10.1038/NCLIMATE1080.

[77] L. C. Hamilton, "Education, politics and opinions about climate change evidence for interaction effects," Clim. Change, vol. 104, no. 104, pp. 231–242, 2011, doi: 10.1007/s10584-010-9957-8.

[78] E. Hestness, R. C. McDonald, W. Breslyn, J. R. McGinnis, and C. Mouza, "Science Teacher Professional Development in Climate Change Education Informed by the Next Generation Science Standards," J. Geosci. Educ., vol. 62, no. 3, pp. 319–329, Aug. 2014, doi: 10.5408/13-049.1.