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Abstract

Human activities, in particular those related to water, energy and food security, involve inherently complex interactions between natural and human-created systems. Therefore, proper identification and management of vulnerabilities associated to systemic risk in such systems is vital to optimize water, energy, and food supply. This research study characterizes the current status of those systems in Norway through the water-energy-food nexus approach, identifying the main stakeholders that influence the interactions between the systems and the vulnerabilities within the Norwegian water-energy-food nexus associated to system risk through the use of the MACTOR method.

Key Words: Systemic Risk, Complex Systems, Water-Energy-Food Nexus in Norway, MACTOR Method

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Chapter 1: Introduction to the Study

1.1. Background and Research Motivation

Water, energy, and food security depend on the robust functioning of complex multi-agent water, energy, and food supply systems. Vulnerabilities related to systemic risk associated with such systems depend on the efficient interactions of the different actors. For instance, a disruption in the supply of electric power may destabilize supplies of food and water. Threats and vulnerabilities resulting from systemic risk towards water, energy and food security cannot be characterized by a single criterion. Inherent uncertainties of the interactions among the actors with a lack of observations and analysis that take into account the complex interactions among systems restrict exact risk assessments (Centeno, et.al., 2015).

In the context of complex systems, the main objective is identifying the vulnerabilities of the interactions and optimize resilience in order to design of robust systemic risk analysis. Although exact evaluations are impossible to perform, identifying the degree of responsibility or influence of the actors/stakeholders involved provides a stable basis for relative ranking of them in order to find solutions robust with respect to all potential scenarios of uncertainties.

This research study was prompted by the motivation of analyzing the water energy-food nexus of a country like Norway, which scores high in international human development indexes, with the objective of finding out the strengths and weaknesses of its water, energy, and food security dynamics.

1.2. Conceptual Underpinnings of the Study

1.2.1. Systemic Risk

Systemic risk is the probability of an event to trigger severe instability or collapse in an entire system. Systematic risk is the part of the total risk caused by factors beyond the control of a specific factor or stakeholder. Systemic risk is a category of risk that describes threats to a system. Systems with interconnected institutions and interdependent operation are most susceptible to systemic risk. In such systems, a failure at one entity or a small group of entities could have a cascading effect that might disrupt the entire system (Cole, 2014).

1.2.2. Water-Energy-Food Nexus (WEFN)

The water-energy-food nexus is a concept, approach, and framework formulated by the Food and Agriculture Organization (FAO). The nexus places emphasis on the importance on analyzing the interrelations of water, energy, and water security, instead of treating them as isolated issues (FAO, 2020).

1.2.3. Water Security

Water security is humanity's ability to protect sustainable access to water for the sustainability of livelihoods, well-being, and socio-economic development. At the same time, it undertakes actions to protect the ecosystems that provide water resources for millions of people in the main cities of the region (Lankford, et.al., 2013).

1.2.4. Energy Security

Energy security is the ability to avoid the adverse impact of power outages caused by natural, accidental, or intentional events that affect utility and power supply and distribution systems. Energy security is the ability of an economy to guarantee the availability of energy in a sustainable and timely manner, with prices that do not negatively affect economic performance. The concept of energy security is synthesized in four words: availability, accessibility, affordability, and acceptability. These are the four criteria of energy security, which mean availability and access to environmentally acceptable energy sources and at an affordable price, in other words, that the resource exists, that it is available in the market, that it is economical, that it does not contaminate excessively and that its use is compatible with the aspirations of sustainable development (Yergin, D, 2006).

1.2.5. Food Security

Food security involves applying strategies to ensure that food is safe for consumption. In other words, food safety is concerned with food not posing a risk to people's health and that it is nutritious. Food security is based on four essential pillars: physical availability: food must be available to everyone, that is, aspects such as production and the number of stocks must be taken care of. Access: food must also be accessible from an economic point of view for all people (Berry, et.al., 2015).

Stability: food security must be stable and not occur only during a certain period of time. All these aspects are influenced by factors such as the weather, natural disasters, conflicts, and wars. In developing countries, the main problems related to food security have to do with access to safe water, diets with low essential nutrients and food shortages. However, in developed countries, food safety problems are related to deficiencies in production, handling, or preservation (Berry, et.al., 2015).

1.3. Contextualization of the Problem

In the current global society, there are 748 million people without basic access to water, 805 million who suffer from chronic hunger and 1.3 billion without accessto electricity (Bhavani & Gopinath, 2020). The most immediate conclusion seems obvious: continuing with the current global dynamics of water, energy and food governance is not the most appropriate path to face these challenges. In this context, the relationships between vital resources such as water, food and energy take on special relevance.

It is thus necessary to focus research endeavors into the water-energy-food interlinkages through a comprehensive approach that pays attention to the complex interactions between human activity, resources availability and supply processes.

The efficient governance of water, energy and food is crucial for strengtheningtheir systemic interconnections and reduce their vulnerabilities to guarantee their security. Access and good functioning of water, energy and food supply systems are interconnected. Therefore, integrating a characterization of systemic risk within the context of the water-energy-food interlinkages is of utmost importance (Kurian, et.al. 2018).

Norway is characterized by its low degree of landscape fragmentation. The Norwegian terrain is separated by steep mountains and deep fjords, and in a surface area of 385,207 km², the country only hosts 5,4 million people (Eurostats, 2020).

The country faces several challenges in providing and maintaining a good infrastructure for the provision of services related to energy, water, and food. Several challenges have arisen in the water-energy-food nexus in Norway in the last decades. For instance, Norway's natural resources have been adversely affected by rapid socio-economic development and urbanization (Vennesland, 2005). Biodiversity, water, and soil quality have all been negatively affected by the establishment of large hydropower installations across the country and by switching from traditional agricultural practices to intensive agriculture relying on heavy use of fertilizers and pesticides. Moreover, the Norwegian aquaculture industry, primarily fish farming, is characterized by operations that are susceptible to changing weather, wind, and currents. At the same time, it faces challenges in safety for fish, personnel, environment, and material assets (Nygård & Storstad, 1998).

Based on the context described previously, characterizing the Norwegian Water-Energy-Food nexus, and investigating how resilience can be improved by modeling and managing systemic risks that threaten it, can contributeto the discussion and academic research on systems optimization of water, energy, and food access in Norway.

1.4. Research Objectives and Contribution

The main purpose and contribution of this research is structured upon three general objectives:

- Characterizing the water-energy-food nexus in Norway
- Identifying the nature of the main systemic risks that threaten the nexus in Norway and;
- Descriptively systematize the strategies that can be used to model systemic within the water-energy-food nexus in Norway and how it can be managed by improving resilience of the system

The descriptive systematization takes into consideration the societal and ecosystem factors of the interdependencies of water, food, and energy sectors and ecosystems by ensuring security within these complex supply networks.

Under a nexus approach, the complex interrelationships, interdependencies and conflicts between water, energy and food, and their various actors and sectors are recognized, which force decisions and negotiations between multiple objectives and interests. By recognizing these dynamics and promoting a systemic view, such an approach can help improve our understanding and provide key inputs to inform decision-making in the policy design and implementation processes, and to identify viable options that help promote coherent management. and the efficient use of natural resources (Rasul & Sharma, 2016).

This research study presents the following contributions to academic research in the field of system complexity and risk science:

- An application of two different methodologies to a real-life case: the water-energy-food nexus methodology and the MACTOR (Matrix of Alliance, Conflicts, Tactics, Objectives, and Recommendations) methodology. Both methodologies were applied in the context of the Norwegian water-energy-food nexus.

- A characterization of the current status of water, energy, and food security in Norway, with updated data using the conventional approach in the water-energy-food nexus methodology to quantify the Norwegian nexus.

- A comprehensive literature review that covers at a technical and theoretical level the relevant concepts that are necessary for understanding the complexity and interdependency that characterizes the Norwegian water-energy-food nexus.

- . A risk-based review of the water-energy-food nexus in Norway, placing emphasis in systemic risk and its associated vulnerabilities that threaten the water, energy, and food security in the country.

Chapter 2

Review of Related Literature

Analyzing and characterizing a water-energy-food nexus requires a theoretical background to understand the individual characteristics of the three systems that make part of the nexus. This chapter seeks to navigate the technical and theoretical basis that will be instrumental in understanding the structures and interactions that make the water-energy-food nexus a complex system. Likewise, this chapter will review the most relevant concepts of the research: from human activity and complex systems to systemic risk under the context of complex systems. For that purpose, the chapter is organized as follows:

The first section conceptualizes human activity, socioecological systems and complex systems to give a comprehensive basis for the next three sub-sections of the chapter, which explain how the water, energy and food supply and distribution systems are structured alongside the processes that each system performs, explaining the complex system that results from the interlinkages and interactions that take place between the water, energy, and food supply and distribution systems. The next section is dedicated to the matter of systemic risk. Lastly, the literature review covers relevant topics such as assessing and managing systemic risk as well as the topics of uncertainty within complex systems.

2.1. Human Activity and Complexity: On How Socioecological Systems are Complex Systems

Human activity is defined by Aggarwal & Ryoo (2011) as the specific way in which mankind exists and interacts with the elements and processes of the natural environment that surrounds them, adapting such environment to their subsistence and to build their own system of social relations in which they develop their lives.

All human activities provoke multiple transformations on the natural environment, and such activities are classified into three categories: primary sector, which involves the extraction and production of raw materials, the secondary sector, which concerns the processing of the raw materials that have been extracted from the natural environment and the tertiary sector regards the last stages of distribution and transportation to satisfy consumer needs (Polanyi, 1992).

Some of the tasks that fall within the realm of human activity according to the Office of the Audit General of Canada (2020) are:

- *‘’**Energy:** development, distribution, processing, and/or consumption and use (i.e. oil, gas, nuclear)*
- ***Natural resources:** development, management, and/or harvesting, use (i.e. fisheries, aquaculture, forestry, hunting/trapping, mining)*
- ***Agriculture/Food Production:** Land cultivation, animal husbandry, food processing (i.e. water handling, treatment, and disposal)*
- ***Physical Infrastructure:** creation or use of infrastructure, such as roads, housing, facilities, railways, sewage, or waterworks*
- ***Transportation:** road, marine, rail or air transportation, and all related activities and infrastructure*
- ***Toxic/Hazardous Substances and Materials:** generation/manufacture, use, management, regulation, transportation, or disposal (i.e. toxics and pesticides)*
- ***New Substances and Organisms:** development, deployment*
- ***Industrial Activity:** resource processing and manufacturing*
- ***Urban Development***
- ***Military Activities:** training, equipment, materials, natural disasters, and other emergencies. (i.e. preparation and response)*
- ***Waste Generation and Management***
- ***Transportation of Good and Services:** local, regional, national, international*
- ***International Trade:** Export and Import*
- ***Occupational/Workplace Hazards***
- ***Cleanup/Rehabilitation of Contaminated Sites***
- ***Procurement and Consumption of Goods**’’ (*Audit General of Canada, 2020)

By looking at the vast realm of human activity, it is noticeable that several tasks are too large or too complex for a sole supply system to handle by itself. Human activity, in general, has several implications — specifically when seeking optimal human life maintenance functionality (Mason, 1992). Different activities within one system that concerns human activity require input from multiple other subsystems at different levels. Individual specialized systems need to interact with other systems since no single system can solve a broad issue independently (Perrings, 2005). Therefore, the interrelationships resulting from these interactions lead to the virtual creation of a system made up of individual specialized subsystems; this resulting system is commonly known as a complex system (Sterman, 1994).

Although human actions have always transformed the natural environment, a characteristic of our time is that these transformations have reached planetary scales. For this reason, some scientists have compared this millennium with a new geological era: the Anthropocene (Zalasiewicz, et.al., 2010). A key aspect in this phase is the increase in interdependence between the human system and the ecological system, which is why there is an increasing discussion regarding the processes of co-evolution and the mutual evolutionary adaptation of human and ecological systems (Dalby, 2019). The coupling of human and ecological systems is known as: socioecological system (Cioffi-Revilla, 2016).

2.1.1. Socioecological Systems and Social Metabolism

The old view that considered the natural world and the social world as separated entities can be considered outdated. A new paradigm that emphasizes that human societies, economies, and cultures are constitutive parts of the biosphere and transform it both locally and globally is more relevant within the current general perception (Young, et.al., 2006).

A central aspect of these interactions involves ecosystem services, that is, the benefits that society obtains from ecosystems and that constitute the basis of their development and sustainability (Daily, 2003). In this context, a socio-ecological system is a complex structure that involves the social subsystem and the ecological subsystem. Coupled natural and human systems are integrated and complex systems in which nature and humans interact (Daily, 1997). For Folke, et.al., (1998) the concept of socioecological systems integrates humans in nature, however, they recognize that there is no single, universally accepted way to define the interlinkages between social and ecological systems and that the delineation between them is arbitrary and artificial.

Using the theoretical foundations of Folke, et.al., (1998), it is established that the concept of socio-ecological systems embodies the decision-making processes about ecosystems and the implications on their composition, structure, and functioning. Socio-ecological systems are based on the perspective of the 'human being in nature', where it is considered that human societies are embedded in the limits imposed by the ecosphere and have co-evolved with the dynamics of ecological systems.

Ecosystems and social systems are variable in time and space, which partly explains their complexity. Consequently, socioecological systems have the ability to provide natural resources conditioned by scales of spatial and temporal variability. The dynamic where socially grouped human beings extract materials and energy from nature for their consumption is called social metabolism (Holling, 2001).

Social metabolism is defined as the pattern followed by the uptake of energy and material flows carried out by the socio-ecological system through its interactions with the environment, as well as its dispersion through its components and relations with the outside. In general, each socio-ecological system presents a specific metabolic profile that can be associated with a type of metabolic regime that is characterized by manifesting a pattern in the society-nature relationship based on the predominance of a certain type of exchange of energy and materials (Martinez-Alier & Walter, 2016).

Three metabolic regimes have been identified in human history: hunter-gatherer, agrarian, and industrial. In the first regime, the social groups present a very low energy consumption. The Neolithic revolution that happened 10,000 years ago and gradually gave rise to the appearance of the second model, the agrarian regime, which is characterized by the control of energy flows of solar origin by society to transform them into biomass as the main energy source, reaching 95% of the primary energy (de Molina & Toledo, 2014)

The third regime arises with the industrial revolution and manifests a primary energy demand that is eminently of fossil origin, which was abundant and with a great capacity to produce goods. This explains all the material and technological development that characterizes the lifestyle of modern societies. The process of transition from one model to another has not been homogeneous in time and territory, both globally and locally, as there are currently industrialized countries that follow the pattern of industrial production and consumption with other areas of the world in which the agricultural model is still the primary regime (Fischer-Kowalski & Haberl, 2007).

2.1.2. Complex Systems

Complex systems are sets of non-homogeneous elements or subsystems that work together as an interconnected network towards a common end, they are sensitive to both internal and external stimuli and function in the context of a specific scenario or environment. Complex systems are multifaceted, not only in terms of their size, but also because of the intrinsic, interactive nature of the elements that usually make part of them. System complexity is a multi-dimensional element and concept, since there are multiple ways in which it may manifest itself within a set of systems that concern human activity (Ottino, 2003).

A complex system consists of many diverse and autonomous components that are interdependent; they are selectively coupled by self-organization through numerous interconnections and they behave as a unified whole when learning from experience and adjust by adapting to changes in the environment (Bossomaier, & Green, 2000).

Complex systems are classified into three groups: artificial, this means, man-made complex systems, such as an electrical energy distribution network, food production chains, and technological information systems. Biological, such as a plant, an animal, a human being. Abstract, such as thinking systems, and organizational, such as political systems or families (Ottino, 2004). The complexity of a system is not only determined by the heterogeneity of the elements or subsystems that make part of it and which nature normally places them within the domain of various branches of science and technology. In addition to heterogeneity, the determining characteristic of a complex system is the interdefinability and mutual dependence of the functions that these elements fulfill within the total system. This characteristic excludes the possibility of obtaining an analysis of a complex system by simply adding sectoral studies corresponding to each of the elements. Results of various investigations show that socio-ecological systems constitute complex systems (Sheard & Mostashari, 2009).

In addition, a complex system is characterized by the following factors:

1. They have a large number of elements, and if that number is large enough, it is difficult for analytical modeling mechanisms to allow a prediction of their behavior (Kirshbaum, 2002).

2. Interactions within complex systems are not "one to one", but multiple. Each element influences and is influenced by many others. An essential precondition is that the interactions are non-linear. The duplication of a stimulus does not necessarily mean the duplication of the response. That is why small modifications in a part can sometimes trigger large changes in the system (Rivkin & Siggelkow, 2007).

3. Interactions are generally short ranged, that is, information is primarily received by immediate neighboring actors. This does not mean that, through linkages, the influences cannot be far-reaching. Thus, the influence is modulated along the way, and can be amplified, reduced, modified, or eliminated in various ways. Interactions between the parties have feedback. An activity receives effects on itself, through amplifications or inhibitions, and can occur directly or through indirect circuits. This is called a recurrence (Nicolis & Nicolis, 2012).

4. Complex systems are "open", that is, they interact with their environment. Organizations exist because their essential purpose is to add value to their users, and they operate within a regulatory, institutional or competition framework. It is impossible to understand a system of this nature without beginning by understanding its multiplicity of interactions with the environment. Instead, closed systems are merely "complicated." They operate in conditions far from equilibrium. Even if they are in a "steady" state, it is a dynamic stability, and they can change rapidly. Therefore, there is a constant flow of energy to maintain the organization and survival of the system. Total equilibrium, for lack of this flow of energy, is equivalent to death (Liu, et.al., 2013).

5. Complex systems evolve over time, and therefore have a history, that history strongly influences their present behavior. Any systemic analysis that ignores the time variable is therefore incomplete. Each element of the system is largely ignorant of the behavior of the system as a whole and responds primarily to stimuli from its close environment. If each element had all the information of the system, that would mean that all the complexity of the system would be condensed in each of its parts (Corning, 1995).

6. Complex systems exhibit irreversibility, which means that when certain boundaries (positive or negative) are transcended, turning back is very difficult. Likewise, different parts of the system can be grouped into local clusters, and one part of a system can simultaneously belong to several clusters (Li, et.al., 2004).

Complex systems are very diverse, they can vary to a large extent in terms of scale, proportion, nature, and context, where the complex system is physically or abstractly located. For instance, complex systems can range from control-dominated systems, such as those found in the large industries such as the aerospatial or automotive industries; data-intensive systems, such as transaction processing systems and decision support systems, to safety-critical systems such as nuclear reactor control systems or human activity systems, such as supply of water, energy and food systems. The latter systems are the main scope of study within this literature review.

2.1.3. Socioecological Systems as Complex Systems

Socio-ecological systems are complex adaptive and evolutionary systems, in which cultural, political, social, economic, ecological, technological, and other components interact. They are composed of different parts that interact to form a more complex entity, the vision is comprehensive because it does not focus on a detailed understanding of the parts, but on how the main components contribute to the dynamics of the whole system (Bonilla-Bedoya, et.al., 2018).

Parts of a socioecological system respond to changes in other components, sometimes triggering feedbacks that can amplify changes throughout the system or can have a stabilizing effect. Through these interactions, socio-ecological systems can be organized, new configurations can emerge, and adaptation is possible. This characteristic of integrated socio-ecological systems can make their management challenging, but it also creates opportunities for recovery or reorganization after a disturbance (Weible, et.al., 2010).

2.2 Social Metabolism: The Water-Energy-Food Nexus as a Complex System

The water, energy and food supply and distribution systems are the most essential socioecological systems for the sustainability and development of human and animal communities. The interrelation between water, energy, and food is undeniable. For instance, worldwide, the agriculture sector consumes 70% of fresh water, while food production consumes around 30% of the energy produced. Global energy production consumes around 15% of water available, which is necessary for the extraction of energy sources as well as for energy processing (Mielke, et.al., 2010).

The extraction, pumping, harvesting, and transportation of water also consume significant amounts of energy. Water is essential for agricultural production, and energy is required to produce, transport, and distribute food. Some projections indicate that the demand for water, energy, and food will increase significantly in the upcoming decades. 60% more food will have to be produced to feed the world population, which is estimated to reach close to 10 billion people by 2050. World energy consumption will increase by 50% by 2035. Water withdrawals will increase by a 10% by 2050. Therefore, the existence of structured water, energy, and food supply systems are crucial for human subsistence (Grafton, et.al., 2015).

In this context, the water-energy-food nexus (WEFN) has emerged as a comprehensive concept that seeks to describe and address the complex nature of the interrelationships between water, energy and food, on which modern societies depend to achieve different social, economic, and environmental goals to ensure a good quality of life. In practical terms, it presents a concept to better understand and analyze the interactions between the natural environment and human activities, and thus work towards a more coordinated management and use of natural resources at all sectors and scales (Pahl-Wostl, 2019).

The Water-Energy-Food Nexus is a useful concept to describe and address the complex and interrelated characteristics of our global resource systems, the analysis using a water-energy-food nexus approach can help decision makers and various stakeholders identifying and manage risks and create synergies through such interlinkages, allowing greater integration and cost-effectiveness of planning, decision-making, monitoring and evaluation of water, energy and food systems. Within the nexus, the interrelationships are complex and dynamic, and no sectoral issue can be examined independently of the others. An important observation is that they occur within the broader context of transformation processes - or drivers of change - that must be taken into account (Leck, et.al., 2015).

In order to understand the water-energy-food nexus, the individual structure of each of the water, energy, and food systems will be described at a technical level. Then, an explanation of the interactions, interdependencies and interrelationships among such independent systems will follow to describe how individual systems of water, energy and food supply and distribution become a complex system through such interactions. In this context, it is fair to state that the water-energy-food nexus is the real-life representation of socioecological systems, social metabolism, and complex systems. It integrates three socioecological systems (water, energy, food), concerns the processes of extraction, transformation and distribution of water, energy, and food (social metabolism) and studies the interrelationships among the water, energy, and food supply and distribution systems (complex system).

2.2.1 Drinking Water Supply and Distribution Systems

A water supply system is the engineered infrastructure that is instrumental in delivering water from sources to end-users. A water supply system makes it possible to collect, treat, storage, and distribute water to households, commercial establishments, industries, irrigation, and other vital activities (Wang, 2013).

The water supply system is the set of pipes working under pressure, which are installed in the communication routes of the urban area and from which different plots or buildings will be supplied. These systems can be classified by the source from which the water is taken: seawater, surface water (from lakes or rivers), stored rainwater, groundwater, and water from natural springs (Kuczera & Diment, 1988).

Taken individually, water supply systems are closely related lo lifeline systems that ensure security of the needs of human communities. Therefore, they are also important to emergency response and recovery after disastrous events such as earthquakes, as well as for activities that meet public needs such as street flushing and firefighting (Franchin, & Cavalieri, 2013).

2.2.1.1 Types of Water Supply and Distribution Systems.

There two main types of drinking water supply systems. Continuous water supply systems and intermittent water supply systems. Continuous water supply systems provide non-stop water supply. The installation of this kind of system is possible where adequate quantity of water is available. Continuous water supply systems need less maintenance due to the continuous flow of water; water remains fresh and rusting of pipes therefore remains low. However, losses of water will be more in case of any leakage (Civil Engineering Terms, 2012).

In intermittent water supply systems, water supply is either aimed to supply a whole village/town for fixed hours or supply of water in divided areas where each zone is supplied with water for fixed hours in a day or as per specified day. Such system is installed when there is low water availability, however, in certain cases, waste of water is higher due to the tendency of community for storing higher amounts of water than is it actually necessary. In such system, pipelines are likely to rust faster due to wetting and drying. (Ilaya-Ayza, et.al., 2018).

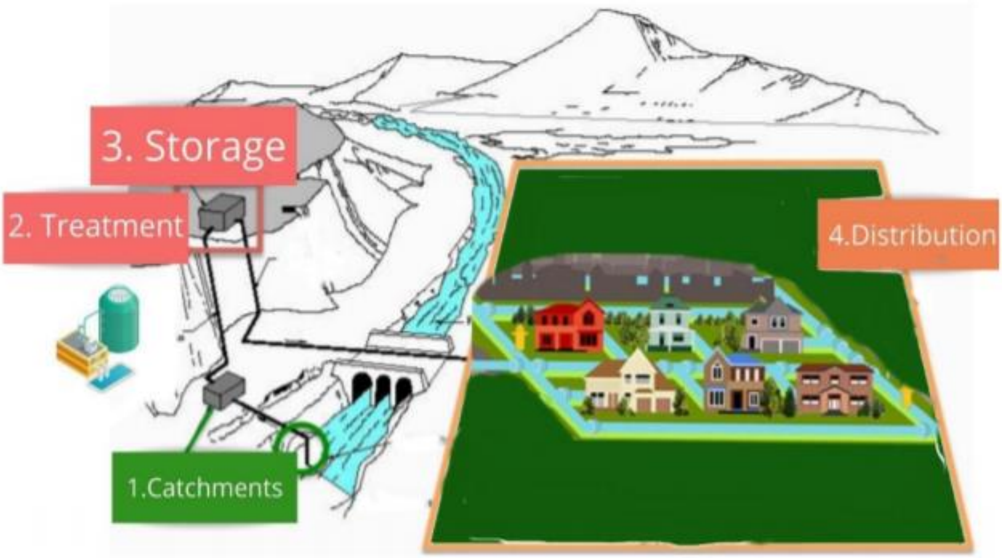


Figure 1. General Scheme of a Drinking Water Supply and Distribution System

2.2.1.2 Processes of Water Supply and Distribution.

The drinking water supply comprises a series of technical processes by which the water is led to the points of consumption to be used by humans. These processes are: collection/catchment, conduction, treatment, storage, and distribution (WHO/UNICEF Joint Water Supply, & Sanitation Monitoring Programme, 2014). Figure 1 represents the flow of processes that take place within a drinking water supply and distribution system.

Water Collection/Catchment: Conventional water supply systems use two different types of water sources in the catchment phase: surface water and groundwater. Surface water sources refer to visible sources, such as rivers, streams, lakes, lagoons. Rainwater is also categorized as a surface water source. Underground sources, on the other hand, refer to sources that are in the subsoil, and the water must be obtained through man-made structures such as wells and hand-pumps (Waseem, et.al., 2015).

The system is operated by pumping when the source is below the level where the end-users are, the various types of water catchments depend, to a large extent, on the characteristics of the source, as well as the required flow and the geological, hydrological, and topographic characteristics of the area (Li, et.al. 2017). As for the catchments in rivers and streams, a previous hydrological study must be carried out to measure the flows that guarantee an efficient use of the water, as well as a continuous and safe supply to the population (Dawes, et.al., 2004)

The same principle applies to lakes and reservoirs, in which the quantity and quality of water that is needed and available must be known, as well as the depth of the sources (Paniconi, 2015). Groundwater harvesting can be done through artesian wells, pumping wells or spring wells (Pyne, 2017). Artesian wells draw water from a captive aquifer, which is located between two impermeable layers and are usually wavy (Chamberlin, 1885).

Pumping wells, on the other hand, draw water from a natural aquifer. Natural aquifers draw infiltrated rainwater through the permeability of the terrain. These wells are characterized by the hydrostatic level below the ground which makes pumping necessary to get the groundwater out. Springs originate when the aquifer is cut by a valley. In pumping wells and springs, the increase in flow is facilitated by increasing the water outlet section, going deep enough below the water table to increase performance (Bayer-Raich, & Jarsjö, 2003).

Water Transportation: Water transportation is an important part of the functioning of the water supply system, it consists of conducting the water from the collection point to the treatment plant or the point of consumption. Water transportation can be performed through an open channel or pipe network, the structure that conducts the water is known as transportation line. A transportation line is the part of the system that transports the water from the catchment site either through pumping or by gravity pressure, to a water treatment plant. The transportation lines must be easily inspected, and this aspect should be taken into account when planning the water supply system (Coelho & Andrade-Campos, 2014)

Water Storage: This stage refers to the need to store water in a reserve when the source does not have a sufficient flow during the year to satisfy the population's demand. Once the water has been treated and made drinkable, it is transported to urban reservoirs connected to the supply network. Its objective is twofold: on one side, it seeks to ensure a continuous supply of drinking water under controlled parameters, and on the other hand, it aims to ensure the availability of water in the future, taking advantage of the moments in which there is a surplus that exceeds current supply needs (Boelter, 1964).

For this purpose, tanks are distributed at different strategic points from where the water supply is performed, either through pumping installations or gravity force, as they are located at high points on the ground. There is a wide variety of water storage methods: reservoir, water tank or water silo. A deposit can be dug to any required size. This means that it can store a large amount of water, and it is a relatively an inexpensive solution. Additionally, water tanks are compact and can be installed both indoors and outdoors (Housner, 1963).

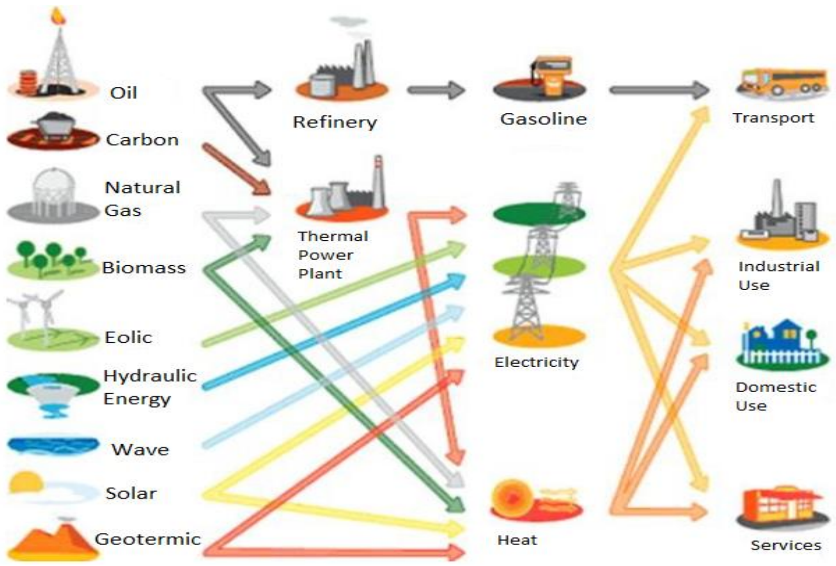
Water Treatment: After the processes of water collection, transportation and storage have been fulfilled, the collected "raw" water is suitably treated in order to eliminate potentially harmful substances for human consumption. The purpose of this process is to ensure that water has the appropriate characteristics for the intended use. For this reason, the water treatment process varies depending on the starting properties of the water and also on its end use. Water treatment is increasingly necessary due to the shortage of drinking water and the increasing demand of the world's population.

Processes such as sieving, solids decantation, filtration and disinfestation are some common ways of water treatment. Sometimes, storage is needed after water treatment; once the water is treated, it is stored in tanks that are usually made of reinforced concrete (Binnie, et.al.,2002:).

Water Distribution: Finally, the distribution process starts. From the storage tanks or facilities, the water is conducted to the points of consumption through a system of pressure pipes called distribution networks. The distribution network is made up of the public distribution network or external supply network and the private distribution network or private supply network (Mays, 2000).

2.2.2 Energy Supply and Distribution Systems

Energy supply and distribution systems are the sets of processes and infrastructure required to extract, convert, and distribute energy from the source to the end-user. Energy supply can come from a wide variety of sources. Primary energy sources are those that are available in nature without having been physically or chemically transformed for energy use, some of these are: solar, hydraulic, biomass, wind, oil, coal, among others. (Schrattenholzer, 1981). These sources of energy must be then transformed for humans to be able to make use of them. (Voropai, et.al., 2017). The current global energy supply is currently obtained in three main ways: (1) combustion of fossil fuels such as oil, natural gas, and coal; (2) nuclear fission; and (3) other non-fossil-fuel-based sources such as hydroelectric power and biomass (Breyer & Knies, 2009). Figure 2 represents the varied primary energy sources and their transformations into readily available energy sources for human use.



(Schock, et.al., 2012).

Figure 2. Primary Energy Sources and their Conversion into Readily Available Energy Sources for Human Use

Energy conversion implies the use of energy carriers, energy carriers are substances or phenomena that have the ability to operate chemical or physical processes to produce mechanical work or heat. There are several kinds of energy carriers in present energy systems, for example, gasoline, kerosene, electricity, city gas, LNG, and LPG. (Falk, et.al., 1983).

In the case of renewable energies, new storage systems have to be achieved and at the same time new energy carriers have to be obtained that allow the energy produced in the energy use systems to be carried to the different energy users and especially to transport (Krause, et.al., 2010).

Energy carriers are also known as energy media or secondary sources of energy. All primary energy sources through conversion to energy carriers and end-uses, show interrelationships and current technologies make large contributions in the processing of the energy sources. Figure 3 represents such interrelationships (Warren, 1983).

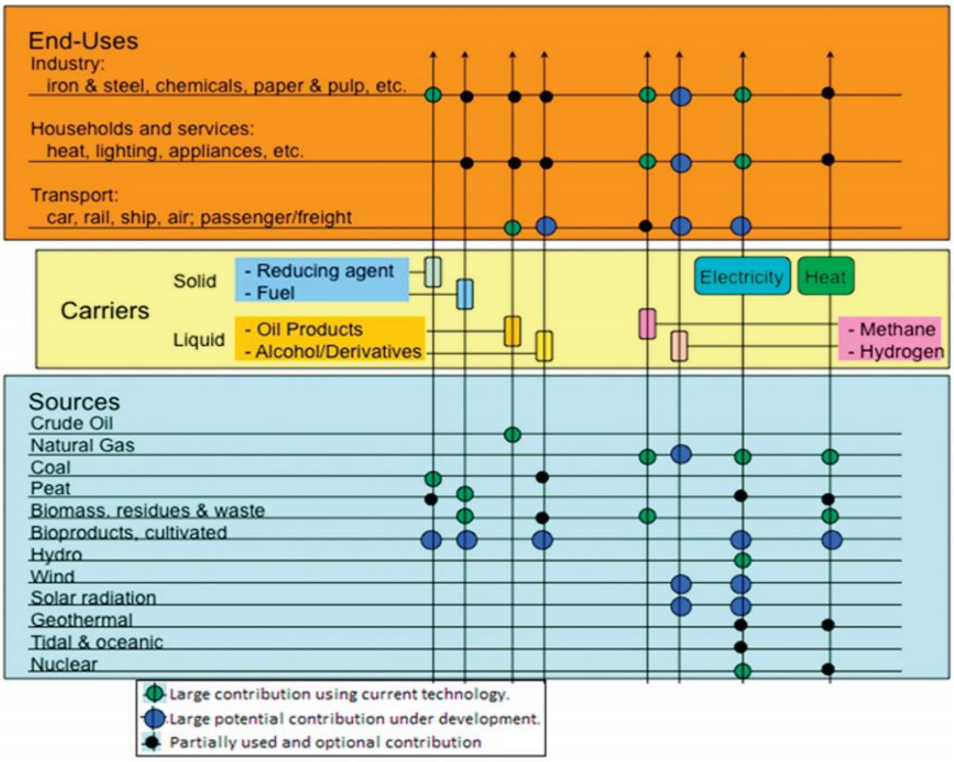


Figure 3. Interrelationships from Primary Energy Sources through Conversion to Energy carriers and End-Users

(Warren, 1983).

Energy conversion implies the use of energy carriers, energy carriers are substances or phenomena that have the ability to operate chemical or physical processes to produce mechanical work or heat. There are several kinds of energy carriers in present energy systems, for example, gasoline, kerosene, electricity, city gas, liquefied natural gas, and liquefied petroleum gas (Falk, et.al., 1983). The transition from primary energy to final energy ready for consumption, involves a series of different processes depending on the source of extraction and the end use, whose common objective is to transform the natural resource into suitable readily available energy sources for human use. There are many types of energy, and therefore, many types of energy supply and distribution systems (Geidl & Andersson, 2007).

For the purpose of this research, due to its relevance to water and food supply and distribution systems, the electrical power supply and distribution system is the one that will be further studied and described.

2.2.2.1 Electric Power Supply and Distribution Systems.

The electrical power supply system comprises the set of means and elements that are instrumental for the generation, transmission, and distribution of electrical energy. An electrical power distribution system is the set of equipment that allows a certain number of loads to be safely and reliably energized, at different voltage levels, generally located in different places. Depending on the characteristics of the loads, the volumes of energy involved, and the reliability and safety conditions with which they must operate (Das, 2007).

Electrical power supply systems require a centralized economic organization to plan the production and remuneration of the different market stakeholders. These systems are equipped with control, security, and protection mechanisms. It constitutes an integrated system that, in addition to having distributed control systems, is regulated by a centralized control system that guarantees a rational exploitation of generation resources and a quality of service in accordance with user demand. (Guerrero, et.al., 2008).

Electrical power systems can be industrial, commercial, urban, and rural. Industrial distribution systems include large consumers of electricity, who generally receive high voltage electricity supply. Large industries often generate part of its demand for electrical energy through steam, gas, or diesel processes. Commercial distribution systems are a collective term for existing power systems within large commercial and municipal complexes. Urban distribution systems supply the distribution of electrical energy to populations and urban centers with high consumption, but with a low density of loads. They are systems in which the proper selection of equipment and its correct sizing is very important. Rural distribution systems are responsible for supplying electricity to areas with lower load density, which requires special solutions in terms of equipment and network types. (Zhukovskiy, et.al., 2018).

Figure 4 represents the processes that generally are carried out within an electric power supply and distribution system:

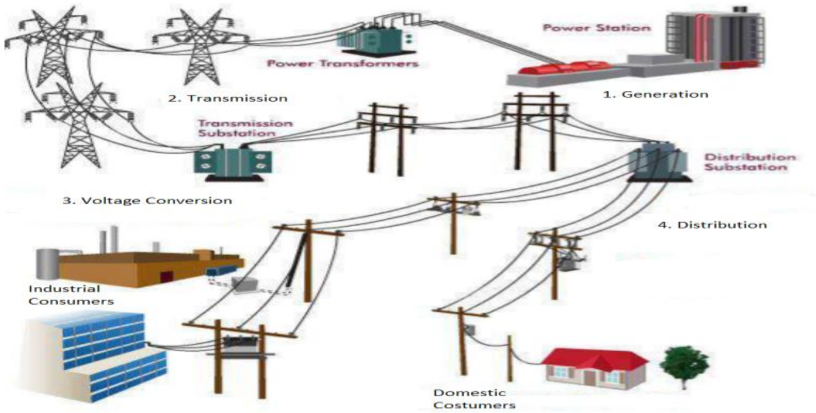


Figure 4. General Scheme of an Electrical Power Supply System

Electric Power Generation: In electric power supply systems, electric power is generated in power plants. A power plant is a facility that uses a primary energy source to turn a turbine, which, in turn, turns an alternator, thus generating electricity. In distributed electricity supply systems, electrical energy is produced (collected) both in power plants and in many of the consuming nodes themselves, which are capable of reverting their surplus energy to the grid to supply others. The fact that electricity, at an industrial level, cannot be stored and must be consumed at the time it is produced, makes it necessary to have production capacities with high powers to cope with consumption peaks with operating flexibility to adapt on demand (Grigsby, 2018)

Electric Power Transmission: The transportation network is responsible for linking the power plants with the points of use of electrical energy. For a rational use of electricity, it is necessary that the transmission lines are interconnected with each other with a mesh-like structure, so that they can transport electricity between very distant points, in any direction and with the lowest possible losses. This transport can be done with alternating current or direct current lines (Kaplan, 2009)

Voltage Conversion: After the transmission process, the electricity voltage is reduced from the transmission voltage to distribution voltage. This conversion process is performed through facilities that work as transformer plants, known as substations. Substations are located next to the generating plants on the periphery of the various consumption areas, linked together by the transmission network (Chang, 1995).

Electric Power Distribution: Electricity distribution is the final stage in supplying electricity to end-users. The network of a distribution system carries electricity from the high-voltage transmission network and delivers it to consumers. Typically, the network would include medium voltage power lines and transformer substations and low voltage distribution cabling (Short, 2014).

The modern power distribution process begins when the primary circuit leaves the substation and ends as the secondary service enters the customer's metering base through a service line. Distribution circuits serve many customers. The distribution circuits are supplied from a transformer located in an electrical substation, where the voltage is reduced from the high values used for power transmission (Brown, 2017). The voltage used is appropriate for the shortest distance and ranges from 2,300 to around 35,000 volts depending on standard practice of the utility, the distance, and the load to be supplied. Conductors for distribution may be made on pole overhead lines, or in densely populated areas, buried underground. Urban and suburban distribution is done with three-phase systems to serve all residential, commercial, and industrial areas. Distribution in rural areas can be only single-phased if it is not cost-effective to install three phased power installations for relatively few or small customers (Gonen, 2015)

In rural areas a pole mount transformer can serve a single customer, but in more urbanized areas it can serve multiple customers. In very dense urban areas, a secondary network can be formed with many power transformers on a common operating voltage. Each customer has a service line connection and a meter for billing. Some very small loads, such as gardening lights, may be too small for the meter and only charge a monthly fee (Rojas-Zerpa, et.al., 2014).

2.2.3. Food Supply and Distribution Systems

Food supply and distribution systems are complex combinations of activities, functionalities, and interrelationships among different actors that enable communities, cities, and whole countries to meet their food needs and requirements (Aragrande, 2001). The activities within the system are performed by many stakeholders, such as food producers, farmers, packagers, assemblers, importers, exporters, wholesalers, retailers, among many others, are involved in the manual and technical work processes of food production and distribution. However, public stakeholders such as government agencies, public food boards, ministries of agriculture and transport are vital to the system due to their power of governing decisions in infrastructure, policy, regulation, and guidelines that give a framework to the system, in order for it to work in a sustainable way (Landon, 1997).

As in any other type of system, all elements and actors that make part of the food supply and distribution systems influences the other elements due to their reciprocal relationships. Due to all the implications of food supply and distribution, the system gathers a large array of activities that are distributed in either 5 to 6 different phases, depending of the unique characteristics of the specific food supply and distribution system. Such phases are (Figure 5): production, imports/exports, processing, distribution, sales, and consumption. Food supply and distribution systems - from production to export/import, distribution, and end consumption - must ensure that enough nutritious food is available for everyone, whether they live in urban or rural areas. (Armendàriz, 2015).

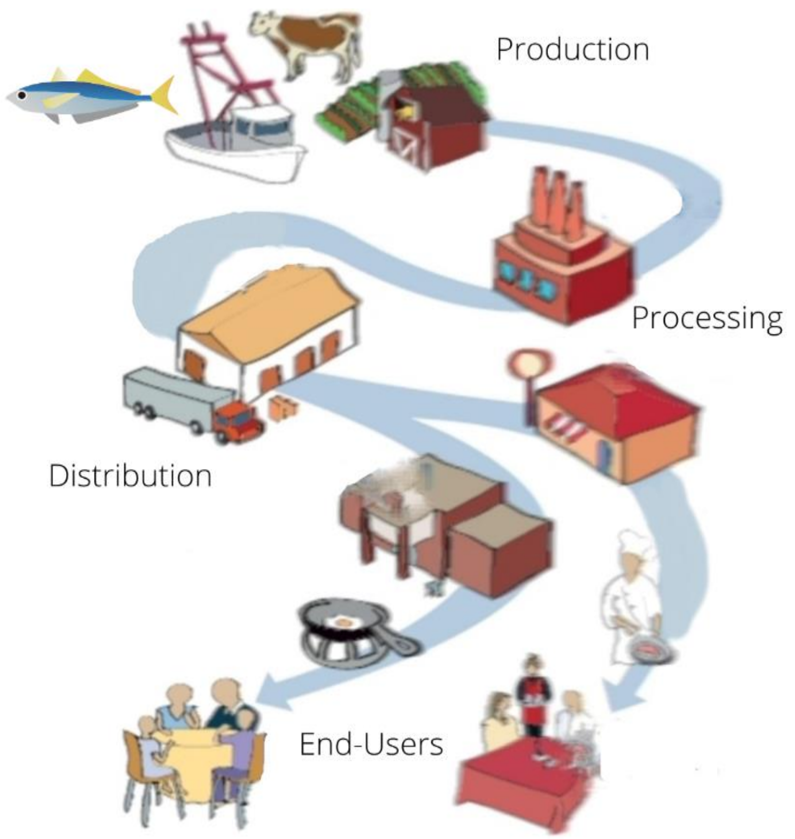


Figure 5. General Scheme of a Food Supply and Distribution System

Food Production: Food production is the first phase of the activities that take place within the food production and distribution systems. This phase involves all the activities to produce or extract edible goods from the sea, the soil, or animal sources (livestock and fishery). Food production based on animal sources consists on the management and exploitation of domesticated animals for production purposes. Depending on the livestock species, various derived products can be obtained for human consumption. Some of these goods are meat, milk, eggs, honey, and many others. The science in charge of studying livestock is zootechnics and professionals directly in charge of the development of animal production are farmers, assisted by zootechnicians and animal production engineers, in close collaboration with veterinarians who are in charge of the prevention and control of animal diseases. Livestock is related to agriculture since both activities can be performed simultaneously in a farm. In these cases, livestock provides dung, which is used as compost or fertilizer, and crops provide food for the animals (Pimentel, et.al.,1973: Considine, 2012).

As of edible goods that come from the soil, such as fruits, cereals, and vegetables, the process consists on sowing, maintaining, and harvesting. Vegetal food production concerns all the set of economic and technical activities related to the treatment of the soil and the cultivation of the land for the production of food. It comprises a whole set of human actions that transforms the natural environment in order to supply human and animal communities with the necessary food they need. These activities make up the agricultural sector. All the economic activities that this sector covers are based on the exploitation of the resources that the soil produces aided by human action (Hatfield, 2014).

On the other hand, when referring to edible goods that are extracted from the sea or freshwater bodies, the stages of production consist on fishing, cleaning, and conserving. It must be taken into account that the environment in which the goods where obtained from must be safe. In the case of seafood and other goods that come from the sea, for example, they must be extracted from waters not contaminated by any factor (Royce, 2013)

Food Processing: Food processing concerns the activities to treat and transform raw materials after they have been extracted or produced from the natural environment. At first, it is necessary for such edible goods to be stored in optimal facilities and with all the necessary requirements to avoid contamination. Moreover, throughout food processing, edible goods are subjected to modifications with the objective of improving its condition from its natural state so that they become safer for human consumption (Brennan, et.al. 2006).

Over time, the demand for food has increased and the dedicated systems to process food have had the need to involve several scientific disciplines in the process, such as: toxicology, chemistry, microbiology, engineering, physics and biology are just some of the areas that have been combined to design and implement the necessary technologies that give food the required and efficient treatment. The purpose of food processing is to make food available to the consuming public the variety and quantity of food requested; this, regardless of the time of year and the availability of certain products in certain seasons (Fellows, 2009).

As a general rule, the processed foods are usually subjected to a subsequent process, either for immediate consumption or for later preservation. The mission is to stop the microbial activity that deteriorates the food and does not allow its consumption. The process is a task that is carried out at source in the food industry, and that is prior to its commercialization. The freezing process is one of the most used for the conservation of meats, although it can also be used for fruits and vegetables in order to avoid the bacterial process. As a reference there are many methods of food preservation, for example: curing meats with common salt, refrigeration, slow or fast freezing or fermentation (Hui, et.al., 2008).

Food Imports and Exports: After food processing, the processes of imports and exports might take place. Food imports are the set of edible goods that are purchased from the rest of the world by a country's residents, rather than buying domestically produced items. The reason for imports might be a lack of certain foods in the country or demand for better quality edible goods. Food exports, on the other hand, are goods and services that are produced domestically, but then sold to customers residing in other countries (Wagstaff, 1982).

In 2013, food products accounted for more than 80% of total agricultural imports and exports, forming the third group in order of value among the commodities in international trade, after fuels and chemical and pharmaceutical products. Several countries, including many developing countries, import a significant proportion of their food supplies, while some countries depend almost entirely on food imports to ensure food security. By organizing food import systems, countries establish inspection measures in order to protect the health of their populations and guarantee fair practices in trade (Athukorala, 1998).

The importance of food imports and exports lies mainly in foreign exchange to the country and access to edible products that the country's economy does not produce. Exports are important because they constitute a source of income in addition the profit that providing for the domestic demand represents. (Hertel, & Keeney, 2006).

Food Distribution: Food distribution is the set of intermediation activities between the agricultural sector or the food industry and the final consumer. Food distribution includes food distribution channels: there are distribution channels for domestic consumption and distribution channels for commercial consumption (Oates, 2008).

Domestic distribution channels are the places where consumers buy food. Two main types of channels can distinguish them: conventional channels and short marketing channels. In conventional channels, the food passes through different intermediaries before reaching the store where the consumer purchases it, while in short channels the producer sells it directly to the consumer or does so using a single intermediary. Most of the food is traded through conventional channels. (Neves, et.al., 2001)

One of the most common retail establishments are traditional stores, supermarkets, and hyper-markets, which are characterized by having a counter to serve the public and self-service with 1 or 2 checkout boxes. An establishment is considered a supermarket, if it has more than 3 checkout boxes and at least 2,500 m2 of sales area. These establishments are usually located in the neighborhoods. An establishment is considered a hypermarket if it has more than 2,500 m2 of surface. Due to their greater size, they are usually located within a shopping center on the outskirts of the urban area. Hyper and supermarkets are usually owned by large companies or distribution groups. Consumers generally prefer the traditional store or farmers markets to buy fresh food (Cadilhon, et.al., 2003).

2.2.3.1 The Role and Importance of Logistics within a Food Supply and Distribution System.

Logistics concerns, specifically, the planning, execution, and control of the flow of goods in an efficient and effective way, both in relation to transport and storage, with information to meet customer requirements (Hou & Xu, 1990).

In this sense, logistics is an integral part of supply chain management, dealing with activities such as: the management of the transport of goods in incoming and outgoing condition, the management of fleets of vehicles that meet the requirements to transport the products, the management of materials and tools for handling products, the management of storage in adequate conditions, inventory management, controlling the storage and distribution of goods, the management and preparation of orders, including secondary packaging and assembly, planning and customer service in the next phase of the supply chain (Murphy & Knemeyer, 2018).

Logistics in the food sector plays a vitally important integrating role that concentrates transport, storage and distribution, functions that allow coordination and optimization of other activities. In the case of food, whether it is it non-perishable or non-perishable, the logistics operator has to guarantee safety in two main aspects: temperature control and avoiding cross contamination (Manzini & Accorsi, 2013).

2.2.4. The Water, Energy and Food Supply and Distribution Systems: On How They Interact as a Complex System

2.2.4.1 Interdependencies of Water and Energy Supply Systems.

The water and energy supply and distribution systems are closely linked and highly interdependent. Decisions made in one sector have direct and indirect consequences for the other (Scott, et.al., 2011). The amount of water required for production depends on the form of energy to be produced. At the same time, the availability and location of freshwater resources determine the amount of water that can be allocated to produce energy. Moreover, the amount of energy required to carry out the operations necessary to serve it to the final consumer is highly dependent on local conditions and the quality of the water (Gleick, 1994).

The energy-use component of each stage of the water supply and distribution cycle is not complementary but appears in most of the technical studies that concern water supply systems.

For example, many studies have collected the average energy consumption data linked to the stages of the water cycle: supply and transport, treatment, distribution, and collection plus wastewater treatment (Hussey & Pittock, 2012). Authors such as Bonton, et.al., (2012) clearly point out that it is the water and wastewater treatment stage the one that requires the most energy and where scientific research should be focused.

Energy generation depends on water, mainly for the cooling of thermoelectric plants, as well as for the production, transport, and processing of fossil fuels. In addition, more and more water has been used to irrigate crops that are then used to obtain bioenergy and biofuels. Likewise, as a counterpart, energy is vital for the functioning of the systems that collect, transport, distribute and treat the water, guaranteeing the supply for its various uses (Pan, 2018). Both energy and water are resources that face increasing demands and restrictions in many regions as a result of population growth, socio-economic development, and climate change. Therefore, their interdependence tends to amplify their mutual vulnerability (Ghenai, 2014). For the energy sector, water-related restrictions can undermine the reliability of existing plant operations, as well as the physical, economic, and environmental viability of future projects. In the same way, the use of water for electricity production can affect freshwater resources, both in quantity and quality, influencing the capacity to provide drinking water and sanitation services to the population (Fricko, et.al., 2016).

Complex interdependencies between the water and energy sectors may deepen in the coming decades. The concerns regarding the water-energy nexus have arisen due to the relevant research carried out on the use of water sources during the last decades and the considerable volume of water that is required in the energy sector, in addition to the amounts of water that will be needed for the new related technologies within the energy sector. The considerable energy consumption of the facilities for the use, treatment and distribution of water is also a factor within these concerns (Machell, et.al., 2015).

This is the motivation of Pate, et.al. (2007) when highlighting the interdependencies between both sectors, stating that energy production and electricity generation need water, and processes such as water pumping, treatment, and transportation need energy. As the demand for these two resources increases, increasing limitations in the supply of energy and water must be also considered as highly interdependent critical resources that have to be managed together.

In a study performed by the Pacific Institute (2008) for the evaluation of world water resources, the authors have calculated a range expressing as a percentage of the water that will be needed in the energy sector in the year 2030 according to two scenarios: one of reference, basically a “business as-usual” scenario; and the other "alternative", in which the impacts of energy efficiency and climate change policies are taken into account.

The results obtained by their estimates are explored below. Regarding the water used (not consumed, but referring to the total of sustainable water resources) is not expected to cause problems at a global level, since it represents between 0% and 2% of the water both in the case of the reference scenario as in the alternative).

However, in more regional settings, it can be expected that regions such as Latin America, and countries such as India or China can dedicate a fairly large fraction of their sustainable water resources in the production of energy, as shown in Table 1.

	2005	2030 Reference Scenario	2040 Alternative Scenario
China	0% - 22%	0% - 29%	0% - 26%
India	0% - 14%	0% - 47%	0% - 37%
Latin America	0% - 26%	0% - 54%	0% - 47%

Table 1. Future Demand for Water Use for the Energy Sector Relative to the Current Total Water Supply

(Pacific Institute, 2008)

If water consumption is analyzed with respect to the total water consumed at present, the situation presents more worrying scenarios. The results show that in many regions of the world, the range of water consumption for the energy sector can reach up to 10% or 20% of the total volume of water consumed. This, undoubtedly, can significantly make the dynamics of the systems vulnerable because of the increasing number of water users that depend on the energy sector, irrigation, and food supply (The Pacific Institute et al., 2008).

By 2030, The demand for water treatment (and other high levels of treatment) will grow especially in emerging economies. Moreover, the amount of energy used in the water industry is projected to be more than double than it is today. For instance, it is forecasted that 16% of electricity consumption will be related to water supply by 2030. Desalination capacity will increase markedly in the Middle East and North Africa. It is important to note that sea water is practically an inexhaustible resource. Its effective use, however, depends on the availability of abundant and low-cost energy for desalination and the subsequent transport and distribution of fresh water to those who need it (Zarzo,et.al.,2018)

This opens a wide field for the application of desalination on a large scale, where nuclear power could be a viable alternative. Indeed, nuclear energy is already being used for desalination and has the potential for much greater use. Nuclear desalination is very competitive in terms of costs and only nuclear reactors are capable of providing the large amounts of energy that these large-scale projects will require in the future (Alkaisi, et.al., 2017).

The efficient governance and management of water-energy supply systems interdependence is crucial for the success of meeting the needs of human communities of water and energy resource supply. The integrated development, and not in isolation, of water and energy governance is of the utmost importance considering the high risks to which the current and ever-changing dynamics of the water-energy nexus is exposed. Therefore, the inclusion of the interdependence of water and energy in their individual strategic plans is now more essential than ever.

2.2.4.2 The Role of Water in Electric Power Generation.

The use of water is closely involved in almost all the methods to produce electric power. The types of energy that are involved in electric power generation and use water in their processes are: thermoelectric, hydraulic/hydroelectric, biomass, geothermal, tidal and wave energy.

Thermoelectric energy is the type of energy that makes use of heat to generate electricity. Although the mechanisms to achieve the electric power generation are very similar in all thermoelectric installations, the way such mechanism functions can be different depending on the type of energy that is being used to produce the heat. In the case of electric power type of generation.

The main mechanism of thermoelectric energy is based on using heat to increase the temperature the water used in the process until it evaporates. The released steam activates a turbine, which begins to rotate. In this way, thermal energy is converted into kinetic energy (energy of motion). This turbine is connected to a generator that, due to such movement, produces electricity (Di Pippo, 1985). Figure 6 shows the main components of a thermoelectrical power plant and the process previously described.

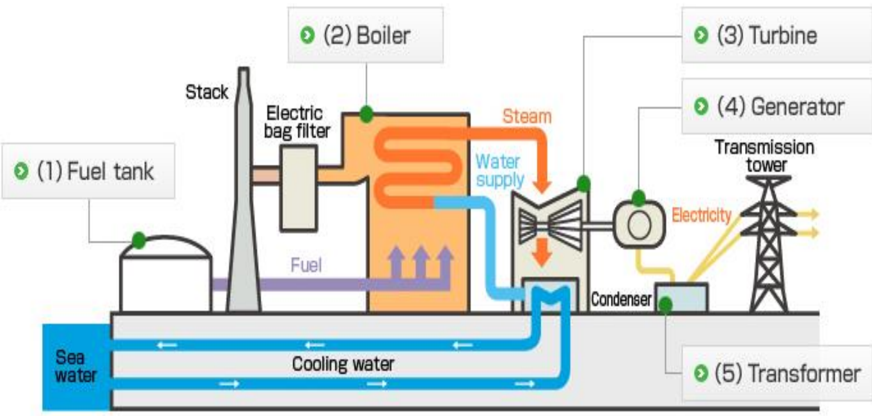
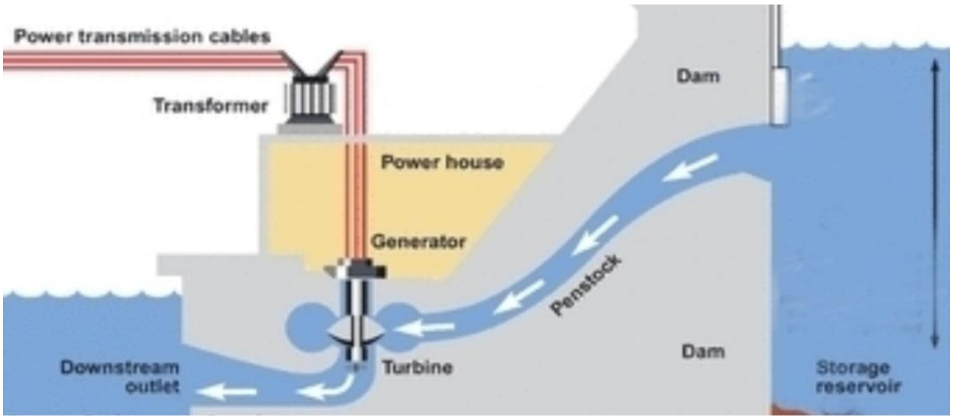


Figure 6. General Scheme a Thermoelectrical Plant and Process for Electric Power Production

(KEPCO, 2020)

Hydroelectric energy is generated by transforming the force of water streams into electrical power. Hydroelectric power is generated as follows: the water located in a reservoir and retained by a dam enters a turbine through high-pressure pipes in which the water acquires a great speed that will later be transformed into energy. In the turbine room, normally located underground, where the water reaches its maximum speed due to a rotational movement. This type of process is widely known since many hydroelectric plants depend on the use of such type of turbine. This machine transfers the energy obtained by the force of water to an electric generator that will be responsible for its transformation into electrical energy. Electricity travels already transformed from generators to transformers in which its voltage is converted to be able to be used and transported through the electrical network (Das, et.al., 2018). Figure 7 shows the main components of a hydroelectrical power plant and the process previously described.



(USGS, 2018)

Figure 7. General Scheme of a Hydroelectrical Power Plant and Process for Electric Power Production

Biomass energy or bioenergy is a type of renewable energy that is obtained from the use of organic and industrial matter formed in a biological or mechanical process, it is generally extracted from the waste of substances that constitute living beings (plants, human beings, animals), or their remains and residues. The use of biomass energy is done directly (for example, by combustion), or by transformation into other substances that can be used later as fuel or food. For these reasons, producing energy with biomass is an ecological system, which respects the environment and it is also cost-effective (Turnbull, 1993). The generation of electric power with biomass is carried out through the burning of solid biomass on a large scale. This is mainly due to the fact that the necessary facilities require a large economic investment. Furthermore, the overall yields obtained are as high as the power generated. The biomass is burned in a boiler, this combustion heats the water that circulates through the pipes of the walls of the boiler and turns into steam. The steam drives a turbine connected to a generator that produces electricity (Solantausta, et.al., 1996). Figure 8 shows the main components of a hydroelectrical power plant and the process previously described.

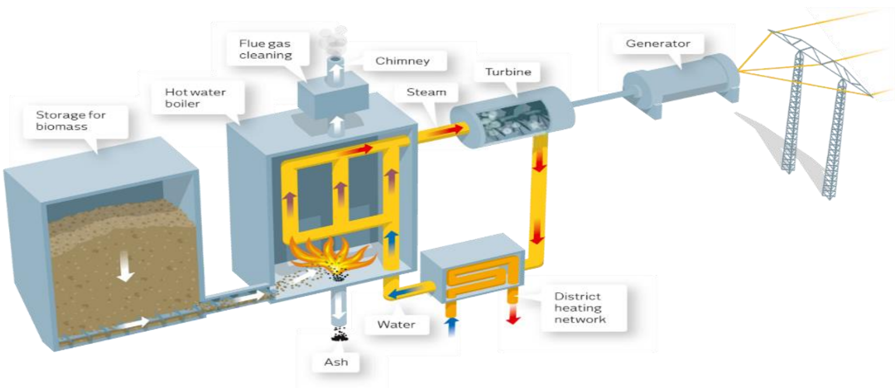


Figure 8. General Scheme of a Biomass Power Plant and Process for Electric Power Production

(Salix Rewewable, 2016)

Geothermal energy is a type of renewable energy that takes advantage of the heat from the subsoil to obtain sanitary hot water and, on a larger scale, generate electricity through a steam turbine system. High temperature geothermal resources, above 100-150ºC, are used mainly for the production of electricity. When the reservoir temperature is not sufficient to produce electricity, its main thermal applications are channeled to the industrial services and residential sectors. Thus, in the case of temperatures below 100ºC, it can be used directly or through a heat pump for heating. When it comes to resources with very low temperatures, below 25ºC, the possibilities of use are in air conditioning and obtaining hot water. As depth in the ground increases, the temperature of geothermal resources increases (Dickson & Fanelli, 2004)

Electric power through geothermal energy is produced as follows: through the fractures in rock strata, hot water and vapors from heat sources (for example, shallow magmatic rises and / or narrowing of the earth's crust) rise to the surface, where they are intercepted by geothermal extraction wells. The steam that comes out of the wells is then transported to pipes and sent to start up a turbine, where the energy is transformed into rotating mechanical energy (Barbier, 2002).

The turbine shaft is connected to the rotor of the alternator, which, when rotating, transforms mechanical energy into alternating electricity, which is transmitted to the transformer. This increases the voltage value to 132,000 volts and passes it on to the distribution network. The steam that comes out of the turbine is converted back to a liquid state in a condenser, while the non-condensable gases present in the underground steam are dispersed in the atmosphere after specific treatments to reduce the main pollutants, such as hydrogen sulfide and mercury A cooling tower allows the water produced by steam condensation to be cooled. Then, the cold water is used in the condenser to lower the temperature of the steam or is reinjected into the deep rocks through the reinjection wells, so a new cycle of renewable energy production can start. (Dickson & Fanelli, 2013). Geothermal power plants use three main technologies: dry steam, flash steam and binary cycle

Dry steam (Figure 9): it is the most widely used technology, which involves the use of steam at high temperature (more than 235 ° C) and pressure to activate a turbine coupled to an electric power generator (Di Pippo, 2015).

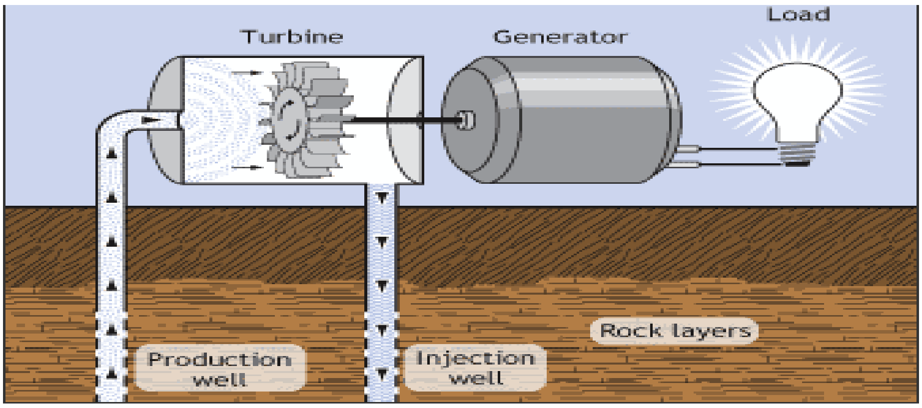


Figure 9. Dry Steam Geothermal Power Plant

(Geothermal Steam Power Plant | Open Energy Information, 2017)

Flash steam (Figure 10): dominant water tanks (temperature above 150-170 ° C) are used to supply single or double flash power plants. The water reaches the surface through wells and, due to the rapid change in pressure from the reservoir to atmospheric pressure, it is separated into a part of vapor that is sent to the plant and a part of liquid that is reinjected into the reservoir (single flash). If the geothermal fluid reaches the surface at especially high temperatures, it can be subjected to the process twice (double flash) (Yari, 2010).

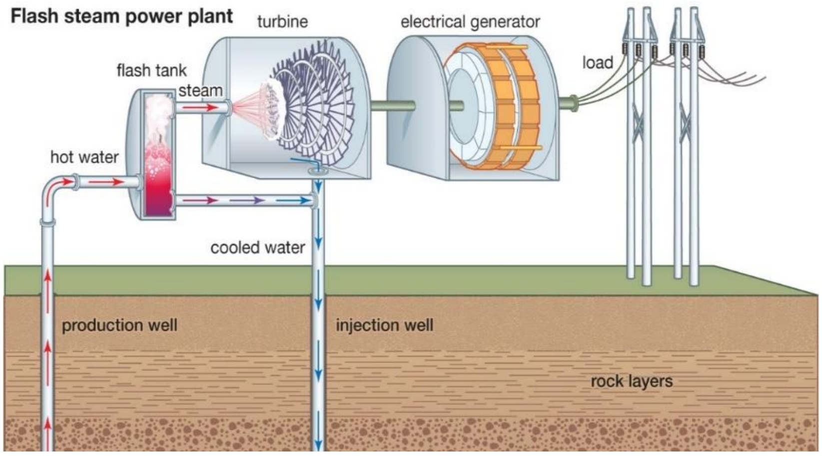


Figure 10. Flash Steam Power Plant

(Encyclopaedia Britannica Inc., 2016)

Binary Cycle (Figure 11): in reservoirs that produce water at moderate temperatures (between 120 and 180 ° C), the geothermal fluid is used to vaporize, through a heat exchanger, a second liquid (which is usually isobutane or isopentane), with a temperature boiling lower than the one used to boil water. The secondary fluid expands in the turbine, condenses, and returns to the exchanger in a closed circuit, without exchange with the outside (Di Pippo, 2012).

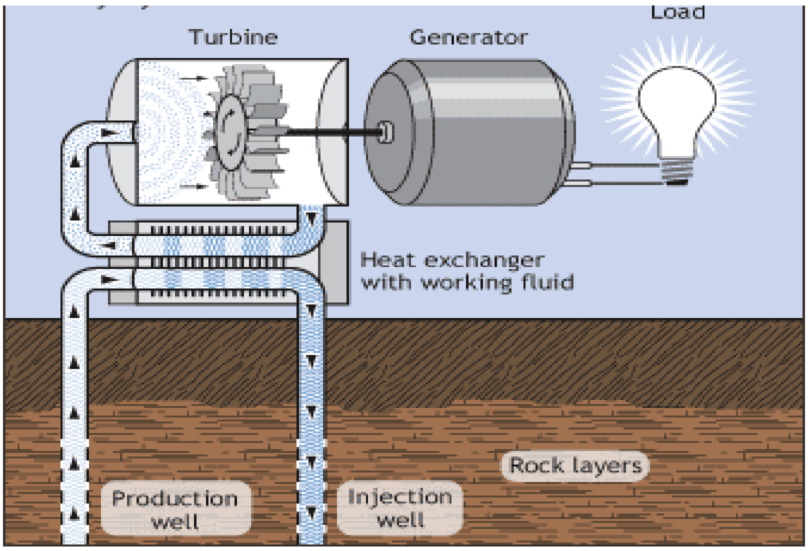


Figure 11. Binary Cycle Geothermal Power Plant

(Geothermal Steam Power Plant | Open Energy Information, 2017)

Tidal energy is produced through the movement generated by the tides, this energy is used by turbines, which in turn operate an alternator that generates electric power, finally the latter is connected to a power station on land that distributes the energy towards the community and industries. There are three different methods of electric power generation through tidal energy (Gorlov, 2001):

Tidal Stream Generator (Figure 12): Tidal stream generators make use of the kinetic energy of moving water to power turbines, similar to the wind (moving air) that wind turbines use. This method is gaining popularity due to lower costs and less ecological impact compared to tidal dams (Alternative Energy Tutorials, 2021).

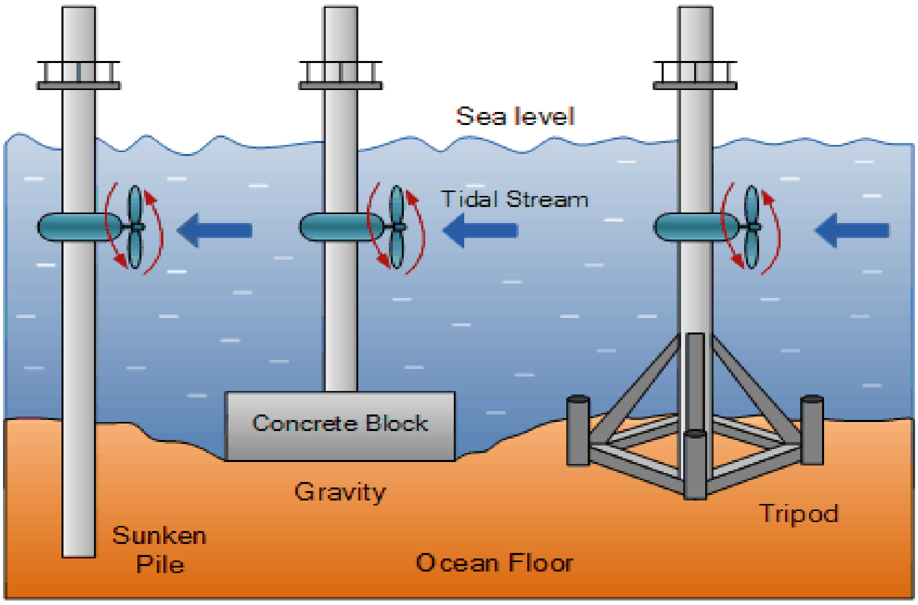


Figure 12. Tidal Stream Generator
(Alternative Energy Tutorials, 2021)

Tidal Dam/Barrage (Figure 13): Tidal dams use the potential energy that exists in the rise and fall of the sea tides. It is a retention work along an estuary or a bay whose main mission is to dam the incoming tidal water in the retention area. It is normally built to form two separate reservoirs and thus facilitate the operation of the tidal power plant. The scarcity of places in the world that meet the conditions to host them and the environmental impact that they represent are two major drawbacks for their use. In tidal dams the cost per kWh is usually lower than of a conventional power plant (Hill, 2015).

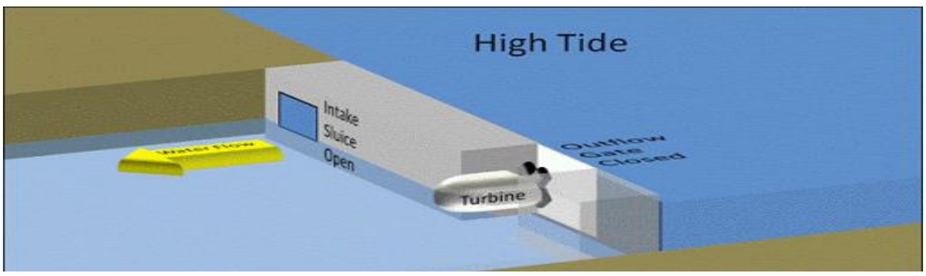


Figure 13. General Diagram of a Tidal Dam/Barrage
(Encyclopeadia Britannica, 2017)

Wave Energy is often confused with tidal energy, although both produce energy from marine potential, there are differences among these types of electrical power production. Wave energy takes advantage of the movement of waves to generate electrical energy, it obtains it from the mechanical and potential energy of the movement of the waves, while tidal energy does it through the movement of the tides. Wave energy makes it possible to obtain electric power from mechanical energy generated by the movement of waves. It is one of the types of renewable energies with the most recent studies and presents enormous advantages over other renewable energies because it would be easier to predict optimal geological conditions that allow greater efficiency in its processes because it is easier to predict optimal wave conditions, compared to that obtained with winds to obtain wind energy, where its variability is less (Thorpe, 1999).

2.2.4.3 The Role of Energy in Water Supply and Distribution Systems.

Hoffman (2012) highlights that 7% of world energy consumption is channeled to water supply and distribution systems. That average, however, includes a wide variability. For instance, it is estimated that in the United States, a country that is especially characterized by its high levels of energy consumption, the use the water supply and distribution sector is 3% of the total energy use of cities, but in some states, like California, can show up to 20% mainly due to the scarcity of water resources and the use of more energy-intensive production systems (WWAP, 2014).

These differentiations can vary significantly depending on the topographic and climatic conditions of a country or regions, as well as economic, technological, and cultural aspects. Data for Brazil from 2010 showed that the energy consumption of water service providers was approximately 2.4% of total national consumption. (Vilanova, et.al., 2015). Burns (2013), on the other hand, estimates a 5.8% for Spain. The energy use of the drinking water supply and distribution sectors can be divided into two parts: the processes associated with the stages of the provision of the service (collection, transport, treatment, distribution, and treatment of wastewater), and the final uses of the water (pumping and internal distribution of the building, heating, dilution, steam generation for industrial uses). (Ramos, et.al., 2005)

There are multiple estimates on the energy consumption of drinking water supply and distribution services, but the data are very dissimilar since, in addition to the local particularities where the service is provided, the spectrum of investigations is heterogeneous since some studies cover only certain stages of the processes of the water supply system and other energy expenditures linked to the final uses of water. However, there is a similarity regarding the relevance of energy consumption in the drinking water and distribution sector in general. Also, many articles are consistent in stating that energy consumption associated with end uses far exceeds the energy associated with the process of provision of drinking water and treatment of wastewater. Therefore, policies aimed at energy conservation and efficiency have a high impact, especially those aimed at end uses that require hot water (Wakeel, et.al., 2016: Rasmussen, 2012: Cook, et.al., 2012).

The extraction of underground water with this destination typically requires more energy because the water must be pumped from the soil. It also needs to be treated accordingly to the purification standard specified by the applicable health authority, although conventional treatment — the most common — for purification usually uses very little energy in comparison. In addition, it tends to be pumped over longer distances and higher altitudes, while industrial and agricultural users are generally self-sufficient by consuming the water in the vicinity where their activities take place (Sanders & Webber, 2012).

As for drinking water supply system, energy is required to capture water from the source, make it drinkable, and distribute it to residential and non-residential users. Energy intensity is defined as the total energy required to provide a certain volume of water in a specific location (Cohen, et.al., 2004). The energy intensity of a volume of water is influenced by factors such as the type, location and quality of the source, the proximity to the treatment plant and the end-users, the topography of the land where the distribution is an important factor to take into account as well. The electricity consumption of each provider ultimately depends on the design of the water system, as well as the height and distance to which the water needs to be pumped (Denig-Chakroff, 2008).

For instance, groundwater requires a much higher pumping load to extract than surface water in lakes or rivers. The distance from the catchment source to the plant is also important. When the fountains are in areas far from the end-users, the water must be transported through aqueducts that require a large dynamic energy load to overcome the friction that the liquid exerts on the walls of the conduct, for which it may be necessary to use pumping, while when the catchments are close to the population, this load can be much lower.

The topography of the land is a third element to consider. Populations found in areas with little difference in height require less dynamic energy load for the distribution of the liquid than others with great slopes and whose static loads are greater due to the pumping equipment to get the water to higher areas. The extraction phase may require an average of 10-30% of total energy consumption, depending on whether the source is surface or underground (Jackson, et.al., 2010).

As for the water treatment phase, the energy intensity of a given technology is correlated with the volume, concentration and type of contaminants, and the nature of the bacteria to be removed. Groundwater generally requires much less treatment than surface water, sometimes only the chlorination of raw water that requires very little electricity is enough (Nyer, 1992).

If water supply has a poor quality or are degraded, more purification treatment is required, and this consumes more energy to remove pollutants. Similarly, water that requires high-quality end-use typically demands more energy. Since these requirements differ according to geographic location, climate, season of the year, and local water quality standards, the energy consumptions of different systems vary significantly. Water, (2010).

Desalination is a process that demand higher use of energy than surface and ground sources of freshwater. The recycled water is used mainly for the recharge of aquifers (underground water), irrigation of parks, gardens, and intensive crops. The energy cost for its use has to do with the treatment to which it is subjected and the energy necessary for transport to the place of use. If used for purposes different than human consumption, it has comparatively lower costs than other sources. The purification stage may require on average between a minimum of 1% and a maximum of 10% of the total energy consumption for water, depending on the source, whether it is underground or surface, respectively (Elimelech & Phillip, 2011).

The transport and distribution stages are the most expensive in terms of energy usage, since pressurization and pumping of water are required in order to keep a proper distribution and maintenance of the water supply network pressure. Moreover, pumping is also required to move the water to the reservoirs, water must then be transported from the source to the treatment plant and then to the tanks or reserve or storage spaces to finally reach the user through the pipes. In addition, when the population settles in peripheral sectors located in higher elevations, additional pumping is required. In turn, there are losses in the network, partly unavoidable, such as breaks in the pipes due to excess pressure or the presence of corrosion in steel pipes and, partly avoidable, such as the lack of maintenance or replacement of the pipes that have already completed their useful life (Carravetta, et.al., 2012)

The losses increase the energy intensity, since the energy consumed in the collection, treatment and transport is partly lost due to the aforementioned leaks. The distribution stage may require on average between 69% and 80% of the total energy consumption. In practice, due to the length of the urban water networks, it is complex to carry out an energy audit of the distribution stage, except for the energy consumption of the pumping equipment (Fontana, et.al., 2012).

Regarding lifting pumps, Kenway, et.al. highlight that raising the water 6 floors of a vertical building implies an expense of 0.14 kWh / m3, so that in cities with many high-rise buildings, energy consumption is increased. However, in geographically widespread cities with a centralized supply system, the need for horizontal pumping over long distances (to the suburbs) the level of energy consumption can also be significant. Once the water reaches the users, more energy is required there to heat it, cool it, or even pump it. Therefore, changes in water demand directly affect energy consumption. In the United States, between 75-80% of the variability in total energy consumption by providers is explained by the volume of water used. Consequently, the greatest potential for energy savings consists in reducing the volume of water consumed, since water conservation eliminates energy requirements both in the production stage and in final use (Beaudin, et.al., 2010).

Table 2 summarizes the energy use in the stages of the water supply and distribution systems.

Stage	Percentage of Energy Used by Stage	Percentage of Energy Used by Complete Cycle
Water Supply	100%	65%
Catchment and Transportation of Raw Water	10% (Surface Water) 30% (Groundwater)	7% (Surface Water) 20% (Groundwater)
Water Treatment	10% (Surface Water) 1% (Groundwater)	7% (Surface Water) 1%(Groundwater)
Transport Pumping and Drinking Water Distribution	80% (Surface Water) 69% (Groundwater)	52% (Surface water) 45% (Groundwater)
Sewage	100%	35%
Collection of Wastewater	10%	4%
Wastewater Treatment	55%	19%

Table 1. Energy Usage in a Water Supply and Distribution System by Stage and by Complete Cycle

The table shows the proportions over the ranges of energy use that can be taken as indicative of consumption in each stage. This table shows general, average figures. It must be taken into account taking that there are cities that take great advantage of their topography, while others are plain, and in turn, the systems need to consume more energy within the process of water supply and distribution systems. Those percentages, however, are not much different from the average percentages shown in the table. For instance, in water supply and sewerage companies in England and Wales, electricity spending is distributed as 52% for drinking water and 48% for sewerage (Brandt, et.al., 2012). However, these percentages can vary significantly depending on the conditions in which the services operate.

For example, in the water supply systems of Melbourne, Australia, the electricity consumption of the drinking water service represents only 23%, since the raw water conduction system occurs by gravity where the pumping is minimal, while the wastewater treatment represents 65% since the technology used is intensive in the use of energy and a part must be pumped about ten thousand kilometers for its discharge. On the contrary, in services, such as those that predominate in the countries of the region, where drinking water coverage is higher than sewerage coverage and the percentage of wastewater treatment is low and of low quality, the energy consumption of the drinking water service has a greater share in the total consumption. (Northey, et.al., 2016).

2.2.4.4 The Role of Water in Food Supply and Distribution Systems.

Water is an important ingredient in almost any food or drink that is produced or consumed, it constitutes the most valuable material for food in the present and in the short, medium, and long term. According to the World Health Organization (WHO), having quality fresh water available is important for the supply of drinking water and food supply. Water is therefore a key element due to the diverse uses that human beings make of it: direct consumption, irrigation, hygiene, and many others (World Health Organization, 1993). In order to understand the role of water in food supply and distribution systems, its use has to be studied under the light of primary food production; that means, agriculture, and the use of water in the food industry.

2.2.4.4.1 Use of Water in Agriculture

According to data from the United Nations Department of Economic and Social Affairs (UN-DESA) the agricultural sector is one of the largest consumers of water on the planet, spending about 70% of the fresh water extracted for human use. For instance, the department reports that in order to produce a kilo of rice it is necessary to spend 3,500 liters of water; and for a kilo of veal about 15,000 liters. In addition, it is estimated that by 2030, 60% more food should be produced, with the consequent need for drinking water. . (Desa, U. N. 2016). The challenge is to produce the necessary food for the world’s population with a sustainable use of water. According to the European Food Information Council (EUFIC), there are four main uses for water in food production: primary production, cleaning, and sanitation, as an ingredient or component of an ingredient, and as a transformational element in processes (Achterbosch, et.al., 2019)

The term ‘‘water footprint of food’’ was created in 2002 by Arjen Hoekstra to refer to the amount of water used in food production, the water footprint is one of the environmental footprints that show how production decisions in agriculture and consumption are affecting natural resources. As the population grows and the standard of living increases for many people, the water footprint represents how much water is used every day in all human activities. (Jackson, et.al., 2015)

The concept of created by Hoekstra distinguishes between three types of footprint that depend on the origin that each one has. The green water footprint is a measure of the water that is incorporated into the product from rainfall and the blue water footprint represents the water consumed that comes from surface and underground sources (Hoekstra et al, 2011). Finally, the gray water footprint is an indicator of the volume of water necessary to assimilate the pollutants involved until reaching the permitted levels of concentration in water (Mekonnen, et.al., 2011).

The water footprint of food measures the amount of water used to produce each of the edible goods that are consumed in the market. It can be measured by a single process, such as growing rice or a specific product, such as coffee or meat. The production of agricultural products is responsible for the highest volumes of freshwater use on the planet (Hoekstra et al, 2014). The food production market pressures agricultural systems to higher volumes of productivity, promoting intensification processes (Koohafkan, et.al., 2012). Table 3 shows the water footprint of some common edible goods.

Food item	Unit	Global average water footprint (litres)
Apple or pear	1 kg	700
Banana	1 kg	860
Beef	1 kg	15,500
Beer (from barley)	1 glass of 250 ml	75
Bread (from wheat)	1 kg	1,300
Cabbage	1 kg	200
Cheese	1 kg	5,000
Chicken	1 kg	3,900
Chocolate	1 kg	24,000
Coffee	1 cup of 125 ml	140
Cucumber or pumpkin	1 kg	240
Dates	1 kg	3,000
Groundnuts (in shell)	1 kg	3,100
Lettuce	1 kg	130
Maize	1 kg	900
Mango	1 kg	1,600
Milk	1 glass of 250 ml	250
Olives	1 kg	4,400
Orange	1 kg	460
Peach or nectarine	1 kg	1,200
Pork	1 kg	4,800
Potato	1 kg	250
Rice	1 kg	3,400
Sugar (from sugar cane)	1 kg	1,500
Tea	1 cup of 250 ml	30
Tomato	1 kg	180
Wine	1 glass of 125 ml	120

Table 2. Global Average Water Footprint for Common Edible Goods (Hoekstra, et.al., 2011).

From the total water footprint of the agricultural sector in the world, 29% is related to the production of products of animal origin and a third of this is related to cattle (Mekonnen & Hoekstra, 2012). Water is a critical input in the dairy activity, whether for obtaining animal feed and drink, as well as for cleaning and disposing of effluents, at different stages of the milking and industrialization routine. The water footprint of the agricultural sector constitutes the critical and determining component of this indicator in agri-food products, because primary production is the link with the greatest weight in the footprint.

Agricultural and diary production in general, use large volumes of water both directly and indirectly. Most studies agree that although there are generally water resources in the world to satisfy the demand for food, their geographic availability is uneven even within the same country. Agricultural production accounts for between 30% and 40% of freshwater withdrawals in developed countries and 90% in developing countries (Mekonnen & Hoekstra, 2012).

The agricultural sector receives drinking water through public means, through local government authorities, or through private channels or from the food companies themselves. Generally, almost all the drinking water supply to the food industry is publicly sourced. The quality of the water is determined by its origin, which also establishes if it is necessary to apply a treatment to ensure that the standards for drinking water are met and that it can be used safely in food production (for example, that it is safe for human consumption). In some circumstances the agricultural sector uses non-drinking water, for example in fire prevention and steam production. Pothukuchi, K., & Kaufman, J. L. (1999).

In these cases, the water must be clearly marked ‘’not for drinking purposes’’ and must not contain any connection to the supply of water used directly in food production or be any possibility of mixing with it (Pimentel, et.al., 1997).

Water intended for a use related to agriculture must be healthy and clean, which means that it must not contain any microorganism, parasite or substances in quantities that may pose a risk to human health. Some parameters that can help assess its safety are transparency, turbidity, color, odor, or taste. The agricultural sector is required to have a supply of sufficient drinking water for use in food production to ensure that food is not contaminated (Mälzer, et.al., 2010). There are a number of ways to manage water in agriculture, from tilling the soil to increase rainwater filtration to modern irrigation systems. According to the "Save and Grow" guide from the Food and Agriculture Organization of the United Nations (2011) approximately 80% of cultivated land in the world is rainfed and responsible for 60% of world agricultural production. In this case, the application of water does not depend so much on the decision of the producer; it is directly determined by rainfall.

The remaining 20% of the cultivated area is irrigated and produces about 40% of the production. This is because they combine techniques that allow greater intensity and performance. The control of the water cycle together with the management of the necessary inputs is in charge of the field worker, which makes this type of production between 2 and 3 times greater than that of dry land. It is clear that an efficient, controlled, and flexible use of water is essential to improve agronomic practices and use each resource fairly (Venot, et.al., 2017).

2.2.4.4.2 Use of Water in the Food Industry

Water is used in the food industry for countless uses. From the preparation of food, cleaning processes of facilities and surfaces, as well as for the manufacture of ice and to wash and disinfect fruits and vegetables. (Beuchat, et.al., 1997).

In the juice industry, the production of nectar involves a large consumption of water since approximately 50% of the product is water. Beside that amount of water, it is necessary to consider the water necessary for washing the raw material and the water used for the rest of the processing, in the end there is a significant use of water. The individual water footprint of a glass of orange juice (200ml) is 170 liters of water (Water Footprint Network, 2020). The brewing industry also uses a high amount of water, since 95% of the weight of beer is water. The individual water footprint of a glass of beer (200ml) is 75 liters of water. On the other hand, for the sugar industry, although the final product is not rich in water, the amount of water required to produce the product is very high. The water footprint of sugar is 1,500 liters of water for 1 kg of refined sugar. The canning industry also uses large volumes of water and steam, although highly variable from one industry to another.

The average water footprint in the canning industry is: 1 ton of water per 1 ton of treated product in the case of water scalding, or 0.15 - 0.300 ton of steam per 1 ton of product in the case of steam scalding (Water Footprint Network, 2020: Hoekstra, 2010).

As for the amount of water that the meat industry needs, it is very high since the meat undergoes many treatments before being fully processed. Water footprint: 4500 liters of water for: 300g of 300g steak; 1440 liters of water for a 300-gr fillet of pork; 1800 liters of water for 300 gr of roast beef fillet. Finally, the dairy industry where there are many processing phases in which the function of water is essential. Water footprint: 1000 liters of water for 1 liter of milk (Water Footprint Network, 2020: Hoekstra, 2010).

Progress has been made through the development of ISO 14046: 2014, an international standard that specifies the principles, requirements and guidelines related to the evaluation of the water footprint of products and processes, based on the life cycle assessment approach, specifically for livestock production systems, there are international efforts to standardize computation and analysis procedures (Pfister & Ridoutt, 2014).

On the other hand, the sources of water supply in the food industry can be various: public network, own catchment (underground or surface), with or without intermediate reservoirs. The health, quality and cleanliness of the water is, therefore, key to ensure the safety of the food that is processed. Food industries that have their own catchment (well) will be responsible for guaranteeing water quality throughout the supply network. If the water comes from a supplying company (public network), the responsibility of the food industry will be limited to the distribution network that goes from the delivery point of the supplying company to the water outlet points (Trienekens & Zuurbier, 2008).

If water is used as an ingredient in food processing, it should be considered as one more raw material, so it is necessary to establish quality and safety specifications that must be met by the food industry. Food businesses must monitor water quality according to a risk-based sampling plan. They will establish the controls to be carried out by their own means, such as: organoleptic controls (checking the smell, taste, color, and turbidity) and control of residual free chlorine. They must also know the suitability of the water with respect to other parameters such as conductivity, turbidity, radioactivity, pH, ammonium, copper, iron, lead, and microbiological characteristics (Enterobacteriaceae, Escherichia coli) (Rock, et.al., 2019).

If the food industry is supplied from the public network, this information is provided by the water supply company, on an annual or five-year basis. When the food operator takes water from its own sources, it must commission analyzes from laboratories that master the technique, with the periodicity and determinations required by the regulations. The maintenance, cleaning and disinfection of the supply system is extremely important when water is taken from wells or received from an external company with storage tanks. In facilities with direct supply from the external supplying company, and without intermediate deposits, the actions will be limited to checking that abnormal situations do not occur on the distribution network, such as works that imply breakage of pipes, which may pose a risk to the quality of the water (Geldreich, 2020: Stokes, & Horvath, 2006).

Due to the multiple purposes that water is given within the food industry, it is vitally important for food safety to ensure compliance with the quality of both the water and the water supply system, therefore a water control plan is needed within this industry. The main objective of a water control plan in the food industry is to certify the safety that the water used in the processes of both manufacturing, treatment, cleaning or use of materials and tools that may be in contact with food, is adequate and free of any type of chemical or infectious pollutant, which does not cause harmful effects on health. The water control plan will establish different actions, the level of demand of which will depend on the consumption carried out and the degree of involvement of the industry in water management: autonomous supply or supply through an external company, with or without intermediate deposit (Davison, et.al., 2005).

In the food and beverage industry, dairy products, slaughterhouses and meat processors, bottled beverages, breweries, baked goods, and flour and grain facilities there is a high demand for hygiene and water treatment in order to maintain high quality end product standards and extend shelf life. Industrial food and beverage facilities test production water for impurities and verify the efficiency of solutions to ensure that all consumed process water remains suitable for use in their production processes (Lelieveld & Holah, 2016).

With increasing international and local pressure, the food and beverage industry have had to find new ways to direct its product development and achieve continuous control over costs and health risks in an attempt to meet the demands of its customers. In this context, water is a major factor to consider, whether seen from the perspective of it being an integral part of production processes, as part of the product composition, or used for refrigeration, steam production, or cleaning operations. To keep water consumption under control and ensure the reliable operation of its production, taking into account seasonal variations is crucial in the food industry (Roy, et.al., 2009).

Beverage manufacturers and processors face unique challenges in the area of water treatment. Water sources, disinfection processes and treatment residues can affect the taste and quality of the final product. The production of beer and soft drinks begins with a pure source of water. Drinking water often contains traces of various ions that alter its taste. Contamination of the water from the alcoholic beverage process can result in loss of product (resulting not only in production losses, but also higher waste effluent costs), product recalls, and loss of consumer confidence. Bottlers use filters and other treatment equipment to remove residual impurities and standardize the water used to make beverages. (Mahalik, & Nambiar, 2010).

Regarding dairy products, slaughterhouses, and meat processors, all the water used for their production must comply with proper guidelines. From slaughter to cleaning and processing: source water, process water, and wastewater must be free of iron and manganese. Process water from iron and manganese contamination will infuse into product, create boiler problems, or clog pipes and sprinklers. Biological fouling from excess iron and manganese will stunt the growth of fresh produce and inhibit the supply of consumer crops to market. These controls must be carried out in the protection of water resources, adequate treatment in drinking water, management of distribution and storage systems to maintain the quality of the treated water (Alayu & Yirgu, 2018)

The maintenance, cleaning and disinfection of the supply system is very important when using water from wells or external companies with storage tanks. If these external companies do not have intermediary tanks, the checks will be limited to unusual situations in the distribution network, for example, a pipe break, which leads to a problem with the quality of the water (Drinan & Spellman, 2012).

Food industries must have appropriate facilities for water supply, storage, and distribution for all the processes that concern the handling of the food. Guaranteeing the safety of the water supply in agriculture and the food industry is a crucial factor for food security, therefore, optimizing the link among water and food interlinkages is an issue that requires research and application of proper safety measures.

2.2.4.5 The Role of Energy in Food Supply and Distribution Systems

The food sector is very varied, made up of companies that present a large number of processes that make possible the production, processing, and handling of edible products. The production and distribution of food generally require different forms of energy since the processes carried out within the system contemplate the transformation of food raw materials through different procedures such as cleaning, washing, selection, cooking, grinding, and transport, which require the use of machinery and equipment that in turn need some form of energy for their operation (Okos, et.al., 1998).

Among the different forms of energy used in the food production and distribution process, electricity is the most widely used, both for the operation of machines, and in equipment that uses other types of energy. Electrical power supplies a large number of systems such as: the movement of production lines, conveyor belts, cooling systems and fluid impulsion (pumping systems), among others. Other sources of energy used in the food industry are fossil fuels such as oil and gas, generally to generate heat or in steam generation equipment for cooking, in drying and dehydration ovens. For these same purposes, biomass is also used as fuel, or gasoline or electricity for the means of transport by which food is transported (Escriva-Bou, et.al., 2018).

In the sector, the use of fuels, mostly fossil fuels, is associated with the generation of thermal and electrical energy. Activities related to the control of pathogenic loads such as blanching, pasteurization and sterilization correspond to processes that require a greater use of thermal energy in the form of heat, however in many cases it is possible to observe the use of fuels for the generation of electricity, through backup electrical systems, commonly used during peak periods. Likewise, wind energy and solar energy are used in the process of generating electricity, heating water and dehydration processes within the food industry. The intensity of use of the different forms of energy will depend on access to the type of energy, the production process to be developed and the design and selection of technologies (Muller, et.al., 2007).

In the industrial food sector, electricity and fuels are used as energy sources for the operation of the productive apparatus and the provision of services. Generally, natural gas or liquefied petroleum gas-LPG are used as a source of thermal energy (Notarnicola, et.al., 2012).

World's average annual energy consumption in a food industry is 200 EJ per year. (FAO, 2017: IEA, 2017), of which a 45% corresponds to processing and distribution activities (FAO, 2011: Sims, et.al., 2015). In the agriculture sector, the use of thermal energy for the production of heat through fossil fuels is highly used in the different production processes and its main focus is the control of the pathogenic loads of the product. Within the agriculture subsectors, it is possible to identify those processes that have the highest demand for this energy source. An example of the above is the blanching, pasteurization, fruit washing, aseptic and packaging processes (Leach, 1976).

The total electricity consumption of a food plant is on average 44.14% of electricity channeled to motor force; this can be explained by the numerous motors that move machines and equipment during the production process. While the generation of refrigeration to preserve food and heat to process food, consumes electricity in a 26.65% and 21.62% respectively, and auxiliary services such as compressed air and lighting, consume only 1.96% and 2.4% of electricity respectively, while the rest of various activities consume 3.2% of electric power (Hall, & Howe, 2012).

The meat industry shows a large variety within its processes, from hatcheries and animal feed production, to slaughterhouses and meat processing. Those companies in the livestock sector specialized in raising animals and generating their food (intensive livestock), have an almost equitable distribution of their energy sources, considering that 46% of their total energy use comes from fuels and is destined to the generation of heat through the production of steam and hot water (Barbut, 2014).

On the other hand, those companies that manufacture meat products, such as pig and chicken slaughterhouses, have a thermal consumption close to 60% of the total energy demanded in their processes. The generation of steam and hot water are the main thermal sources of heat and are applied to the processes of scalding, skinning the animal, cleaning, sterilization, and heat shrinkable packaging, among others. The energy consumption achieved in the aforementioned processes can range from 25% to 55% of the operation's total energy consumption (Fritzson & Berntsson, 2006).

In the production of sea products, specifically canned and frozen fish and seafood, there is a high energy consumption related to the burning of fuels, which are close to 70%. The use of this thermal source of heat is aimed at generating steam through boilers, which is subsequently used in conditioning processes. The main thermal heat processes of a company in this area can present consumptions ranging from 35% to 80% of the operation's total energy demand (Troell, et.al., 2004).

Within the fruit production sector, those factories that produce fresh fruit have thermal processes whose main objective is the inactivation of microorganisms and native enzymes that alter food. Its distribution of thermal energy associated with heat production and fuel consumption is close to 20%. The main thermal uses of heat are presented in the packing process, specifically in the washing of the fruit and later its drying. Said energy consumption can range from 5% to 25% of the operation's total energy consumption (Thompson, et.al., 2010).

Those industries that belong to the wine sector have an energy consumption for heat production close to 45% of the total energy used, their main objective being the generation of hot water for heat-demanding processes such as: fermentation, malolactic fermentation , barrel heating and washing. The energy demand in the aforementioned thermal processes can reach consumption from 20% to 40% of the total company (Smyth & Russell, 2009).

2.3. Systemic Risk within Complex Systems

Complex systems play a fundamental role in modern societies. Depending on their nature, these types of systems may have different functions depending on the context in which they perform. These functions are essential for the well-being of human communities and the functioning of the current dynamics of global economy (Cilliers & Spurrett, 1999).

Therefore, the robustness of complex systems and their ability to cope with systemic risk are essential factors in maintaining the stability of human activities. Due to the costly consequences that can result from the disruption of human activities, complex systems are deemed as highly vulnerable. Eventual malfunction and uncertainties in the economy, logistics, climate, and other decisive factors in human activity make systemic risk an inherent factor in the forces at work of the interlinkages that lie within a complex system such as the water-energy-food nexus. For that reason, identifying and managing systemic risk is extremely important to achieve optimal performance of the multifaceted, interrelated activities of complex systems (Gribble, 2001: Carlson & Doyle, 2000).

2.3.1 Systemic Risk

Systemic risk is defined as the risk of having breakdowns in a specific, entire system (Goldin & Mariathasan, 2015). In order to understand this definition, it is necessary to comprehend the meaning of risk. The following compilation of risk definitions created Aven and Renn, (2009) is useful for that purpose.

- *‘’Risk equals expected loss (Willis, 2007)*
- *Risk equals expected disutility (Campbell, 2005)*
- *Risk is the probability of an adverse outcome (Graham and Wiener, 1997)*
- *Risk is a measure of the probability and severity of adverse effects (Lowrance, 1976)*
- *Risk is the combination of a probability and the extent of its consequences (Ale, 2002)*
- *Risk is equal to the triplet (si , pi , ci), where si is the scenario, pi is the probability of that scenario and ci is the consequence of the scenario. (Kaplan, 1991; Kaplan and Garrick, 1981)*
- *Risk is equal to the two-dimensional combination of events/consequences and associated uncertainties (will the events occur, what will be the consequences) (Aven, 2007; Aven, 2008, 2009)*
- *Risk refers to the uncertainty of outcome, of actions and events (Hansson, 2004).*

• Risk is a situation or event where something of human value (including humans themselves) is at stake and where the outcome is uncertain (Rosa, 2003; Rosa, 1998)
• Risk is an uncertain consequence of an event or an activity with respect to something that human's value (IRGC, 2005)''

In this sense, systemic risks are characterized by tipping points combined indirectly that have the potential to produce large failures and spread the consequences to all parts of the system, as one loss triggers a chain of "hysteresis" - this means that systems are unable to recover equilibrium quickly after a shock (De Bandt & Hartmann, 2000). Systemic risk is also defined as the risk of an event causing disruption in value production within a part of a system, such disruption would increase uncertainty within the overall system, generating adverse effects on the activities that it performs (Schwarcz, 2008).

Systemic risk can also be related to the breach of the obligations of a participant within a system, this breach can manifest effects of considerable importance in other interconnected participants of the system, which can lead putting in danger the stability of the activities of a system. The impact and extent of systemic risk can vary from reaching only certain actors within the system to affecting a whole market or the majority of the complex system, these effects can extend locally, nationally, or internationally, depending of the magnitude of the complex system (Huang, 2012).

Systemic risk manifests as a side effect of the close and complex interdependencies in a system, in which the failure of one or many components of the system can cause a cascade failure. A cascade failure is a condition of interconnected systems that occurs when the failure of a part or component causes further failures in related areas of the system, resulting in a general system failure. Cascading failure events can arise in both natural and man-made systems (Cai, et.al, 2018).

Numerous factors such as size, interconnection, sustainability, balance, and quality of systems contribute to the levels of systemic risk. Systemic risk can be categorized in two ways: exogenous and endogenous. Exogenous systemic risk refers to the potential negative consequences or threats to the system from factors that do not belong to the system. Endogenous systemic risk is the one that develops from factors that belong to the system (Smaga, 2014).

Systemic risk is characterized by various aspects, the interdependence between the participants of a system is one of the most important, the level of dependence among crucial parts of the system determines the severity of eventual disruptions within the system. The size of the system is another determining factor, as well as the balance, sustainability, and robustness of the system. A key element of systemic risk is the evolution of nodes and networks in which certain nodes become dominant in the integrated system. Whether they are cities or logistics, IT systems or financial hubs, more and more traffic circulating through them increases the levels of interdependence (Engle, et.al., 2015).

Interdependence often reflects the dynamics of the economy and undoubtedly carries significant advantages and disadvantages. While governance strategies have focused on the size of institutions, in a world of systemic risk the interdependence of key infrastructure systems is an important factor to consider. Each of the systems that belong to the realm of human activities is vulnerable to a series of possible catastrophes, such as pandemics, terrorism, natural and infrastructure disasters. The more a human activity is dependent of other systems, the more vulnerable is the global system integrated to that center to the risks of shocks in a specific place. Higher degree of interdependence means more probability of failure in the system (Goldin & Vogel, 2010)

Within that framework, it is crucial to analyze systemic risk within complex systems.

2.3.2 Systemic Risk within Complex Systems

The context of complex systems is characterized by uncertainty, interdependence in terms of networks and subsystems that are part of it, and complexity. Complexity is characterized in two different ways in the context of complex systems: a) structural complexity (a complex system is made up of many parts and is relatively difficult to control); b) dynamic complexity (complex systems are difficult to predict) (Bonabeau, 2007).

Systemic risk within complex systems is related to the vulnerability resulting from the tightly coupled interconnections of the subsystems that are part of a specific complex system. Systemic risk within complex systems is mainly related to risk associated to disruptions in the chain of activities that a complex system performs. One of the characteristics of complex systems is that the subsystems that comprise them are closely related to each other and are interdependent in their activities. This means that the activities of one subsystem cannot be developed without the activities of the other subsystems. Consequently, this interdependence causes vulnerability (Lucas, et.al., 2018).

Complex systems are constantly growing at all levels; this dynamic involves a great variety of factors such as products, structures, technologies, processes, and regulations. Generally, the disruptions of complex systems are characterized by insufficient attention paid to the inherent inputs and outputs and generation of gaps, failures, and defects that result from the growth and / or partial development of complex systems (Foster, 2005).

The large array of vertical and horizontal interactions and tightly coupled interrelationships between complex systems can lead them to a state of crisis. Therefore, it is important to take into account the systemic risk factor to improve their functioning. The connections among the chains of activities trigger other actions that create more interdependence, thus creating vulnerability, disturbance, or cascading effects. The complexity of the systems given from the appearance of interdependencies in the components that articulate their actions create systemic risk. Therefore, the systemic risk arises due to the interdependencies between the systems that are part of the complex system (Boccara, 2010).

In order to know what the resistance thresholds of the complex system are, alongside its capacity for adaptation and self-organization, an approach where systemic risk is considered within the analysis of complex systems assumes that systems are interdependent and non-linear, with feedbacks at different levels that allow the system to self-organize, continuously adapt, and change in an unpredictable way (Renn, et.al., 2020)

Based on the two ways to refer to complexity, it is considered that systems are generally characterized by the interactions that exist with the environment, these are: a) non-linear between their elements, they adapt mutually and are influenced by their environment and have an impact on the setting in which the systems are located; b) no interactions between its elements, this means that the causes and effects are not proportional to each other; heavy-tail distributions, when there are strong interactions the elements of the system change their normal distributions and often the statistical distributions characterize their behavior, resulting in extreme events; creating in this way network interactions (these are not linear), they have feedback loops and vicious circles with side effects. These risks lead to a critical point or inflection point, thus causing damage or disaster (Herring & Carmassi, 2014).

Systemic risks can manifest as unexpected changes or threats to complex systems, these changes and threats are unavoidable and the way to cope with them is to properly model and manage systemic risk. It is important to bear in mind that human activity systems develop in unstable and complex environments that leads them to situations of continuous risk and to changes that directly affect them (Cai, et.al., 2018). Below is a diagram showing the different interconnections that exist in the risk.

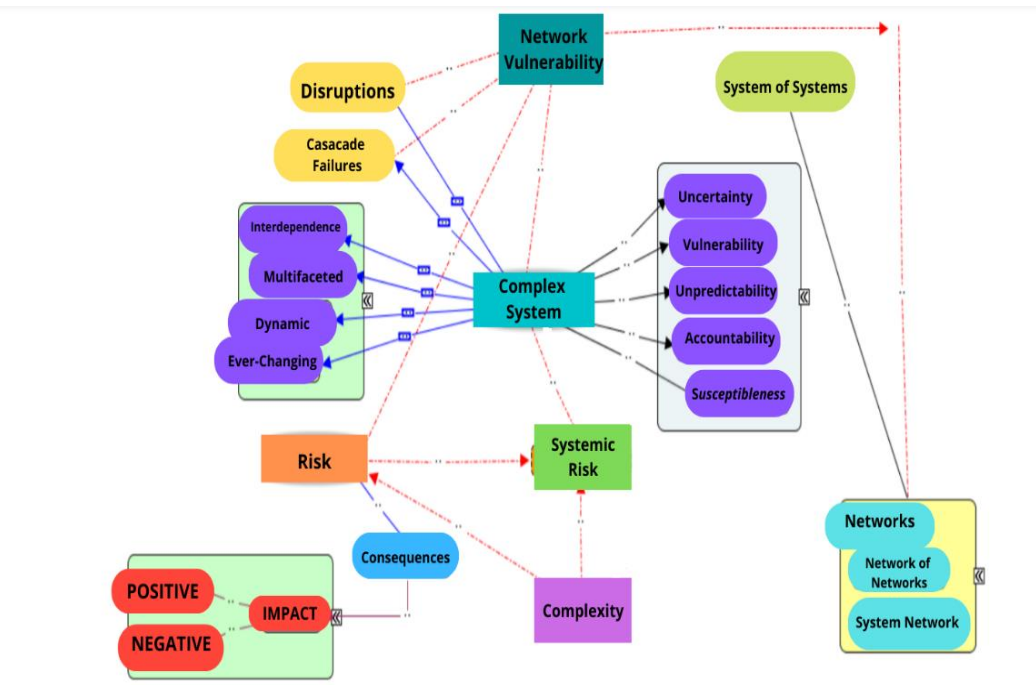


Figure 14. Systemic Risk within Complex Systems

A failure in a system has effects on other dependent subsystems. Systemic risk is gestated in the coupling of different types of systems and new vulnerabilities, it is the result of growing interdependencies. Within organizations, systemic risk results from the possibility of disturbance, since the characteristic of systematic risk is uncertainty, therefore: its effect is unpredictable. There are risks whose effects can be of opportunity and therefore lead to a successful dynamic; as well as there can be threats (Ellinas, et.al., 2016).

2.4 Modeling and Managing Systemic Risk Within Complex Systems

2.4.1. Modeling Systemic Risk within Complex Systems

Systemic risk is unavoidable and although it cannot be fully identified, predicted, or eliminated it can be identified by spotting its common characteristics when it arises within a specific systemic setting. The repercussions that are produced by systemic risk within a complex system track to power-law. The trigger or systemic event that produces further downstream events, where the impact of the repercussions involves not only the extent of the systemic risk but also the time dimension where it occurs. Moreover, the losses resulting from systemic risk might accumulate over a future period of time, that means even after the crisis is over (Hansen, 2013).

The challenges of identifying systemic risk arise from the fact that historical data cannot be used as evidence of the presence or absence of systemic risk since it is characterized by outcomes that lead to unanticipated behavior. The factor of causation, which is an important factor in risk identification cannot be determined only through data. It is necessary to have a knowledge-based analysis of the processes that produce the data, the quality of such analysis depends of the strength of such knowledge (SoK) (Mezei & Sarlin, 2016).

In modelling systemic risk, a broad understanding of the structure and patterns of intra- and inter-subsystem interactions to explore and increase their resilience and adaptive capacity is strictly necessary. Complex systems fluctuate constantly and if systemic risks are not anticipated nor managed correctly, large-scale disasters can occur (Danıelsson, 2002).

Systemic risk modelling within complex systems can be carried out by identifying the agents that make part of the system, carrying out a cost-benefit assessment and/or assessing the vulnerabilities and uncertainties under the context of a specific complex system, the use of such measures vary depending of the nature of the complex system (Serguieva, 2014).

Some authors (Amblard and Phan, 2006) argue that agent-based models can be used to predict, describe, understand, and even act, as is the case with participatory modeling. Agent-based risk modelling improves the understanding of the structure of a complex system and simulating its dynamic evolution over time. Agent-based models can be built with different objectives or purposes.

Agent-based risk modeling makes it possible to explicitly represent three elements of central interest to complex systems: agents, the environment, and behavior rules. The latter refer to at least three main questions: (i) what agents can do with the elements that make up the environment (agent-environment rules); (ii) to the action and interaction between the agents that make up the model (agent-agent rules); and (iii) the behavior of the elements that make up the environment (environment-environment rules) (Epstein and Axtell, 1996). Therefore, agent-based modeling allows not only to model agents within the system but also to represent “the interaction structure between the social actors in the environment that surrounds the system” (Janssen & Sharpansky, 2017)

Through agent-based modeling the real heterogeneity of the actors that make up a complex system, taking into account the diversity of behaviors, identities, social networks of functionality and activity. Consequently, agent-based modeling makes it possible to overcome one of the problematic aspects of mathematical and statistical modeling of complex systems, which lies precisely in the fact that this type of modeling eliminates the heterogeneity of real phenomena and models an "average agent", " ideal ”or“ representative” (Railsback & Grimm, 2019).

Agent-based modeling does not use representative agents but heterogeneous agent populations that vary across a number of characteristics. Therefore, agent-based modeling makes it possible to operationalize the diversity and heterogeneity of activities, processes, and interests of individual and collective actors represented in a complex system. The agents within the modeling are not autonomous, that is, there is no central control over the behavior of the individual agents (Macal & North, 2009)

Agent-based modeling addresses the micro-macro link in two directions. First, they allow to model and simulate the link from the micro to the macro, that is, “how local and decentralized interactions between autonomous and heterogeneous agents generate a certain macrosystemic regularity (Epstein, 2006). Agent-based modeling constitutes an emergent modeling strategy in which the dynamics “from the bottom up” are studied, from the local to the global, from the micro to the macro (bottom-up modeling), which contrasts with the traditional modeling techniques that operate top-down or top-down, that is, "top-down." While traditional modeling starts with structures already created, agent-based modeling studies the process of creating new structures. Second, agent-based modeling contributes to understanding the link from the macro to the micro, relative to the way in which “social structures constrain and influence future actions and interactions between individual actors” (Fouque & Langsam, 2013).

Taking into account vulnerability and uncertainty when modelling systemic risk within complex systems is also important. Vulnerability assessment, in the context of complex systems, is the assessment of the capacity of a system to withstand or absorb the impact of an event that characterizes a hazard. The vulnerability assessment from the point of view of complexity has developed remarkably. Its study has directly benefited from the conceptual contributions and technological advancement of engineering in various fields. The analytical and experimental study and the investigation of new models and methodologies for estimating the possibility of failure, and the reliability and security of systems has contributed significantly to the study of vulnerability (Blancher, et.al., 2013).

Likewise, the vulnerability assessment is a process by which the degree of susceptibility and predisposition to damage of a complex system exposed to a particular threat is determined, contributing to the knowledge of risk through interactions of said elements with the dangerous environment. The elements exposed, or at risk, are the complex social and material system represented by people and by resources and services that can be affected by the disruption of a human activity system, such as buildings, vital lines or infrastructure, centers of production, profits and vital services (Blancher, et.al., 2013).

2.4.2. Managing Systemic Risk within Complex Systems through Improving System Resilience

An approach that has resulted useful when seeking to manage systemic risk within complex systems is to strengthen resilience within the system. There are six principles that are fundamental to improve resilience within complex systems.

Maintaining Diversity and Redundancy: Focusing efforts on the diversity and redundancy of a complex system can enhance the resilience of complex systems, as it allows system actors to adapt in response to changes in markets or the environment. Redundancy is rarely conserved or managed, but to provide resilience is as important as diversity. Special attention should be paid to important functions or services that have low redundancy, such as those controlled by key actors (Low, et.al., 2003).

Manage Connectivity: Connectivity refers to the structure and force with which resources and actors are dispersed, migrate, or interact throughout the areas and domains of a complex system. Connectivity can be managed by mapping it. In order to understand the effect of connectivity on the resilience of the activities that are carried out within a complex system, the first step is to identify the relevant actors, its interactions, and the force of the connections. Once the mapping has been carried out, the visualization and network analysis tools can help reveal the structure of the network. (Turnbull, et.al., 2018).

Identifying important elements and interactions is crucial to guide possible interventions and optimize connectivity, it is important to identify the central nodes or the isolated fragments of the complex system. This helps to identify vulnerable and resilient parts of the system. Retrieving connectivity is also important in this context. Retrieving connectivity implies conservation, creation, or elimination of nodes. Finally, optimizing current connectivity patterns can be useful to reduce or structurally change the connectivity of a system to increase its resilience (Shargel, et.al., 2003).

Manage feedback variables: Feedbacks within a complex system are "connectors" in both directions, between variables that can reinforce (positive feedback) or dampen change (negative feedback). The main challenge in managing feedback variables within a complex system is to identify the variables and feedbacks that maintain the regimes that produce the desired activities within the complex system and to identify where the critical thresholds are that could lead to a reconfiguration of the system (Haimes, 2018).

Once this has been identified, the following guidelines can be applied, albeit tentatively:

- Strengthen the feedbacks that maintain desirable regimes in the system.
- Avoid actions that hide feedback.
- Monitor important slow variables.
- Establish governance structures that can respond to monitoring information.

Strengthen a Complex Adaptive Systemic Approach: Researchers from a wide variety of disciplines now debate, embrace and advocate for a complexity approach as a fundamental basis to understand and deal with the current and pressing challenges of complex systems. An adaptive complex systems approach means moving away from reductionist thinking and accepting that in a complex system there are several connections at the same time at different levels. What's more, complexity thinking means accepting unpredictability and uncertainty, and acknowledging a multitude of perspectives (Rammel, et.al., 2007).

Although this principle is not a strategy necessarily aimed at directly enhancing the resilience of a system, recognizing that these particular types of systems are based on a complex and unpredictable network of connections and interdependencies is the first step towards management actions that can promote the resilience.

Channel Efforts to Constant Learning: Knowledge about a system is always partial and incomplete, this reality is no different in terms of complex systems. Therefore, efforts to improve the resilience of complex systems through continuous learning and experimentation should be supported. Resilience is about dealing with change, adapting, and transforming in response to change (Small, et.al., 2018).

As complex systems are always in development, knowledge should be reviewed constantly to allow adaptation to change, and approaches to management. Adaptive management, adaptive co-management, and adaptive governance focus on learning as an integral part of decision-making and base their strategies on the fact that knowledge is incomplete and that uncertainty, change and the unexpected play an important role in the management of complex systems (Cilliers, 2005).

Promote Polycentric Governance: Polycentric governance is a governance system in which multiple governing bodies interact to create and enforce rules within a specific policy field or location, it is considered one of the best ways to achieve collective action against disturbances and change (Berardo, & Lubell, 2016).

Unlike other more monocentric governance systems, it is argued that polycentric governance improves the resilience of systems in different ways: it provides opportunities for learning and experimentation, enables broader levels of participation, improves connectivity, creates modularity, enhances the potential for a diversity of response and creates redundancy that can minimize and correct governance errors (Ostrom, 2010).

However, the appeal of using polycentric thinking is hampered by the lack of clear principles on how to put it into practice. There are several examples of different attempts at cross-scale collaboration but very few analyzes evaluating their impacts on governance. Polycentric governance also raises challenges, which could weaken rather than strengthen the resilience of complex systems: the need to balance redundancy. A second challenge is to negotiate tradeoffs between various users of ecosystem services. These concessions often give rise to the third challenge, which is not only dealing with resolving political conflicts and the potentially skewed benefits of common resources, but also so-called scale-shopping, in which groups dissatisfied with Policies on a scale are simply directed to a more favorable political arena in which to frame their interests (McGinnis, 2005).

2.4.3. Complementary Strategies to Manage Systemic Risk within Complex Systems

According to Bonabeau (2007), there are three complementary strategies to mitigate risk these are i) assessing risk to make better-informed decisions, ii) detecting vulnerabilities and solving them before catastrophic events occur, and iii) projecting weaknesses based on resilience. For each of these strategies, there are specific concepts, models, and methods:

i) Make predictions (from the bottom up) and act: agent-based models, which are a recent technique for modeling and simulating complex systems, allow the global properties of the system to be captured from the understanding of its constituent parts and their interactions . Such models can be run multiple times (as many as desired) in order to capture synergies, usually counterintuitive, between risk factors. In other words, the best way to assess risk and discover potentially catastrophic synergies is by simulating how the organization operates in particular environments. These simulations allow you to design mitigation strategies and help to proactively manage risk (Duffey, 2011).

ii) Testing based on diversity: the best option to discover the vulnerabilities that exist and are incorporated in a complex system, is to test the system through "attacks" that demonstrate its effectiveness. For this, the simulated models provide the propitious scenario. This means that before doing tests on the real system, they are carried out on a simulated model of it. The computational simulation also allows exploring the diversity of possible attacks, their nature, and their impacts (Alderson, et.al., 2014).

iii) Robust designs: self-organization offers systems capable of responding, reorganizing, and counterattacking in situations of stress, external problems, or internal failures. One of the advantages of self-organization is that it is based on modular components from the beginning; In other words, in a self-organized system, its constituent modules and the interactions between them are designed so that they generate high-level dynamics (not designed). This implies the possibility of disturbing the constituent modules in order to achieve desired overall behaviors (Schildknecht, 2015).

Chapter 3

Research Design and Methodology

Characterizing the water-energy-food interlinkages in Norway and performing a risk-based analysis around the complexity of such interrelationships is a task that requires a holistic research methodology. Thus, two methodological frameworks were used as the core of the research design of this study. The Water-Energy-Food Nexus framework (WEF) and the Matrix of Alliances, Conflicts, Tactics, Objectives and Recommendations (MACTOR) provided the necessary set of methodological tools to carry out the research. These frameworks were chosen to carry out this research to perform different tasks. The Water-Energy-Food nexus framework was used to characterize the specific interactions of the Norwegian water-energy-food nexus. On the other hand, the matrix of alliances, conflicts, tactics, objectives, and recommendations will be used as a diagnostic tool to apply on the data collected through the characterization of the nexus.

Both frameworks will be presented and defined in this chapter, alongside the main guidelines for the research and analysis that were instrumental in elaborating a discussion of the relevant findings and results. This chapter has six sections, the first three sections provide the reader with the starting points of this study research: the statement of the problem, the purpose of the study and the research questions. The fourth section presents the research limitations of the study, while the fifth and sixth sections present the practical and technical aspects of the research process, such as design controls for the study, data collection and instrumentalization

3.1 Statement of the Problem

In the current global society, there are 748 million people without basic access to water, 805 million who suffer from chronic hunger and 1.3 billion without accessto electricity (Bhavani & Gopinath, 2020). The most immediate conclusion seems obvious: continuing with the current global dynamics of water, energy and food governance is not the most appropriate path to face these challenges. In this context, the relationships between vital resources such as water, food and energy take on special relevance.

It is thus necessary to focus research endeavors into the water-energy-food interlinkages through a comprehensive approach that pays attention to the complex interactions between human activity, resources availability and supply processes. The efficient governance of water, energy and food is crucial for strengtheningtheir systemic interconnections and reduce their vulnerabilities to guarantee their security. Access and good functioning of water, energy and food supply systems are interconnected. Therefore, integrating a characterization of systemic risk within the context of the water-energy-food interlinkages is of utmost importance (Kurian, et.al. 2018).

Norway is characterized by its low degree of landscape fragmentation. The Norwegian terrain is separated by steep mountains and deep fjords, and in a surfacearea of 385,207 km², the country only hosts 5,4 million people (Eurostats, 2020).

The country faces several challenges in providing and maintaining a good infrastructure for the provision of services related to energy, water, and food. Several challenges have arisen in the water-energy-food nexus in Norway in the last decades. For instance, Norway’s natural resources have been adversely affected by rapid socio-economic development and urbanization (Vennesland, 2005). Biodiversity, water, and soil quality have all been negatively affected by the establishment of large hydropower installations across the country and by switching from traditional agricultural practices to intensive agriculture relying on heavy use of fertilizers and pesticides. Moreover, the Norwegian aquaculture industry, primarily fish farming, is characterized by operations that are susceptible to changing weather, wind, and currents. At the same time, it faces challenges in safety for fish, personnel, environment, and material assets (Nygård, & Storstad, 1998).

Based on the context described previously, characterizing the Norwegian Water-Energy-Food nexus, and investigating how it can be optimized by measuring, modeling, and managing systemic risks that threaten it, can contributeto the discussion and academic research on systems optimization of water, energy, and food access in Norway.

3.2 Research Hypothesis

This research study focuses on the systemic risk and the importance of identifying the vulnerabilities associated to it in the context of the Norwegian water-energy-food nexus. The point of departure for the present research study is the hypothesis that systemic risk within a complex system such as the water-energy-food nexus relates to the vulnerabilities that disruptions within the sub-systems could provoke.

In order to discuss this hypothesis, the investigation will seek to identify the main vulnerabilities that threaten the Norwegian water-energy-food nexus to ascertain whether they are associated to systemic risk or to other factors. The investigation will also relate these findings to system resilience and complexity and the uncertainty in the context of complex systems. Moreover, this investigation also departs on the assumption that awareness of the vulnerabilities associated to systemic risk that threaten the nexus can contribute to the optimization of water, energy, and food supply systems, ensuring security of these three valuable resources for human activity.

3.3 Research Questions

This research study is based upon the following research questions:

- What are the specific characteristics, dynamics, and challenges of the Norwegian water- energy-food nexus?
- In what ways could systemic risk be modelled and managed within the Norwegian water-energy-food nexus?
- What strategies could contribute to proper modelling and management of systemic risk within the Norwegian water-energy-food nexus?

3.4 Research Limitations

The Water-Energy-Food nexus is a matter of global relevance and importance.However, this research study has limited its scope to analyze the nexus within the geographical limits of Norway and will therefore not analyze the research variables on any regard outside those geographical limits. Moreover, although this study analyzes systemic risk within the Norwegian water-energy-food nexus, the research has been directed specifically to the systemic risks resulting of some global change processes.

Global change processes are vast, and this research study cannot cover all the array of global processes that coexist within the vast global dynamics. Consequently, this research study will only cover the risks associated with the global processes of ecosystem services associated to water, energy and food and water-energy-food supply. Factors such as economy, urbanization, globalization, health and several more that also makepart of global processes will not be addressed in this study in a specific fashion.

In addition, although there is a wide array of managing systemic risk within complex system, this research study places particular emphasis on resilience improvement as a way to improve resilience

3.5 Design Controls of the Study

Design controls as explained by Kirschenbaum & Perri (1982) are required to assure internal validity of research designs and can be accomplished through four different techniques: manipulation, elimination, inclusion, statistical control, and randomization.

Through the manipulation technique, the treatments of the research variables are manipulated by the researcher, so they can be compared against the results of a study or research with the same variables but with a different control group. The elimination technique relies refers to eliminating extraneous variables and take specific variables and holding them constant across treatments. Through the inclusion technique, the role of extraneous variables is considered by including them in the research design and separately estimating their effects on the dependentvariable. In the statistical control technique, on the other hand, the research hypotheses are tested through observed data that has been modelled through statistical inference or analysis. Lastly, the randomization technique is aimed at canceling out the effects of extraneous variables through a process of random sampling, if it can be assured that these effects are of a non-systematic nature (Kirschenbaum & Perri. 1982).

Two different control techniques were applied to this study: The elimination technique and the inclusion technique. Elimination, since the application of the WEF nexus in geographical location outside Norway was eliminated and the study hold that geographical location constant across all levels of data collection and usage in the research process. The Inclusion technique was applied since extraneous variables (global processes) were taken into consideration in the research process alongside the research variables (systemic risk/WEF nexus in Norway) separately estimating the mutual effects of such variables.

3.6 Data Collection and Instrumentation

Collection and analysis of data for this study were performed by using the following tools: Document analysis and the WEF Nexus Modelling Tool 2.0. Document analysis describes the analysis of documentation that contains information about a context, scenario, or event. It is used to investigate, categorize, and analyze written papers, articles, or investigations in the social, public, or digitalworld. This research method is just as good as surveys, in-depth interviews, orother observation-based methods and usually it is also more cost and time effective (Bowen, 2009).

The WEF Nexus Tool 2.0 serves as a modelling tool and database that brings together hard data, scientific knowledge, and policy inputs to identify current and anticipated bottlenecks in resource allocation trends, so that possible trade-offs and opportunities can be identified to overcome resource stress challenges. The tool is scenario-based and, if used properly, can help to quantify the interconnections between the main three resources, while capturing the effects of population growth,changing economies and policies, climate change and other stresses. It provides theresearcher with the ability to create scenarios for a given country by defining its food, water, and energy portfolios; to then visualize and compare the resource requirements of their scenarios and calculate the 'sustainability index' of each scenario (Dargin, Daher & Mohtar, 2019).

3.6.1. Instrumentation

A mixed methodological approach with both quantitative and qualitative methods was used to answer the research questions of this study. Two main different frameworks were instrumental to analyze the data collected and performan assessment to identify the main research queries: the Water-Energy-Food (WEF)nexus and the Matrix of Alliances, Conflicts, Tactics, Objectives and Recommendations (MACTOR). Both combine qualitative and quantitative resources to assess and analyze specific scenarios. By using a combination of the WEF and MACTOR methodologies, this study represents the interaction of different natural resources and understand trade-offs inherent in the water-energy-food interlinkages as well as the consequences for the surrounding ecosystem and society.

They were instrumental in analyzing the Norwegian water-energy-food interlinkages as a system rather than isolated cases. They also provided a clear methodological framework where defining terms, studying the relationship between items, analyzing the relationship between models/indicator systems/analytical frameworks; and sharing the relationship between metadata items was possible. These factors have been used as a basis to establish the relationship between the water-energy-food interlinkages and the processes of measuring, modeling, and managing systemic risks. The water-energy-food nexus can be used in different ways. For example, as a conceptual framework, analytical tool, or as a discourse. For the purpose of this study, it was used as an analytical tool. As an analytical tool, a WEF nexus analysis uses quantitative and qualitative methods to understand interactions among water, energy, and food supply systems (Albrecht, Crootof, & Scott, 2018)

The MACTOR method proposes a method of analysis of the actors' game through simple tools that allow taking into account the complexity of the system to be analyzed. It seeks to assess the power relations between the actors and study their convergences and divergences with respect to a certain number of positions and associated objectives (Elmsalmi & Hachicha, 2014).

Hereafter, a comprehensive description of both frameworks will be provided.

3.6.1 Water-Energy-Food Nexus Framework (WEF)

3.6.2.1 Definition and Challenges of the Water-Energy-Food Nexus Framework.

The Water-Energy-Food Nexus Framework, when used as an analytical tool, isa conceptual and methodological framework that supports the process of characterizing correlations, interactions, synergies, and trade-offs between the water, energy, and food sectors. Moreover, it also takes into account within the process of characterization the interrelationships between human systems and natural systems in a delimited context. This framework focuses its approach on the biophysical and socioeconomic resources that are needed to achieve environmental and economic optimization related to water, energy and food systems (Terrapon- Pfaff, et.al. 2018).

The interactions between human and natural systems take place in the context of global external factors, such as demographic change, urbanization, industrial development, agricultural modernization, international and regional trade, markets and prices fluctuation, technological advancement, and climate change - in additionto the structures and processes of government, beliefs, and cultural and social behaviors. In this context, the Water-Energy-Food Nexus Framework is then necessary to characterize and understand such complex and dynamic relationships in order to manage these resources in a sustainable way. This approach makes it possible to identify the dynamics and interactions between the different sectors.Liu, et.al (2007).

Within the framework, it is clear that since the interrelationships are complex and dynamic, then no sectoral issue can be examined nor described independently from the others. An important observation that should be emphasized when defining the framework, is that it has to be applied within the broader context of global transformation processes which are intrinsic to the water, energy, and food supply systems. By identifying the dynamics and interactions between the water, energy and food sectors, the Water-Energy-Food Nexus Framework aims to avoid an escapist approach towards the risks that arise within the nexus interlinkages.That means, overlooking the risks that arise from the complex interactions between the sectors.

Additionally, the framework seeks to improve communication between the interlinkages to avoid the existence of separate entities that stockpile crucial information, where a lack of proper sharing of crucial information might lead to flawed risk assessments and increased uncertainties within the nexus. The Water-Energy-Food Nexus Framework presents an interdisciplinary approach to such issues, promoting opportunities for creating mutually beneficial planning, functioning of the nexus, and cooperation among all sectors (Karnib, 2017).

The application of the Water-Energy-Food Nexus Framework cannot be possible without vital factors, such as: active participation and collaboration ofmain stakeholders (i.e. private sector, civil society, and government agencies) and research and analysis from experts in disciplines and areas of concern within the nexus.

This factor is particularly important because expert advice is crucial to translate the theoretical basis provided by the framework to more pragmatic and practical strategies that can be carried out in real life. An efficient application of theWater-Energy-Food Nexus Framework would manifest in a series of benefits that will make possible to meet the increasing and ever-changing global demands, without having to compromise sustainability. The proper application of the framework will aid in the process of creating policies, investments and strategies that will align with the necessities of the specific context in which the Water-Energy-Food nexus framework is being applied (Simpson Jewitt, 2019).

It is important to bear in mind the existence of different conceptions about the Water-Energy-Food Nexus Framework, which vary in terms of scope, objectives, and interpretation from author to author.

For instance, according to the Food and Agriculture Organization of the United Nations (FAO), it is a systematic framework that allows the analysis of the coupled human-nature systems, with the aim of achieving integrated management of natural resources across different sectorial scales by treating trade-offs andmanaging synergies (FAO, 2014).

Other authors, such as Scott et.al., (2015) conceptualize the framework as a tool to improve resource recovery processes and achieve resource usage efficiency. Keskinen et al., (2016) argue that the framework can be understood and used as a governance tool and analytical tool. In addition, they state that the water-energy-food nexus is so complex and wide that it can be anemerging discipline.

In terms of the applicability of the Water-Energy-Food Nexus Framework, Molajou, et.al., (2021) claim that it is a crucial tool to holistically design the future ofinterlinked systems from the very starting stages of planning, which makes it usefulto identify conflicts and synergies within the systems. However, Smajgl, et.al., (2016) on the other hand, state that the majority of applications of the Water- Energy-Food Nexus Framework have not been successful in analyzing the nexus with a proper cross-sectorial approach, but rather they have been and remain water-centered.

The approach where one system is given priority in analysis contradicts the main objectives of the Water-Energy-Food Nexus Framework, which places emphasis on considering each one of the interlinkages (water, energy, and food) as an existing, inherently interconnected system. Within this recurring criticism, it can be argued; that the conceptual framework structured as it is, promotes the integrated and coordinated management of water, energy and food as a means of balancing the protection of resources and the satisfaction of ecological and societal needs alongside economic development. However, a specific focus on water runs the risk of prioritizing water-related goals over others, reinforcing traditional sectoral approaches and compartmentalized thinking, depends on the researcher or analyst carrying out the application of the framework.

If applied correctly, the Water-Energy-Food Nexus framework, incorporates the different dimensions of water, energy, and food, considering them equally within an approach where the interdependencies of different uses of resources are recognized to promote sustainability.

Smajgl's findings leads to highlight the challenges of the Water-Energy-Food Nexus Framework. Lofman, et.al., (2000) state that the water-energy-food nexus encounter difficulties during its application in terms of finding equilibrium betweenthe what the society/users need and the protection of natural resources. Especiallyin the areas of agriculture, industrial sector, and residential areas.

Furthermore, one of the main challenges that the Water-Energy-Food Nexus Framework faces as a conceptual and methodological framework, is that according to some academics and experts, its contribution to existing models, methods and frameworks to analyze the interconnections among water, energy and food supply systems is rather poor and does not provide anything that pre-existing frameworks could not do.

It is argued that approaches such as landscape integrated approach or the integrated water resource management approach are just as efficient in delivering the results the Water-Energy-Food Nexus Framework offers (Serrano-Tovar, et.al., 2019).

Moreover, Albretch et.al., (2000) supports the idea that, although the conceptof the water-energy-good nexus framework is promising, its application as ananalytic tool to diagnose and examine the interlinkages of the water-energy-food nexus has been limited. Middleton, et.al., (2000) argues that the framework has not yet been integrated into practice.

Similarly, Leck et al., (2000) states that the practical application of the water-energy-food nexus in future scientific research is necessary.

In conclusion, the Water-Energy-Food Nexus Framework provides with the theoretical basis to understand the interdependencies among the water, energy, and food sectors. These sectors, within the framework, are conceptualized as interlinkages that are part of a system, meaning that the dynamics, failures, risks, and synergies directly affect the other two interlinkages. Furthermore, these dynamics influence external areas such as policy making and governmental decision-making due to their practical proximity to issues such as climate change and biodiversity sustainability.

3.6.1.1 Origins of the Water-Energy-Food Nexus Framework.

The concept of the water-energy-food Nexus arises from the Davos annual meeting in 2008, where for the first time the interrelationships among these sectors where problematized as a systemic interdependency. Three years later, at the Bonn Conference in 2011; the World Economic Forum exposed the correlation of risks between the water, energy, and food sectors; which were described in the Global Risk Report of the same year.

In 2014, during the Global Water Security & Sanitation Partnership conference (GWSP), research and policy-making organizations from all around the world raised awareness about the importance of developing strategies to analyze the water, energy, and food sectors though an integral nexus approach (Hajko,et.al. 2018).

In this context, FAO, in collaboration with various organizations and groups of experts, developed a framework based on the Water-Energy-Food nexus in order to achieve water, energy and food security in the face of the growing pressures and competencies generated by urbanization, agricultural expansion, economic development and climate change on natural resources.

Over the years, the nexus framework has been integrated into the FAO technical assistance and cooperation policy framework in various regions with different risks and challenges regarding the Water-Energy-Food nexus, at the same time that it has been promoted through learning platforms and dialogue about the Nexus (Mohtar & Lawford 2016).

3.6.1.2 The Water-Energy-Food Nexus Approach.

The framework works under a nexus approach in which the complex interrelations, interdependencies and conflicts between water, energy and food, andtheir various actors and sectors are identified, and it is especially useful in the analysis of such factors in environmentally challenged regions.

By recognizing these dynamics and promoting a systemic view, the approach that the framework offers can help in providing key inputs to mitigate the risk of malfunctioning interconnections between sectors, at the same time that it can be useful to identify viable options that help to promote a coherent management and efficient use of natural resources, to strengthen management and logistics paths effectively.

The historical background of the water-energy-food nexus concept prompted the FAO's institutional efforts that seek to achieve water, energy, and food security. The FAO's approach to the water-energy-food nexus considers the complex interrelationships and feedback between natural and human systems, as it can be seen in Figure 15.

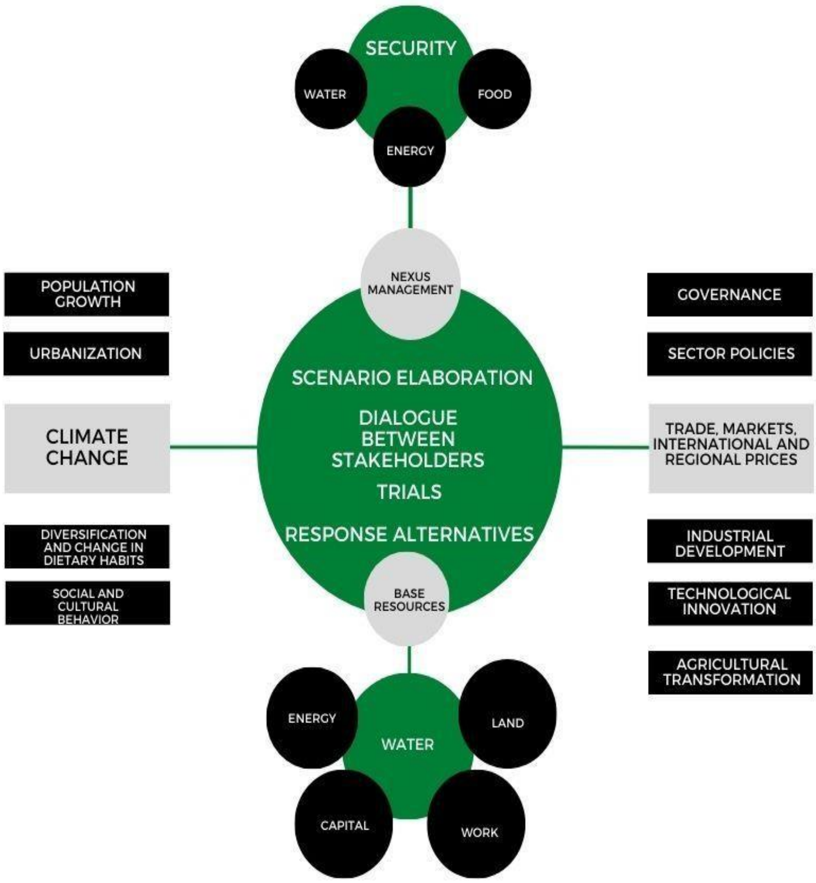


Figure 15. The FAO's Approach on the Water-Energy-Food Nexus

The approach uses base resources as the bottom line of the characterization of the water-energy-food nexus. The base resources are all those natural and socioeconomic resources that are vital to achieve social, environmental, and economic standards for water, energy, and food security.

The interlinkages of the elements that make part of the nexus are related in the way human populations use and manage the resource systems. Therefore, describing the interdependencies that exist among them (the way each of them depends on the others), the difficulties (the imposition of conditions or compromise solutions) and synergies (the way in which certain benefits are strengthened or shared) is crucial withing the application of the water-energy-food framework (FAO, 2013)

The next aspect of the approach is nexus management, and it comprehends a series of elements such as scenario elaboration, dialogue and communication between stakeholders, trials or tests and alternatives of response. The elaboration of scenarios within the nexus is useful for exploring strategic issues, reviewing policies and investment decisions, and generating a commonunderstanding of the mutual relationships between water, energy, and food and the underlying factors of each sector.

The dialogue between stakeholders is necessary to obtain relevant information at the aggregate level and scale required, and lastly, it contributes to generating a spirit of stakeholder ownership and legitimizingdecision-making processes. Trials or tests, on the other hand, are necessary assess and analyze the interrelationships of the Nexus in an accurate, reliable, relevant,and timely manner (FAO, 2014)

It is essential to establish a link with observing systems - existing and expectedto be established - in all parts of the world, given the existing problems in terms of data availability and quality. This will help fill data gaps and provide key data to decision makers (Karatayev, et.al., 2017).

The elaboration of response alternatives deals with a) planning and implementation of new policies, investments, regulations and incentives (such as subsidies, promotion of appropriate business models, institutional mechanisms, financial instruments and fund / financing services, legislation, instruments of policies and support mechanisms), capacity building and technical training and interventions, and b) the process of evaluating and comparing the impacts of different interventions. Lastly, based on the analysis of the previous elements water, energy and food security can be analyzed.

The analysis of resource security will be, in this way, backed by evidence-based assessments and developed to understand local and global resource systems are interrelated. In this way, the Water-Energy-Food Nexus can help to avoid some of the negative consequences of inadequate sector coordination, institutional fragmentation, and insufficient capacity, and to face, in a more participatory and open way, sectoral interests and political sensitivities (FAO, 2014)

3.6.1.3 Application of the Framework: Characterizing the Water-Energy-Food Nexus.

Based on the approach previously described, the application of the nexus methodology is performed through four main stages (Stylianopoulou, et.al., 2020):

- Stage 1: Participatory Analysis of the Nexus:
  - ✓ Situational Assessment
  - ✓ Identification of Key Actors
  - ✓ Conceptualization
  - ✓ Participatory identification of Nexus Interactions
  - ✓ Differentiated Analysis of the Nexus

- Stage 2: Quantification of the Nexus
  - ✓ Definition of Indicators
  - ✓ Development of Detailed Schemes for Quantitative Analysis
  - ✓ Review and Systematization of Secondary Information
  - ✓ Collection of Primary Data
  - ✓ Data Systematization
  - ✓ Quantification of Nexus interactions
  - ✓ Homogenization and Visualization of Quantified Interactions

- Stage 3: Scenarios within the Nexus
  - ✓ Identification and prioritization of Key Variables and Pressing Issues
  - ✓ Trend analysis and generation of variation rates
  - ✓ Correlation of variables between Pressures and Interactions of the Nexus
  - ✓ Planning and Definition of Scenarios
  - ✓ Definition of Variation Rates according to Scenario Type
  - ✓ Generation of Supply and Demand Scenarios
  - ✓ Elaboration of Quantified Schemes of the Scenarios
  - ✓ Validation of Scenarios and Participatory Identification of Risks and Impacts on the Nexus

- Stage 4: Governance Assessment of the Nexus
  - ✓ Mapping of Institutional Functions
  - ✓ Policy Review and Mapping
  - ✓ Governance Capacity Assessment

3.6.2. Matrix of Alliances and Conflicts: Tactics, Objectives and Recommendations (MACTOR)

MACTOR stands for "Matrix of Alliances and Conflicts: Tactics, Objectives and Recommendations". It was developed by the LIPSOR of the CNAM in Paris in the mid-eighties. The MACTOR method seeks to assess the power relations between the actors and study their convergences and divergences with respect to a certain number of positions and associated objectives (Godet, 2003). The use of the MACTOR method consists of analyzing and identifying the role of key actors within a system, in order to optimize processes, improve decision making or establish new guidelines within the system. The MACTOR Method aims to study the role of actors within a system by analyzing the interrelationships between them. For this reason, the emphasis of the method is placed on their convergences and divergences of the interrelationships of actors or stakeholders regarding specific objectives or activities.

Once the analysis has been carried out, strategic recommendations can be formulated not only for the current state of the interrelationships within the system, but for the future interactions as well (Manel and Hachicha, 2014).

The MACTOR method has been used in a variety of projects, some of them related to the exploitation of renewable resources (Mangifera & Isa, 2019), risk management in supply chains (Elmsalmi and Hachicha, 2014), expansion of communication networks (Yamakawa et. Al., 2012) and the recovery and care of the environment (Leach, et.al., 1999). In the field of complex systems analysis, the method has stood out for studies associated with the design of strategic scenarios to make systems activities more efficient (Tourki, et.al., 2013). In other cases, the method has been instrumental to analyze how constant economic and social changes affect the development of human resources in complex systems in human activities (Macharis & Bernardini, 2015). Figure 1 represents the logical structure of the MACTOR method. (Elmsalmi & Hachicha, 2014).

The MACTOR Method provides real added value to the analysis of complex systems through tools that can be applied in multiple types of systems, these applications are capable of taking into account complex data and interrelated data and relationships of various actors (Godet, 2000). In addition, this methodology covers the methodological deficit between the construction of the actors' strategy framework, and the elaboration of the holistic pertinent scenarios existing in the methodology of the water-energy-food nexus. The method offers the possibility of obtaining information based on matrices, where actors and objectives are related, denoting the origin of possible alliances and identification of conflicts, which will give rise to possible hypotheses about the state of the future. The analysis of the relationships between actors and the strategic objectives set, allows highlighting those key variables that would justify the creation of an associative figure. This method stimulates reflection within the group of actors (Bendahan, et.al., 2004).

3.6.3.1 Application of the MACTOR Methodology

The MACTOR method comprises a process of 5 to 7 phases depending on the specific use that the analyst or research needs to give to the application of the method. For the purposes of this study, the MACTOR method will be applied in five phases:

First Phase: Identification of Actors that Control or Influence the Key Variables of the System

This phase makes it possible to identify the key stakeholders that influence the development of the activities of a system. The phase comprises in practice, formulating an exhaustive list of these actors, however, for reasons of operability, it is recommended that the number of actors be limited to between 12 or 15 actors (Popp & Peto, 2018).

Second Phase: Identify Strategic Objectives and Challenges

The dynamic interactions between actors with different interests make it possible to identify their strategic challenges, on which they will have convergent or divergent objectives. The objective of this phase is to make a list of objectives pursued by the actors according to the variables of the system and the challenges posed by these objectives (Popp & Peto, 2018).

Third Phase: Evaluation of Direct Influences among the Actors

Some of the actors will have an important influence on the rest of the actors and on the system itself. The objective of this phase is to create a matrix where it is possible to visualize the degree of "hierarchy" based on its influence within the system. This type of matrix is known as an actor influence matrix (Popp & Peto, 2018).

Fourth Phase: Hierarchy of Actors with Respect to Objectives:

Once the list of key actors, strategic objectives, and the matrix of influence of actors has been made, the current position of each actor with respect to each objective must be described. This is done through a matrix of evaluated positions (Popp & Peto, 2018).

Fifth Phase: Formulation of Strategic Recommendations and Key Questions for the Future.

The analyst, after having carried out the previous phases, can formulate proposals to make the interrelationships of the system actors more efficient, increasing synergies and consequently, achieving a more precise and safe scope of objectives (Popp & Peto, 2018)

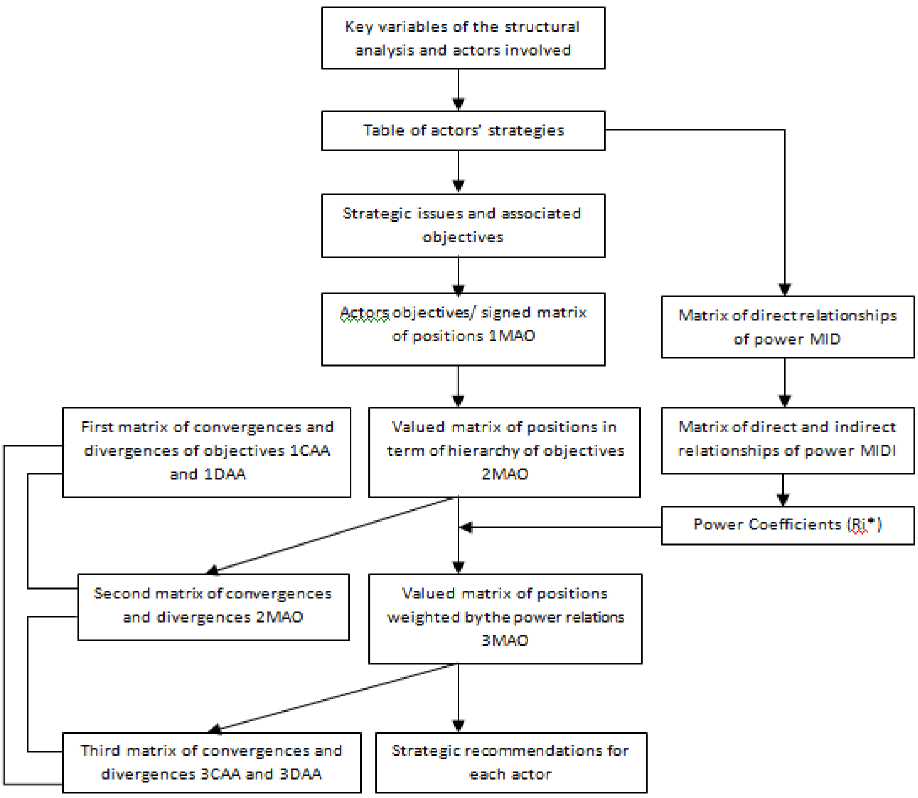


Figure 16. Flow Chart of the MACTOR Method

(Elmsalmi & Hachicha, 2014).

3.6.3. Application of the Water-Energy-Food Nexus Framework and the Matrix of Alliances and Conflicts: Tactics, Objectives and Recommendations in the Research Study

As explained throughout the chapter, this research study applied both of the frameworks explained above to obtain an integral methodological basis for the research. The frameworks were used as follows:

The water-energy-food nexus framework was applied in order to characterize the interactions and interconnections of the Water-Energy-Food nexus in Norway. Through the application of this framework, it was possible to have a clear guide of the necessary data to be collected and how it should be organized in order to characterize the Norwegian water-energy-food nexus in a comprehensive fashion. Carrying out this task was possible due to the series of relevant steps and materials that the framework provides to replicate the analysis based on the nexus approach, which aids the process of replicating such an analysis in a context with the characteristics of the Norwegian water-energy-food nexus. The application of the Nexus approach in Norway generated a better understanding of priority interactionsof the Nexus. In a country where due to its challenged weather and current land useposes risks poses water, energy and food security, the identification of systemic risks is crucial to identify gaps and opportunities in the process of optimization of the nexus.

After having applied the water-energy-food nexus framework, the data collected, which was later converted to a characterization of the nexus, was used to carry out an analytical review of the dynamic interactions of the key actors within the Norwegian water-energy-food nexus.

Through the application of the 5 stages of the MACTOR method, it was possible to not only identify the metabolic dynamics of each of the water, energy and food systems in Norway, by identifying the trade-offs within the nexus and level of influence of each of the key actors. Moreover, the last stage of the methodology was instrumental to identify the opportunities the Norwegian water-energy-food nexus may have in the future in term of the optimization of its activities.

The application of the water-energy-food nexus framework was instrumental in identifying systemic risks within the Norwegian water-energy-food nexus. The MACTOR method is methodologically compatible with the modern risk science approach on risk mitigation, through the analysis, it was possible to carry out the identification of trade-offs within a real-life water-energy-food nexus a realistic task, allowing to elaborate alternatives to more robust scenarios within the nexus.

In conclusion, combining the water-energy-food nexus approach with a methodology based in analyzing trade-offs within a system through the interaction of its key actors and components, was instrumental to avoid the analytical gaps described beforehand about the water-energy-food nexus framework methodology. The combination of the water-energy-food nexus framework and the matrix of alliances and conflicts, tactics, objectives and recommendations, is a feasible and efficient combination to collect data, characterize a water-energy-food nexus, diagnosing the robustness of the nexus, identifying systemic risks, and carryingsuch tasks under a holistic approach where all sectors have the same priority within the analysis.

Chapter 4

Characterization of the Norwegian Water-Energy-Food Nexus Through the WEFN Methodology

4.1. First Stage: Quantification of the Norwegian WEF Nexus

4.1.1. Geography and Topography

Norway’s geographic territory, with a total extension of 385,207 km² comprises the westernmost and northernmost portion of the Scandinavian peninsula. The rugged Norwegian coastline is divided by huge fjords and thousands of islands. The coastal baseline stretches by 2,532 kilometers (1,573 miles) and the mainland's coastline, including the fjords, stretches by 28,953 kilometers (17,991 miles); when islands are included, the coastline is estimated to stretch by 100,915 kilometers (62,706 miles). (Geography of Norway, 2021)

Norway shares a 1,619-kilometer (1,006-mile) land border with Sweden, 727 kilometers (452 miles) with Finland, and 196 kilometers (122 miles) with Russia to the east. To the north, west and south, Norway borders the Barents Sea, the North Sea, and Skagerrak (Christensen, 2021).

The mountainous relief divides Norway into three major regions: Finnmark, which begins where the Alps end, is a set of plateaus with a rounded profile. The Northern Area, bounded by the Alps and the Trondheim Depression, a wide fjord that delimits an inland sea, forms a narrow strip between the ocean and Sweden, with peaks that rise more than 1,700 m above sea level and the Southern Area, south of Trondheim, where the relief takes on an alpine character, with the highest group of mountains in the country, such as Jotunheim (Mountain of the Giants), with the Glittertinden or Galdhöpiggen peaks, reaching 2 469 m, and the largest glaciers in Europe. (Topography - Norway, 2006)

4.1.2. Natural Resources

Norway is rich in natural resources, including oil, hydroelectric power, fish, forests, and minerals. Large reserves of oil and natural gas were discovered in the 1960s, leading to a boom in the economy. Norway has achieved one of the highest standards of living in the world in part by having a large amount of natural resources compared to the size of the population. In 2011, 28% of state revenues were generated by the oil industry. Norway is the first country to ban deforestation to prevent the disappearance of forests, the country declared this initiative at the UN Climate Summit in 2014, along with Britain and Germany (SSB, 2021: Steigum, et.al., 1999).

Oil and gas export earnings have arisen to more than 40% of total exports and constitute almost 20% of the Norwegian gross domestic product. Although it is not a member of the OPEC, Norway is the world's fifth largest oil exporter and third largest gas exporter. In 1995, the Norwegian government established the oil fund, which would be financed with oil revenues, including taxes, dividends, sales income, and license fees. This was intended to reduce overheating in the economy from oil revenues, minimizing the uncertainty of oil price volatility, and provide a support to offset the expenses associated with an aging population (Larsen, 2005).

In 2017, assets controlled by the oil fund exceeded a value of US$ 1 trillion (equivalent to US $ 190,000 per capita), approximately 250% of Norway's GDP in 2017. It is the largest sovereign wealth fund of the world. The fund controls approximately 1.3% of all listed shares in Europe, and over 1% of all publicly traded shares in the world. The Central Bank of Norway operates investment offices in London, New York, and Shanghai. The guidelines implemented in 2007 allow the fund to invest up to 60% of the capital in stocks (maximum 40% before), while the rest can be placed in bonds and real estate. As the stock markets fell in September 2008, the fund was able to buy more stocks at low prices. In this way, the losses incurred by the market turmoil were recovered in November 2009. (The Fund -History, 2021)

In the 2000s, the government sold a third of the state oil company Statoil in an initial public offering. The following year, the main telecommunications provider, Telenor, was listed on the Oslo Stock Exchange. The state also owns significant shares in Norway's largest bank, DnB NOR, and the airline SAS. Since 2000, economic growth has been rapid, pushing unemployment to levels not seen since the early 1980s. The international financial crisis has mainly affected the industrial sector, but unemployment has remained low, at 3.3% (86,000 people) as of August 2011. Unlike Norway, Sweden had substantially higher real and projected unemployment figures such as result of the recession. Thousands of mainly young Swedes migrated to Norway to work during these years, which is easy, as the labor market and social security systems overlap in the Nordic countries. In the first quarter of 2009, Norway's GNP exceeded Sweden's for the first time in history, even though its population is half the size (Boateng, et.al., 2015:Ministry of Trade, Industry and Fisheries, 2021).

The government controls its oil resources through a combination of state ownership in the major oil field operators with about 62% owned by Statoil in 2007 and Petoro, which had a market value of about twice that of Statoil. Finally, the government controls field exploration and production licenses. The fund invests in developed financial markets outside of Norway (Olsen, 2015).

The fund's spending is restricted by the budget rule (Handlingsregelen), which limits spending over time to no more than the fund's actual value return, originally supposed to be 4% per annum, but was reduced in 2017 to 3% of the fund of the fund total value (Calmfors & Heleniak, 2020).

Norway is also the world's second largest fish exporter by value, after China. Fish from farms and fish catch is the second largest export product, behind oil and natural gas. Hydropower plants generate approximately 98–99% of Norway's electrical energy, more than any other country in the world. Norway contains significant mineral resources, and in 2013, its mineral production was valued at US $ 1.5 billion. The most valuable minerals are calcium carbonate, building stone, nepheline syenite, olivine, iron, titanium, and nickel (World Trade Organization, 2021).

The hydrographic network is made up of small streams, often interrupted by waterfalls and steep slopes due to the orography of the country. The highest flow corresponds to the Glåma River, which is 598 km long, located in the southern part of the country, where the currents are more regular and mightier. There are also many lakes surrounded by thick forests, which occupy a quarter of the Norwegian land. In the southern area, beech, elm, ash and lime trees coexist with pines and firs, which reach heights of 1,200 m in altitude, and are combined from these heights with birch trees, more common in cold and northern, to give way to the tundra, dominated by mosses and lichens typical of the arctic vegetation of the north of the country. Due to the orographic configuration of Norway, the rivers are short, but have a great flow due to the large frozen areas of its mountains that thaw in summer. In Norway the lakes occupy about 7,600 km2, which would be equivalent to approximately 2% of the total area (Sælen, 1967).

4.1.3. Climate

Norway is mostly a cold country, but there are two diametrically opposed types of climate: the polar climate in the north and the mountain glaciers and the maritime climate on the west coast. Between both climates there is a narrow strip of tundra climate. The southern and western parts of Norway, fully exposed to the Atlantic storm fronts, experience more rainfall, and have milder winters than the eastern and far northern parts. Areas east of the coastal mountains are in the shadow of rain and have lower rainfall and snow totals than the west. The lowlands around Oslo have the hottest and sunniest summers, but also cold weather and snow in winter (Hanssen-Bauer, et.al., 2009).

Norway's coastal climate is exceptionally temperate compared to areas at similar latitudes in other parts of the world. The Gulf Stream passes directly offshore through the northern areas of the Atlantic coast, continually warming the region in the winter. The temperature anomalies found in coastal locations are exceptional, as Røst and Værøy lack a meteorological winter despite being north of the Arctic Circle. The Gulf Stream has this effect only in the northern parts of Norway, not in the south, despite what is commonly believed. The northern coast of Norway would be covered in ice without the influence of the Gulf Stream. (Ketzler, et.al., 2021).

As a side effect, the Scandinavian mountains prevent continental winds from reaching the coast, causing very cold summers throughout the Norwegian Atlantic. Oslo has a more continental climate, similar to Sweden. Mountain ranges have sub-arctic and tundra climates.

There is also very high rainfall in areas exposed to the Atlantic, such as Bergen. Oslo, by comparison, is dry, shaded by the rain. Skjåk in Oppland county is also shaded by rain and is one of the driest places with an annual rainfall of 278 millimeters (10.9 inches). Finnmarksvidda and the inner valleys of Troms and Nordland also receive less than 300 millimeters (12 inches) annually. Longyearbyen is the driest place in Norway at 190 millimeters (7.5 inches) (Mangerud, 2004).

Due to Norway's high latitude, there are large seasonal variations in daylight. From late May to late July, the sun never fully descends below the horizon in the areas north of the Arctic Circle, hence the description of Norway as the "Land of the Midnight Sun", and the rest of the country experience up to 20 hours of natural light per day. In contrast, from late November to late January, the sun never rises above the horizon in the north, and daylight hours are very short in the rest of the country (Du Chaillu, 1882).

Parts of southeastern Norway, including parts of Mjøsa, have hot and humid continental summer climates, while the most southern and western coasts are mainly oceanic climates. Further inland in southeastern and northern Norway, the subarctic climate dominates. This is especially true for rain-shaded areas of the Scandinavian mountains. Some of Oppland's inland valleys receive so little precipitation annually due to the rain shadow effect, that they meet the requirements for dry sub-arctic climates. At higher altitudes, near the southern and western coasts of Norway, the rare subpolar oceanic climate can be found. This climate is also common in northern Norway, generally at lower altitudes, down to sea level. A small part of the northernmost coast of Norway has a tundra / alpine / polar climate. Large parts of Norway are covered by high altitude mountains, many of which also exhibit the tundra / alpine / polar climate (Wong, et.al., 2011).

4.1.4. Population

Norway is a sparsely populated country with the lowest density in continental Europe (13.3 inhabitants per km²). The inhospitable characteristics of the Norwegian territory and climate are the main factors of such demographic dynamic. The total population in Norway as of 2021 is of around 5.39 million people. (Statista, 2021).

70% of the land is almost uninhabited, and 90% of the population is concentrated in the southwest coastal strip and a quarter of the population lives in rural areas. 10% of the inhabitants are concentrated in the capital, Oslo, and a third of the population lives the main urban centers such as Trondheim, Bergen, and Stavanger. The rest of the population is divided into small agricultural and fishing communities located on the shores of the southern fjords, leaving the northernmost areas and the mountainous areas in the center practically uninhabited. (European Comission, 2019)

Norway has the lowest mortality rate in Europe (10.5%). However, it also has a low birth rate (14.0%), which is creating an increasing elderly population and a low working-age population. The total fertility rate (TFR) in 2018 was estimated at 1.56 children born per woman, below the replacement rate of 2.1, it remains considerably below the maximum of 4.69 children born per woman in 1877. In 2018, the average age of the Norwegian population was 39.3 years (Norwegian Institute of Public Health, 2016)

4.1.5. Economy

The Norwegian economy is an example of a mixed economy: a thriving capitalist welfare state that features a combination of free market activity and large state ownership in certain key sectors, influenced by liberal governments in the late 19th century and later by social democratic governments in the postwar era. The Norwegian economy is characterized by combining a dynamic private sector, state presence in the economy (public companies and regulations), and an extensive social protection network.

The country is endowed with important natural resources, the main ones being the oil, fishing, and forestry sectors. The oil sector is managed by the State through the state company "Equinor" and regulations involving the participation of private capital (The Economic Context of Norway - Economic and Political Overview - Nordea Trade Portal, 2021)

Regarding the fishery sector, Norway is the world's second largest seafood exporter after China. According to the WEF's Global Competitiveness Report 2019, Norway is the 17th most competitive economy in the world among 141 countries and territories analyzed in the report. Norway's strongest pillars were macroeconomic stability, health, and job training (World Economic Forum & Schwab, 2019). In terms of economic freedom, according to the ranking prepared by The Heritage Foundation, Norway is in 28th place, being one of the freest economies. Its total score in this ranking is 73.4 / 100 (Heritage Foundation, 2021). In terms of regional integration, Norway participates in the European common market through its membership in EFTA and contributes significantly to the EU budget despite the fact that the country chose to stay out of it in the 1994 referendum (Gstöhl, 1994).

Norway held first place in the world on the UNDP Human Development Index (HDI) for six consecutive years (2001-2006), and then regained this position in 2009. The standard of living in Norway is among the highest in the world. The Fund for Peace ranks Norway almost last (177th out of 178 countries ranked) on its Fragile States Index in 2021 and considers Norway one of the most stable and best-performing country in the world. The OECD ranks Norway fourth in Equal Best Life Index and third in intergenerational earnings elasticity (UNDP, 2021: The Fund for Peace, 2021: OECD, 2021)

The egalitarian values of Norwegian society have kept the wage gap between the lowest and highest paid worker less noticeable than in comparable Western economies. This is also evident in Norway's low Gini coefficient. State income derived from natural resources includes a significant contribution from oil production. Norway has an unemployment rate of 4.8%, with 68% of the population aged 15-74 employed. People in the workforce are employed or looking for work. 9.5% of the population between 18 and 66 receive a disability pension and 30% of the workforce is employed by the government, the highest in the OECD. Hourly productivity levels, as well as average hourly wages in Norway, are among the highest in the world (Kus, 2012).

The state has large ownership positions in key industrial sectors, such as the strategic oil sector (Equinor), hydropower production (Statkraft), aluminum production (Norsk Hydro), the Norwegian bank (DNB) and the supplier telecommunications (Telenor).

Through these large companies, the government controls approximately 30% of the share values on the Oslo Stock Exchange. When unlisted companies are included, the state has an even larger share of ownership (primarily from direct ownership of oil licenses). Norway is one of the major shipping nations and has the sixth largest commercial fleet in the world, with 1,412 Norwegian-owned merchant ships (Norwegian Ministry of Trade, Industry and Fisheries, 2020)

By referendums in 1972 and 1994, Norwegians rejected proposals to join the European Union (EU). However, Norway, together with Iceland and Liechtenstein, participates in the European Union single market through the European Economic Area (EEA) agreement. The EEA Treaty between the countries of the European Union and the EFTA countries, transposed into Norwegian law through “EØS-loven”, describes the procedures to implement the rules of the European Union in Norway and the other countries of the AELC.

Norway is a highly integrated member of most sectors of the EU internal market. Some sectors, such as agriculture, oil, and fish, are not fully covered by the EEA Treaty. Norway has also acceded to the Schengen Agreement and various other intergovernmental agreements between EU member states (Norwegian Ministry of Foreign Affairs, 2015)

4.2. Second Stage: Participatory Status of the Nexus

4.2.1 Water Supply and Distribution in Norway

Water supply in Norway is mostly taken from surface sources, 90% of the water supplied in Norway is taken from lakes and rivers while the other 10% is taken from groundwater sources. In Norway, the 90% of the population is supplied with water through water works and the other 10% is supplied through private wells. Norway has around 1600 water works to supply water, 1100 of the are owned by municipalities, 400 of them are smaller and private water works and 100 are used to supply holiday cabin areas. 41% of the water supply is destined to households, 2% is destined to holiday cabins and the other 25% is destined to industry purposes. Unfortunately, 32% of water destined to water supply is lost due to leaks in the water distribution systems (Kløve, et.al., 2017).

The rugged landscape of some rural areas in Norway is a difficult environment for the supply of water, sewerage, and wastewater services. The construction of a gravity-fed sewer network is impossible to install, while the waterside location of many houses makes the installation of conventional storage tanks unacceptable for environmental reasons. In order to overcome these technical challenges, many rural households have adopted an alternative to water supply and sewer management: Sulzer's pressurized sewer system technology. These systems use a compact lifting station installed on the ground outside or inside each house. The high-pressure hoses that make up the network are easy to install in difficult terrain. They can be buried in a narrow trench or even run over the fjord bed. In Norwegian rural areas, the pipes are often equipped with heating traces, allowing them to operate in shallow soils without the risk of freezing, and the pressurized nature of the system means the pipes can go up or down slopes. A domestic pump can transport wastewater up to 4 km (2.5 miles). If longer distances are needed, booster stations are installed in the network (Paruch, et.al., 2011)

On average, a Norwegian household pays 7000 NOK (850 EUR) in total fees for water and wastewater services. In order to perform the necessary investments and maintenance, there is a demand for increasing the price for these fees in many municipalities. The average annual renewal rate is 0.48 % for sewers and 0.66 % for water mains. However, it is seen as necessary to double the renewal rate to avoid sending the bill to future generations. The value of the water supply and distribution infrastructure in Norway today is approximately 1053 billion NOK (130 billion EUR). The municipal and private pipes make up around 90 % of such value. The investment needed in the Norwegian water sector is estimated to approximately 490 billion NOK (60 billion EUR) until 2030, due to several reasons such as increasing quality demands for drinking water, wastewater, and sludge, climate change adaptation, an increasing population and urbanization and the need of higher renewal rate for the water mains and sewers (NVE, 2020)

Water treatment is performed in Norway though around 2700 municipal water treatment plants for 84% of the Norwegian population. The water destined for the rest of the population in rural areas is performed by small water treatment plants. The water distribution and transport in Norway is carried out through several means.

Norway has approximately 43.000 kms of water mains, 53.900 kms of combined sewers and 15.700 kms of stormwater drains. Water distribution in Norway is also carried out through the 180.000 kms of private owned house water supply connections. Norwegian municipalities own the majority of water supply infrastructure. However, several municipalities organize their water supply through a mix of inter-municipal water supply. Norway approved a lar on municipal water infrastructure in 2012, the law states that the infrastructure for water supply must be public and cannot be privatized. In Norway, public ownership of natural resources is vital to ensure quality, safety and fair prices for the long-term (SSB, 2020)

4.2.2 Electric Power Supply and Distribution in Norway

Norway is considered a forerunner of the electricity market in the Nordic countries. In 1991, a law known as the Energy Act, was created to liberalize the entire electricity sector. This law seeks to promote generation, transmission, distribution, and marketing of electric power in a more efficient way to eliminate possible price differences between the regions of Norway (Pentzen, 1996).

In 1992, the public company in charge of the production and transmission of electricity, Statkraft, was divided into two companies. Statkraft SF, which continued with the electricity production and Statnett SF, which acquired the functions of transmission and management of the electricity networks. Statnett SF is a public company supervised by the Norwegian Ministry of Petroleum and Energy, also owning 87% of the energy transmission network. Following the merger between the Norwegian Energy Exchange and Statnett in 1993, the first electricity market was created: “Statnett Market AS”. This allowed electricity producers from other Nordic countries to enter Norway, although restrictions still existed. The aim of this reform was that consumers, whether industrial or domestic, could have the possibility of changing their electricity supplier. The main beneficiaries of this reform were industrial consumers since they managed to reduce average electricity prices (Christie & Wangensteen, 1998).

For electricity distributors, this reform did not have a great impact. The most affected by the reform were the companies that were in charge of generating electricity. These companies went from being in charge of production in a region where they had no competition to having strong competition in all regions of the country. Due to the country's orography, it has been possible to produce hydroelectric energy. Hydroelectric energy has had great benefits and therefore it has been possible to apply a tax that is levied on 30% of the excess performance of power generation (Wolfgang, et.al., 2009).

Norway has the highest shares of electric power produced from renewable natural resources in Europe. The Norwegian power supply and distribution system is public, therefore a monopoly regulated by the state, the sector shows low emissions in their electric power production and hosts half of Europe's hydro-reservoir capacity. 75% of the Norwegian electric power production is flexible (Hagos, et,al., 2014). According to the International Energy Agency, the flexibility of a power system refers to "the extent to which a power system can modify electricity production or consumption in response to variability, expected or otherwise" (Flexibility (Power System) - Energypedia, 2018).

The operator of the Norwegian transmission network is the state company *Stanett.* Norway belongs to the synchronous area of the Nordic countries: a region covered by synchronously interconnected electrical energy distribution network managers. In this area, the electricity generation modules must be connected to the system in the specified voltage and frequency ranges, since a change in the frequency in a member state of a synchronous zone can negatively affect the rest of the countries that make up the synchronous zone and damage their equipment (Holttinen, 2005).

The interconnectors link the Nordic market (Norway, Finland, Sweden, and eastern Denmark) with Germany, Poland, Estonia, Russia, and the Netherlands. Western Denmark belongs to the synchronous zone of continental Europe. The transmission network manager is also in charge of maintaining the balance between consumption and generation. In the wholesale market, electricity is bought and sold every hour (Tellefsen, et.al., 2020).

The Norwegian electric power supply system consists of three main sub-systems: the transmission system, the regional system, and the distribution system. Most consumers of electrical power in Norway are connected regional distribution systems. As defined by EU legislation. Statnett, the Norwegian TSO, operates the transmission infrastructure, while approximately 130 different distribution system operators (DSOs) operate the regional distribution subsystems (Fosso, et.al., 2014).

The ability of the Norwegian electricity system to accumulate energy through hydraulic reserves has a dampening effect on prices. In periods of low demand or in summer, when consumption is lower, weather conditions allow water reserves to increase. During winter such reserves can be used to generate hydroelectric power. The consequence is less volatility in the price of electricity in the Norwegian electricity market than in other countries or markets where producing electricity is more expensive and where the predominant source of energy cannot be accumulated, such as hydroelectricity (Morthorst, 2000).

4.2.3 Food Supply and Distribution in Norway

Norway is not an eminently agricultural country. However, despite the fact that a large part of its territory is located above the polar circle, the temperate climate that it has due to the effects of the Gulf Stream allows the development of certain types of productions including in the northernmost areas of the country. The useful agricultural area (UAA) is located in three main regions: southeast, southwest, and central areas of the country; and it represents only 3% of the total area of Norway. This means approximately 0.2 ha of UAA per inhabitant. Its economic and institutional conditions (i.e., infrastructure, labor costs, long distances, small-scale production structure) define high production costs in the agricultural sector (Stålnacke & Bechmann, 2002).

The productions are destined almost entirely to the national market and play an important role in sustaining the viability of rural areas and the conservation of the landscape. Despite the fact that the country is self-sufficient in some agricultural products, Norway must import more than half of the food needed for consumption. Due to its fish farms, Norway is a net exporter of food products. Within Norwegian agriculture, the main productions are milk and meat products, eggs, cereals and some fruits and vegetables. In general, about three-quarters of farm income is derived from livestock production and one-quarter from crop production. Agriculture represents 1.6% of the gross domestic product (GDP). If forestry and fishing are also considered, this percentage reaches 4% (Ministry of Agriculture and Food, 2019).

In recent decades there has been a severe reduction in the number of active farms. In 1950 there were 200,000 farms in Norway, most of them very small, offering only part-time employment. There are currently around 50,000 active farms, which also offer part-time employment. Regarding part-time employment on farms, it should be noted that this term is not clearly defined, because it can refer to a person, a couple, a family. In any case, part-time agriculture has always been important in Norway, in the sense that there has always been a combination of different occupations within the rural sphere, not only linked to agricultural activities.

Regarding forestry, productive forests and wooded areas cover 37% of the country's surface, but this activity represents a small part of the gross domestic product and annual exports. Forestry activities are mainly concentrated in the eastern and southern parts of the country, where 60% of the productive forests are found. Most of the forests are owned by private owners; only in the northern part of the country does the state have most of the forest areas (Almas, 2020).

The forestry sector contributes 1.1% of GDP; 1.6% of employment and 8.6% of the value of national exports (not including oil and gas). Approximately 80% of the forest area is privately owned, divided among some 120,000 properties. In the last 50 years, the volume of harvested wood has varied between 7 and 11 million m3, with a downward trend observed in the last 10 years. A wide range of measures, including legislation, taxes, financial support projects, research, extension services, and administrative procedures were employed in the implementation of the forest policy (Vennesland, 2005).

The Forests and Forest Protection Act of 1965, after several amendments - the most recent in 1997 - is the main legal framework for sustainable forest management in Norway. The use of policy instruments in the forestry sector is changing. Emphasis is currently being placed on developing measures linked to the Norwegian Forest Foundation, which is financed through private funds that are later administered by local forest authorities, for long-term investments in sustainable forest management. Expansion of forest area is no longer one of the objectives of forest policy: the existing area is currently sufficient for future timber production. But in addition to wood production, new objectives are being sought for forestry. The priority projects include the development of bioenergy markets and the maintenance of activities that stimulate the demand for wood products through better communication between the different actors, information, and product development (Tromborg, & Lindstad, 2004).

The food industry is the second most important industry in Norway. In 2018, this sector offers jobs to 49,352 people, approximately 1.86% of the economically active population of the country. The value of the total production reached in 2013 about 30,300 million euros (236,387.8 billion Norwegian crowns), which represents around 7% of the total GDP of the Scandinavian country in that year. Approximately 33% of Norwegian citizens spend on fresh food and grocery.

The retail food distribution sector in Norway is highly concentrated and has a very high level of vertical integration along the supply chain value. The sector's production has increased by 1.1% in 2017, despite the fact that the market continues to grow, it should be noted that it follows the trend of recent years that shows a market stagnation, in fact, 2017 is the year with the lowest increase in the food distribution market that has left a total value of 171,331 Million NOK (Norwegian Ministry of Trade and Industry, 2019).

The evolution of the food distribution sector in recent years with a succession of mergers and acquisitions has led to the current situation of oligopoly, which is characterized by the high bargaining power held by the three large food retail distribution groups. These companies also have a very high share in the wholesale distribution market, which means that their role in the value chain is very high. The large business groups that dominate the retail food distribution sector in Norway are: NorgesGruppen ASA, Coop Norge AS, Reitangruppen (REMA 1000 Norge AS) which are the most powerful and with a small market share we find Bunnpris. These companies make use of different store concepts under the name of different brands of retail distribution chains, focused on different population segments. There are some other retailers, but their share of the market is so small that it is practically negligible (Olsen, 2009).

These large distribution chains are the main players in the sector and have supermarkets throughout the country. They are mainly dedicated to the sale of food products, non-alcoholic beverages, and alcoholic beverages with a percentage no greater than 4.75% alcohol. The commercialization of the rest of alcoholic beverages is carried out through stores belonging to the Vinnmonolopet. The purchasing power of Norwegian citizens is one of the highest in the world. Even so, according to the latest report from Statistics Norway, “This is Norway 2017”, spending on food has stabilized as of 2012, representing 12% of the average expenditure of Norwegian families. On the other hand, the study also highlights the increase in the diversity of edibles that are currently consumed, Norway, which has always been characterized as a country with potatoes as the main food, has changed this trend due to a greater variety in the consumption of food (Statista, 2021b)

4.3 Third Stage: Security Scenarios within the Nexus

4.3.1 Energy and Water Security in Norway

Water security is the ability of a population to safeguard sustainable access to adequate amounts of water of acceptable quality for the sustainability of livelihoods, human well-being and socio-economic development, to guarantee protection against pollution transmitted by the water and water-related disasters, and for the conservation of ecosystems in a climate of peace and political stability (IEA, 2019). Energy security, on the other hand, is defined as the way to provide equitably available, affordable, reliable, efficient, environmentally benign, proactively governed and socially acceptable energy services to end users (FAO, 2015).

The entire population of Norway has access to a safe-drinking water source and electric power. In addition, 99% of the energy that Norway consumes is of water origin and after oil and gas, the most important export item is electricity. Norway has a high security of electric power supply, and the continuity of supply is close to 99,99% in years without extreme weather events. Electric power shortages occur very seldom in the country. However, the security of electric power supply varies from region to region (Worldometer, 2021). Norway has found it necessary to focus on infrastructure, on relevant institutional building and capacity development in order to achieve water and energy security in the country. River basins are fundamental elements in the Norwegian natural landscape and are among the most important areas for recreation and outdoor life, alongside economic activities, settlements, and transport. In Norway, the hydropower sector is economically the most important sector related to the watercourses. For many years the development of rivers for power purposes was made on a case-by-case basis without a coordinated plan for the whole country.

The conditions that Norway has for the generation of clean energy, from water sources, are almost ideal. As previously discussed, a large part of its territory is made up of alpine plateaus, with altitudes that are around a thousand meters above sea level. Its geology is characterized mainly by healthy and impermeable rocky mantles; liquid and solid precipitation is abundant throughout most of the year; and a very high percentage of its rivers suffer abrupt falls between the mountains and plateaus where they originate and the sea. All these factors are fundamental in water and energy security (Andersen, et.al., 2014).

The responsibility for water resources management in Norway is divided between the national, regional, and local levels. At the local level, municipalities prepare water resource plans concerning water supply and quality, land use, sewage, water pollution, and fishing as a part of their everyday planning work. At the regional level, county planning is used as a tool for managing rivers and lakes. Both long-term and corporate plans are statutory and represent essential management tools for both municipalities and counties. Conflicting water needs are handled within political transparency and public participation, and full integration at the local level. Norway has a tradition for formal stakeholder participation during planning processes through written hearings and public meetings. Such processes include land use planning, open-air recreation, hydropower development, drinking water supply, and sewage treatment (NORAD, 2002).

However, the key to Norwegian success in hydropower production is good water management to make the most of it, harmonizing, at the same time, energy demands with the observance of the highest environmental and social standards. For this reason, Nordic engineering found a solution to manage the water resource that, although abundant, is still extremely valuable: the pumping of water between reservoirs of various hydroelectric systems, to allow "storing energy" during periods of low demand. For this, a true labyrinth of tunnels has been built that interconnects several reservoirs located at different heights and that, in times of low demand, receive the water that is pumped from other reservoirs located downstream, and release it when the energy demand requires. higher flows for the generation (Graabak, et.al., 2019).

Norwegian engineering has optimized hydropower production and water consumption. One of its innovative formulas has been the design of plants with turbines of different power, to allow operators to make the necessary arrangements and supply the required energy so that each unit works at or near its optimum levels.

For example, a plant with 90 megawatts (MW) of installed capacity, instead of having three turbines of 30 MW each, which is the standard, in Norway is designed with a 40 MW turbine, a 30 MW turbine and a of 20 MW. This configuration allows the plant operator to “play” with various combinations of generators to produce the required energy in the most efficient way. In this way, when the demand requires a power of 70 MW, instead of having the three 30 MW turbines operating at 78% performance or two at their maximum power and the third at 33% of its capacity (with large losses due to underutilization), the plant can use a 40 MW and a 30 MW plant at full capacity and at peak performance, thus optimizing water use and energy production (Bakken, 2013).

Another interesting point is how the environmental licensing system works. The way to grant environmental licenses for the construction and operation of new hydroelectric plants has been, to a large extent, delegated by the national environmental administration to the so-called Water User Associations. These are made up of all natural or legal persons who have some type of legal or customary right over the waters of the rivers to be intervened.

The licenses, which are granted after a broad process - very broad, which can be extended for several years in order to ensure that the majority of people are included and heard - of consultation and consultation with the associates, have a duration of 30 years. At the end of this period, the terms of this instrument can be revised and the licenses can even be revoked in their entirety, before which the project manager is legally obliged to dismantle the plant in question and leave the place in conditions similar to those that I had before the execution of the project. However, to date, the latter has not occurred and what has normally been reviewed are aspects related to the minimum flows that must be left downstream of the dams and to the management of aquatic fauna in the intervened rivers (Energi Fakta, 2019).

4.3.2 Food Security in Norway

According to FAO, in a definition established at the World Food Summit (WFS) in Rome in 1996, food security is achieved when all people have permanent physical, social and economic access to safe, nutritious food in sufficient quantity to meet their nutritional requirements and food preferences, and thus be able to lead an active and healthy life (Pinstrup-Andersen, 2009).

The Norwegian agricultural production, in general, is not enough to supply the entire country. Therefore, Norway needs to import most of food products for consumption from other countries. In 2020, food imports were worth NOK 71 million (about € 6.27 billion), which is 10% of total imports (Best Food Importers, 2020)

Food security in developed countries with the same profile that characterizes Norway in terms of food procurement is relevant in relation to various crisis situations, as people have access to (more than) enough food under ordinary circumstances. Nevertheless, crises may arise, thus is necessary for governments to effectively address the requirements of their citizens for enough and adequate food at these times (Carvalho, 2006).

The Norwegian Ministry of Agriculture (1999) states that the risk applies not only to international conflicts leading to unstable world markets, warfare, or trade sanctions. Threatening crises such as environmental disasters like climate change, radioactive fallout, outbreak of crop or animal diseases, bio-invasions or major shifts in global demand and food supply could also threaten food availability. The Ministry stressed that crisis scenarios are continuously changing and that it is impossible to pre-specify every conceivable future outcome.

Measures for food in Norway were originally associated with self-sufficiency in food and national agricultural production targets. Self-sufficiency in food is defined by the ratio between consumption of domestic produced food and total domestic consumption of food, measured in the energy content (kJ) of food. In Norway during the early 1950’s self-sufficiency in food was close to 50%. Some 38% of the food was of domestic agricultural origin. Increased dependency on foreign sources of food supply was not desired. Self-sufficiency in food has been rather stable at around 50%, and Norway has among the highest import share of the OECD countries. The share produced in Norwegian agriculture increased from less than 40% in the early 1970’s to currently being around 50% due to an increased production of bread-making wheat. Year-to-year variability in wheat yields causes some variability in food self-sufficiency. The decrease in non-agricultural domestic sources is mostly because animal margarine (from saturated marine fat) has been substituted with imported vegetable margarine (Flaten & Hisano, 2007).

The composition of the Norwegian food consumption in 2018 was: Cereals (29%), potatoes (5%), sugar (13%), vegetable margarine and fat (9%), fruit and berries (4%), vegetables, nuts, cocoa (5%), meat (13%), egg (1%), fish (2%), milk (18%) and animal margarine (1%). Norwegian agriculture is almost exclusively supplying the domestic market; the only export product of some significance is cheese. Self-sufficiency in dairy products slightly exceeds 100%. For meat products and eggs the self-sufficiency is close to 100%. The degree of self-sufficiency for crop products is for potatoes (80%), cereals (60%), vegetables (55%), fruit and berries (5%). All of sugar, vegetable margarine, tropical fruits and vegetables, nuts, peas, cocoa are imported (Bazzani, et.al., 2018).

Norway is one of the world's largest food importers. Due to its cold climate, with long winters and short growing seasons, Norway has a high demand for fresh fruits and vegetables, mainly potatoes, corn, melons, and other tropical fruits. Among its largest suppliers are the EU countries, especially Spain and the Netherlands, and also the United Kingdom, the United States and South Africa.

Tropical fruits represent an important source of income for traders in the Norwegian market, with some of the best-selling products being bananas, melons, kiwi, pineapples, and grapes. Sales of these tropical fruits were worth more than US $ 295 million in 2018. Berries reported sales of US $ 157 million and melons reached US $ 138 million. When it comes to all types of nuts, the United States is Norway's main partner. Total Norwegian nut imports were valued at $ 88 million, of which $ 36 million came from the United States, which is the main supplier of almonds and walnuts. Total almond imports were $ 18 million in 2017, of which 90% came from California. Other providers are Spain, France, and other countries in the Black Sea region (Knoema, 2021)

Seafood imports from the United States were valued at $ 16 million and were dominated by shrimp and prawns, cod, scallops, and Alaska pollock. Prawn and shrimp imports are on the rise, mainly because the shrimp industry in Norway has been in a sharp decline. While the smaller shrimp from Thailand and Vietnam are used primarily for sushi, which is growing in popularity, the larger shrimp from the United States are predominantly used by high-end restaurants (Eurofish, 2019)

Other Norwegian imports worth mentioning are fats and oils, especially vegetable fats, rapeseed or mustard oil, plant-based waxes, beeswax, fish, and marine mammal oils. These come from Denmark, the Netherlands and Germany, and imports reached approximately US $ 165.29 million during 2018. Moreover, Norwegian consumers, over time, have developed particular tastes for a number of international brands, which can be found in many Norwegian supermarkets. We are talking about specialty products and snacks, and most of them come from the United States, particularly sauces and condiments, syrups, beverages, and grains. Classic American products, such as macaroni and cheese, raisins, marshmallows, and popcorn, are also very popular and imports are constantly growing (Statista, 2020)

Due to the crisis caused by COVID-19 and the production stoppage that has resulted from the measures imposed to suppress the pandemic in the most affected countries, such as Spain, Italy or the Netherlands, Norwegian importers fear that, although the transport of merchandise has not been affected by the closure of the Norwegian borders, the supply of food products from these countries may be affected by the situation (Marzo, 2020).

This fear arises from the hygiene and sanitation protocols in Customs, which are delaying the entry of agricultural products from developing countries that need to show phytosanitary certificates. Furthermore, the lack of labor in the main producing countries may also affect exports to Norway since, without labor, production would not go ahead and therefore neither would exports. To alleviate the effects of this situation and safeguard the country's agricultural production, a law has been approved that allows the entry to Norway of temporary laborers from the European Union who have a contract to work in the fields, given the lack of labor that agriculture suffers. They must meet very strict sanitary requirements and be isolated from the rest of the population (Mattilsynet, 2020).

4.4 Fourth Stage: Governance Review of the Nexus

4.4.1 Government Institutions Concerning the Supply of Water, Electric Power and Food In Norway

In Norway there are several authorities involved in the governing of water, electric power, and food.

The Norwegian Water Resources and Energy Directorate (in Norwegian: Norges vassdrags- og energidirektorat - NVE) is the entity in charge to ensure an efficient and sustainable management of the country's water resources (NVE, 2021). In addition, it is in charge to promote efficient energy markets and cost-effective energy systems that contribute to efficient energy use in the country. In addition, there are several ministries that handle matters concerning water sludge, fees, water source ownership, climate change adaptation and wastewater, such as the Ministry of Climate and Environment (in Norwegian: Klima- og Miljødepartementet) (Ministry of Climate and Environment, 2020),

The Ministry of Local Government and Modernization is the entity that handles the general planning and building infrastructure and organizational aspects of services that concern the communities in the city, including water and energy supply (Ministry of Local Government and Modernization, 2020). The Ministry of Health and Care Services handles the matters related to safety of drinking water (Ministry of Health and Care Services, 2020). The Ministry of Petroleum and Energy water cooperates with other ministries with the management of water and energy resources, such as water management strategies and dam management (Ministry of Petroleum and Energy, 2020).

The Norwegian Water Research Institute (in Norwegian, Norsk Vann) is an association that represents the country's water industry. It mainly represents companies own by municipalities and the municipalities as well. Around 96% of the municipalities in Norway are represented by these institutions which affiliates consultants, producers, and research institutions.

For instance, the Norwegian Institute for Water Research (in Norwegian: Norsk Institutt for Vannforskning) is an environmental research organization which researches, monitors, assesses and studies freshwater, coastal and marine environment, and environmental technology. The institute's areas of work include environmental contaminants, biodiversity, and climate related issues. The institute's research reports can be accessed through BIBSYS, and all reports from 1956 until 2015 are available for download. Some of the more widely read articles are also made available by sciencenordic.com and forskning.no.

The institute has twelve sections, led by research managers. Such sections are: aquaculture, biodiversity, innovation, international projects and cooperation, chemicals, effects of climate change, laboratory services, environmental contaminants, environmental monitoring, environmental technology, and measures against pollution (NIVA, 2021)

The Norwegian government entities in charge to ensure food security in the country are Ministry of Agriculture and Food and the agencies of County Governor, or Fylkesmannen Regional authority of the Government, with a Governor in each of 18 counties. Norwegian Agriculture Authority, or Statens landbruksforvaltning Authority for the agriculture industry. Norwegian Food Safety Authority, or Mattilsynet Controls all aspects of food safety, including agriculture, import and trade. Reindeer Husbandry Administration, or Reindriftforvaltningen Authority for the reindeer husbandry industry (Ministry of Agriculture and Food, 2021).

4.4.2. Norway's Policy Review Regarding Water, Energy and Food Security in the Country

Norwegian institutions with policymaking functions concerning the management of natural resources such as water and energy work with models based on scenario prediction. These scenarios are in line with the purposes demanded by the International Energy Agency and include a gradation of scenarios. The first scenario on which we work is the most pessimistic, then the one closest to the current situation, while the last scenario is the most optimistic, the one in which the objectives have been achieved and a situation of total neutrality occurs (OECD, 2016)

The Nordic countries belonging to the European Union are subject to community requirements in all fields of public policy, including water and energy management policy. Likewise, the countries of the region that do not belong to the European Union. Norway must meet certain requirements as an EFTA member. These requirements mean that the national regulations of the countries under study must adhere to criteria set by the European consensus (Majone, 1993). The approach to Norway's energy policy seeks to achieve specific objectives: achieve efficiency in energy production and consumption, ensure intergenerational equity, promote the competitiveness of companies, and achieve reasonable prices for all consumers. Furthermore, Norwegian energy policy in recent years has designed measures to bring the current situation closer to a "carbon neutral scenario" or with a "neutral footprint" (Energi Fakta, 2018)

Norway has established four basic objectives of the country's agricultural and food policy: food security, production in all parts of Norway, increased value added and sustainable agriculture. It is established in which quality services must be provided to consumers in accordance with health standards, and aspects related to the environment, public health and animal welfare must be taken into account in the production processes. Norway's agricultural policy aims to safeguard agricultural resources, develop specialized knowledge, and contribute to the creation of employment and added value in the agricultural sector and agricultural products throughout Norway. Competition in food policy and management of the entire food production chain is shared between the Ministries of Agriculture and Food, Fisheries and Coastal Affairs and Health (ELDIS, 2017)

The Government has launched a program to simplify and improve the regulatory framework and clarify the division of responsibilities between the three ministries. More current regulations indicate that conditions for agricultural production are less conducive in Norway than in many other countries due to cold weather, short growing seasons for crop production, and scattered agricultural land.

However, it indicates that the national population is projected to increase by 20 percent in the next 20 years and proposes that national land-based food production be increased in line with population growth (Ministry of Agriculture and Food, 2018).

In accordance with the Norwegian policy, the Norwegian Agricultural Marketing Board (Omsetningsrådet) seeks to balance supply and demand for major Norwegian agricultural products and ensure the achievement of the following objectives: Stable prices for the producer with a minimum geographical dispersion of prices, stable market conditions for producers who sell their products, stable supply to all consumption areas at relatively uniform prices, ensure that farmers and ranchers obtain prices that comply with the indicative prices established in the agricultural agreement, while the average market prices for the year should remain at the agreed level (Forbord, et.al., 2014).

The variety of specific instruments used to regulate markets may have changed somewhat over time, but the guiding principles of the system have remained largely unchanged. Indicative beef prices were abolished as of July 1, 2009, being replaced by a volume-based regulation. The amendments made to the Marketing Act in 2009 were administrative in nature, notably reducing the number of Board members and authorizing the Board to delegate certain matters to the Norwegian Directorate General of Agriculture, which performs general secretarial functions for the Board (Tennbakk, 2004).

The main parameters of agricultural policy, including certain product prices, aid measures, welfare plans and application issues, are the subject of an annual negotiation between the Government and the two organizations of farmers and ranchers at the national level, the Norwegian Farmers and Ranchers Union (Norges Bondelag) and Norway Farmers, Ranchers and Smallholder Owners Union (Norsk Bonde - og Småbrukarlag). The Basic Farm Agreements system has been in operation since 1950. The system is supported by Norwegian border protection measures, as well as the regulation of the domestic market based on the Marketing Act (Omsetningsloven). The Law covers certain meats (beef, sheep, pig and poultry); milk, butter and cheese; eggs; cereals and oilseeds; potatoes, vegetables and legumes, fruits and berries; and animal skins (OECD, 2018)

Chapter 5

Application of the MACTOR Method in the Context of the Norwegian Water-Energy-Food Nexus

5.1. Identification of Actors that Control or Influence the Key Variables of the System

The key stakeholders of the Norwegian Water, Energy and Food Nexus have been identified according to the main key variables that define the activities of the nexus:

- Water Security
- Energy Security
- Food Security

These variables can be affected by the nexus actors from two different dimensions: social infrastructure and productive infrastructure. Social infrastructure in the context of the Norwegian Water-Energy-Food Nexus refers to the matters of governance of the public and private institutions that make sure Norwegian population is ensured access to safe water, energy, and food at reasonable prices. These objectives are obtained to a large extent through policymaking, laws, and regulations. Productive infrastructure, on the other hand, is mainly formed by the actors that extract, produce and transform the raw materials and energy into accessible goods for human consumption.

In accordance to those dimensions, the mapping of actors shown in figure 17 has been carried out taking them as a reference to categorize them:

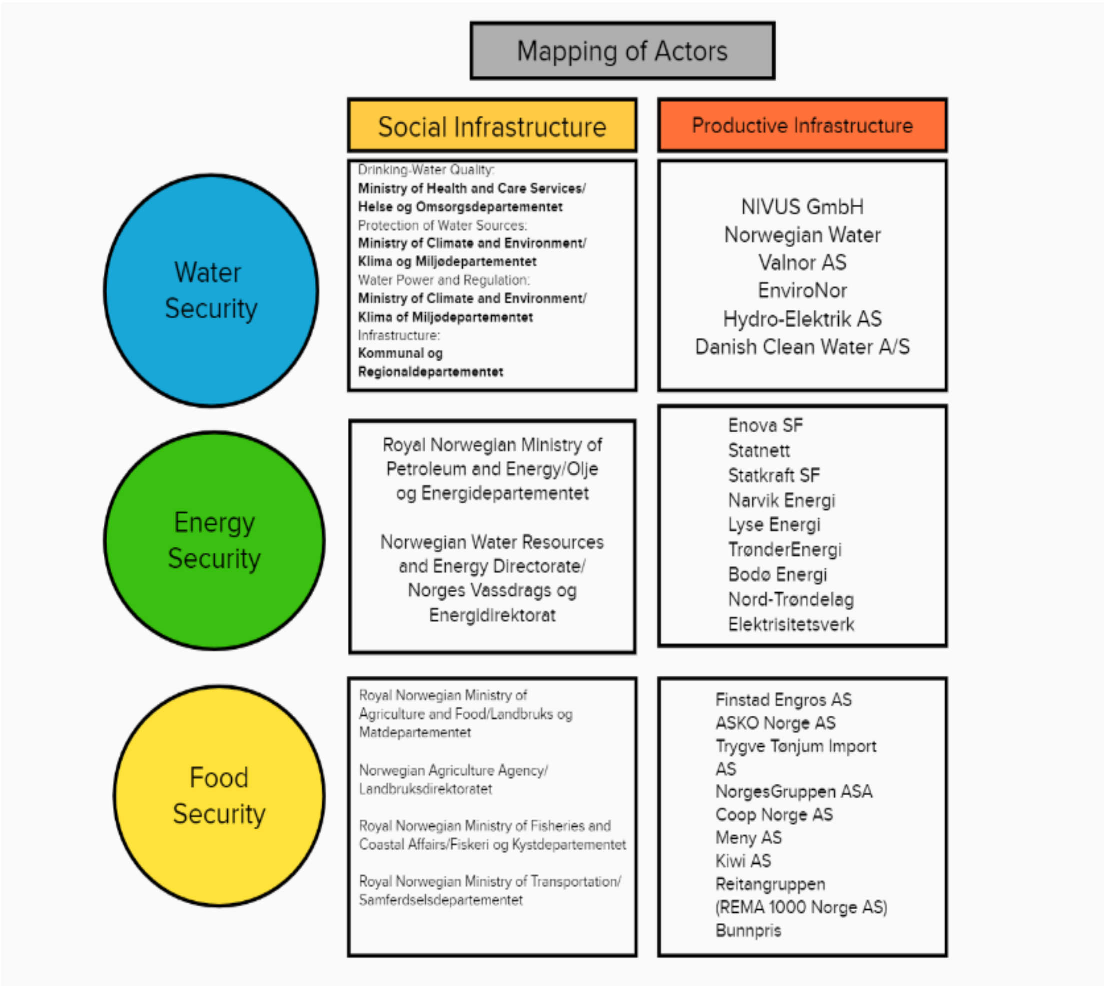


Figure 17. Mapping of Actors in the Norwegian Water-Energy-Food Nexus

In terms of social infrastructure for water, energy, and food security in Norway, the institutions established for the management and administration of water resources follow a comprehensive public administration approach based on public communication and political transparency. In Norway, the sectorial approaches (local and national levels) around public institutions that concern water, energy and food security are organized in a way that the procurement, management, and development of water, energy and food resources are coordinated and translate in efficient supply of those resources to end-users in the country.

The actors shown in the left column do not only regulate the productive infrastructure and the activities of the actors from the right column, public institutions and decision-makers in Norway are aware of the importance of stakeholder participation, therefore involve productive institutions and end-users during the planning process of resource management. In Norway, the natural resource management policy coexists with an active economic policy, with an independent and clearly differentiated status.

5.2. Identification of Strategic Objectives of the Actors

Carrying out a detailed mapping of the actors around the water, energy, and food systems to identify institutional roles in the use and management of natural resources is important. Therefore, the following mapping has been performed from the perspectives of usage, availability, and accessibility of resources, which are the inherent objectives of water, energy, and food security and therefore the water-energy-food nexus.

In this same group, there are also organizations that carry out activities for the conservation of the provision in quantity and quality of water, energy, and food, promoting and executing mainly forest conservation activities. Figure 18 presents a mapping of actors organized by strategic objectives of water, energy, and food security in Norway.

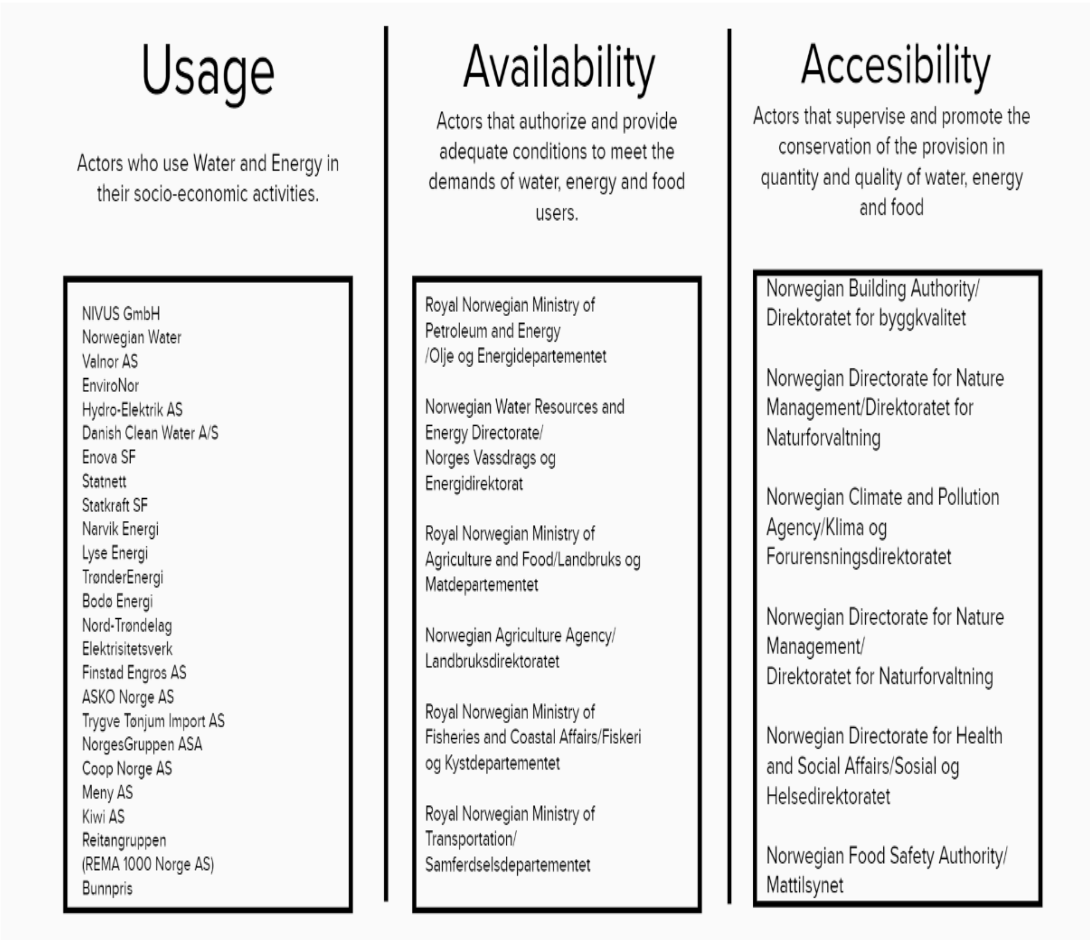


Figure 18. Mapping of Actors Defined by Strategic Objectives of Water, Energy and Food Security

Organizations that are related to the utilization dimension are those that under a condition of formality or informality make use of the resources that other organizations provide them or that they can extract directly from the ecosystem, and even make use of the resources clandestinely without requesting prior permits before the organizations in charge.

There are actors who perform functions as authorizers and / or providers of the resources that determine accessibility. These entities legitimize the use permits and capture and process the resources in advance, assigning them specific characteristics so that they are consumed by the end user.

Other entities are linked to the supervision of the supplier organizations, regarding the adequate fulfillment of their functions, verification of the quality of the resource offered to the end user and evaluation of the quality of the product that they return to the environment.

Policies are systems of principles and objectives that give guidance to decision-makers to achieve desired outcomes for a society, the main objectives of water, energy and food security can be found in the policies the country has formulated. Therefore, a mapping of Norway's policies is relevant to identify strategic objectives for water, energy, and food security in Norway.

The mapping consists of identifying the policies, plans, programs, projects of agricultural investment, energy, infrastructure (hydroelectric, hydraulic, irrigation) and their fundamentals in both gray and green infrastructure, as well as in their governance processes. This information has been collected through the review of policy documents available in the various local, regional, and national governmental entities, or through civil organizations.

The use of the following criteria has been taken into consideration to carry out the mapping:

• Entity (name of the responsible institution)
• Policy name
• Stakeholders
• Scope of intervention (urban, rural, local, regional)
• The objectives or goals set out in the policy or plan for each
sector (water, energy, food / agriculture, forests, growth, or coverage)
• Status of implementation of such policy or plan

Through such information, it is possible to understand what activities are being considered in each sector and what will be the probable trajectory within the elaborated scenarios. In addition, such a mapping helps to understand the challenges facing the country in terms of water, energy, and food security. Figure 19 presents the mapping of the Norwegian policies concerning water, energy, and food security.

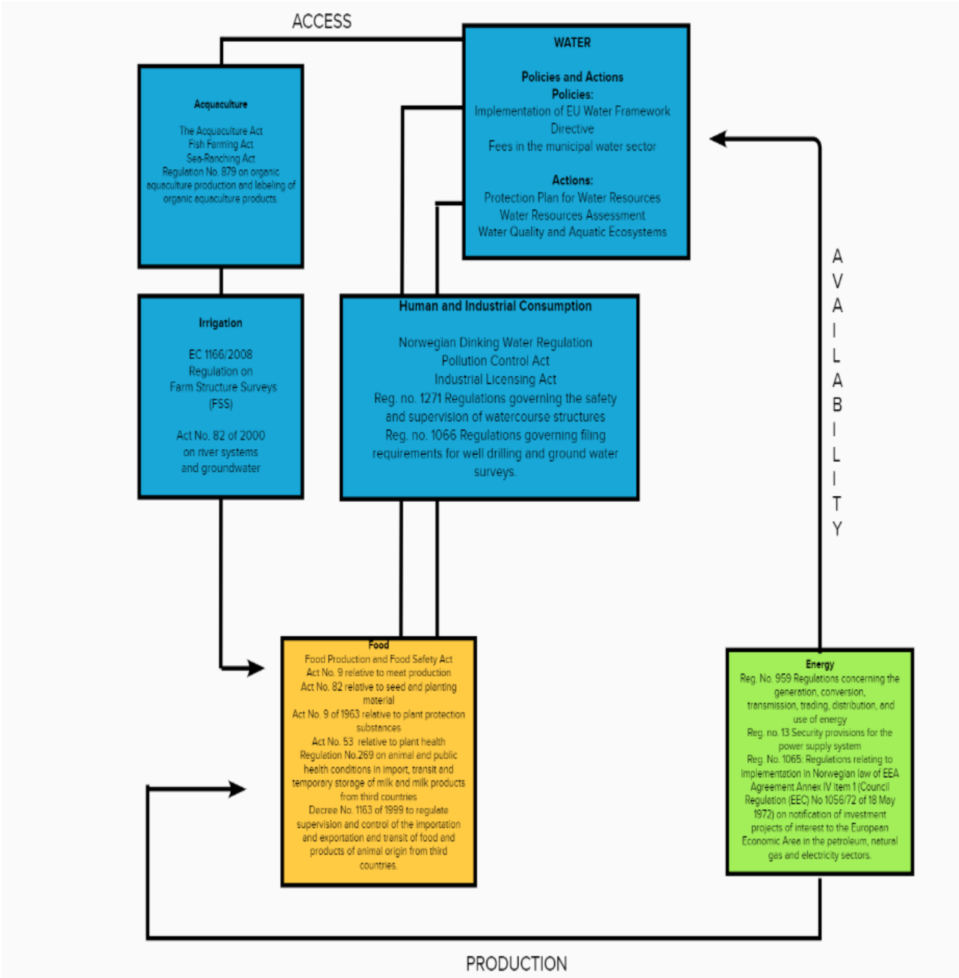


Figure 19. Mapping of Norwegian Policies Regarding Water, Energy and Food Security

Norwegian policies towards water, energy and food security are extensive and specific in their objectives related to water, energy, and food security. In Norway, the government has the competence to strategically coordinate the different development actors, this means that the implementation of coordination mechanisms between the public and private sectors to develop optimal coordination scenarios between the three sectors of the nexus, which will be seen reflected in higher trust indices and better cooperative relationships between the actors. Therefore, government institutions are prone to strategic coordination, through four important factors: exchange of information between actors, monitoring of the execution of policies and regulations, existence of sanctions for non-compliance with cooperative efforts, and deliberation. on strategic issues.

The Norwegian policy strategy is one of the fundamental factors of the outstanding status of the water-energy-food nexus in the country, as shown in figure 20.

Figure 20. Water-Energy-Food Nexus Status in Norway

5.3. Representation of Direct Interactions Among the Actors

The representation of the interactions among the actors of the Norwegian water-energy-food nexus in this study has been carried out in two steps. First, a quantification of the interactions within the Norwegian nexus, and secondly, a mapping of the interaction of the Norwegian water-energy-food based on the institutions that make part of it.

The quantification of the interactions has been determined based on the priority interactions identified by the participatory analysis of the nexus and the availability of data regarding water, energy, and food resources in Norway. The mapping of actor interaction has been made based on the previous mapping of actors and will represent how the functions of such actors are interconnected.

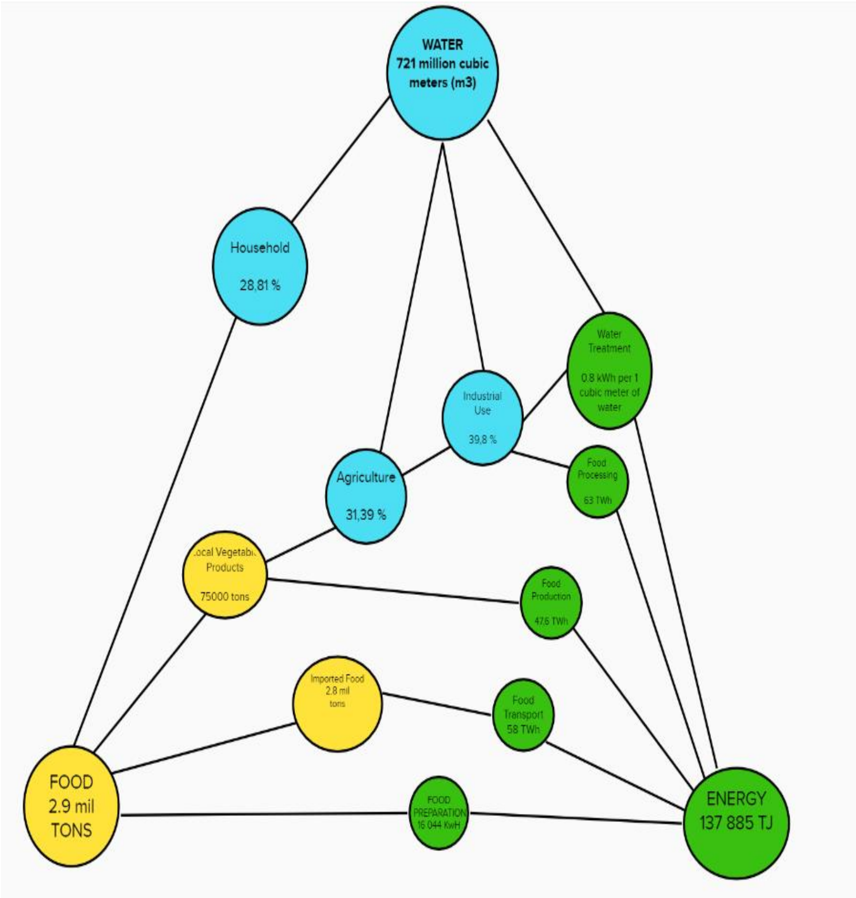


Figure 21. Quantification of the Norwegian Water-Energy-Food Nexus Interactions

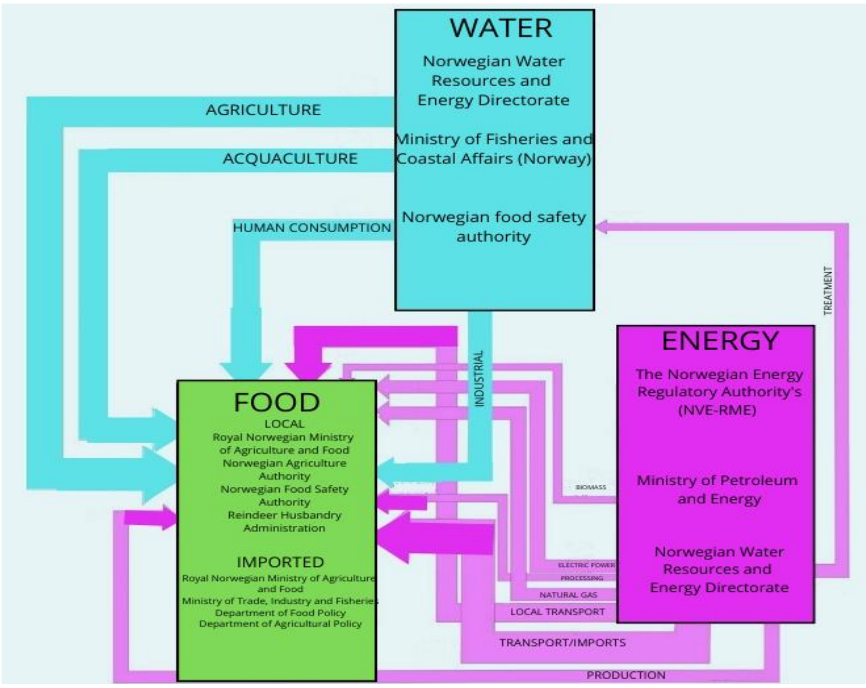


Figure 22. Mapping of Actors by Function

The quantitative value in the water-energy-food nexus in Norway was determined from each interaction resulting from key variables such as the number of users, per capita consumption, irrigated area for agriculture, and the dynamics of the interactions between the different subsystems. It was necessary to analyze to what extent the variables influence the quantification of interactions to determine their points of convergence. For that purpose, the value of each interaction was determined through the data collected and the correlations that served to quantify the interactions of the nexus and the key variables that were chosen to explain them, such as volume of water for irrigation or the energy used to process food.

In order to quantify the use of water, energy and food in Norway specific information has been collected from publicly available sources provided by government and private organizations on number of users and volume of consumed resources. Data collected from Statistics Norway (Statistisk sentralbyrå), the Norwegian Water Resources and Energy Directorate (Norges vassdrags og energidirektorat - NVE) and The Royal Norwegian Ministry of Agriculture and Food (Landbruks og matdepartementet) was useful to identify and quantify the interactions of the Norwegian water-energy-food nexus. Digital information from international databases such as the water-energy-food nexus platform developed by the FAO, among others, were also accessed and consulted to perform the mapping and quantification.

5.4. Hierarchy of Actors with Respect to Objectives

Carrying out the necessary activities to ensure water, energy and food security in a country with the profile that Norway has, requires the participation of different actors. This means that the governance components are just as important as the technical aspects of those activities. In fact, a culture of collaborative work among the different participating actors would serve to achieve greater productivity. Therefore, understanding the influence of the key actors in relation to the objectives is necessary to identify the institutions that need greater strengthening and attention in terms of vulnerability management and systemic risk.

Therefore, identifying the degree of actor hierarchy is essential within the process of application of the MACTOR method. Hierarchy, in such context, refers to the degree of influence of the actors related to specific objectives. In the case of the Norwegian water-energy-food nexus in this research study, the objectives that were considered to perform the mapping of actor hierarchy includes accessibility and availability of water, energy, and food in Norway. Figure 23 shows the degree of importance of the actors that were included in precedent mappings to achieve water, energy and food accessibility and availability for end-users in Norway.

In the case of the actors considered in the hierarchy mapping, it was possible to observe that the alignment of the objectives of availability and accessibility of water, energy and food in Norway is directly related to the level of interdependence and cooperation that exists between the actors.

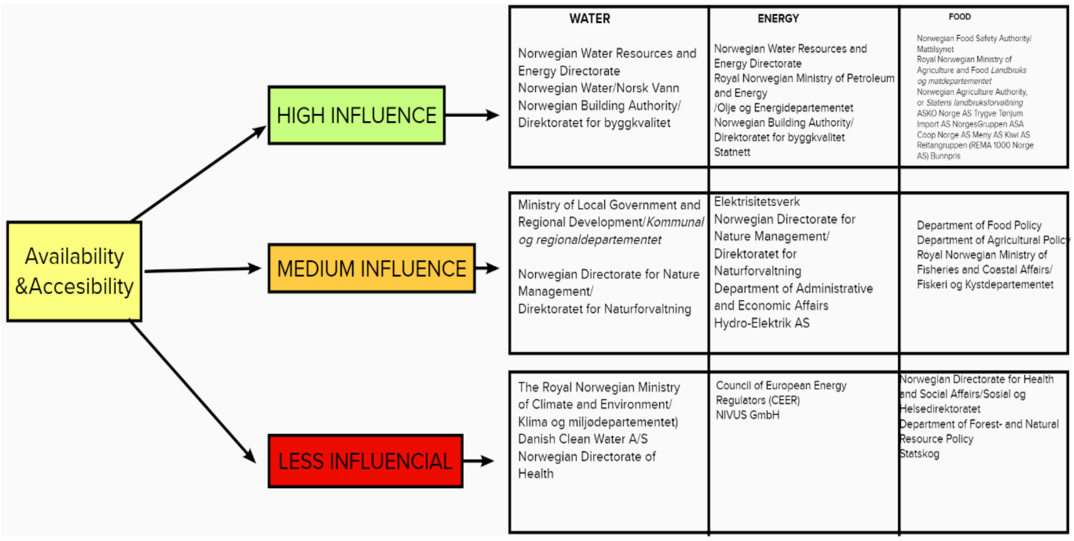


Figure 23. Hierarchy of Actors with Respect to Objectives

Both the interactions and the history of previous experiences converge and determine the interdependence between the different actors. When the parties have a high interdependence, everyone values the resources and skills of the others. Likewise, future economic changes are anticipated. They believe in the need to maintain relationships as well as wanting to cooperate for common goals as well as showing the will to solve common problems.

The culture of cooperation between the actors involved with the availability and accessibility of water, energy and food in Norway is based on clear guidelines of regulations regarding the activities of production, procurement and distribution of water, energy, and food. This type of cooperation is achieved through achieving harmonious working relationships in which they are fundamental to share objectives of the nexus. To achieve this end, the Norwegian institutions accompany these activities with appropriate management mechanisms in problem solving, stakeholder involvement and proper communication, favoring the union of the actors through common objectives.

From the application of the MACTOR method in the context of the water-energy-food nexus in Norway, it can be ensured that the analyzed actors maintain an element in common: alignment of objectives and interests, becoming a fundamental element for the proper functioning of the nexus. in Norway. It also follows that, as a result of this alignment, another element appears that characterizes the interactions of the studied actors: trust. Because these two elements are important within collaborative actors within a complex system, it is fair to attribute the success of the Norwegian nexus to the presence of these two factors.

The alignment of objectives and the trust between the actors would serve as tools or recommendations to act and generate a situation according to an environment in which cooperation and the scope of water, energy and food security prevail.

Chapter 6

Chapter 6: Data Analysis and Discussion of Findings

This chapter summarizes the findings of this research study and give answer to the last two research questions formulated at the beginning of the study as the first research question was answered throughout chapter 4. Modelling and managing of systemic risk within the Norwegian water-energy-food nexus in one of the challenges to be overcome in order to achieve water, energy, and food security in the country.

This chapter seeks to synthesize the importance of modeling and managing systemic risk within the Norwegian water-energy-food nexus and present practical strategies to of managing systemic risk by improving resilience within the water-energy-food nexus.

6.1. Systemic Threats and Vulnerabilities: The Importance of Modeling and Managing Systemic Risk within the Norwegian Water-Energy-Food Nexus

The Norwegian water-energy-food nexus as a complex system is subjected to threats and vulnerabilities derived from the complexity of the interrelationships and interactions among water, energy, and food supply systems. Analyzing systemic risk within a complex system has different implications than analyzing systemic risk within a single system, and therefore, such analyses must be performed differently.

The main difference lies in the fact that complex systems are exposed to more sources of systemic risk, and therefore the approach to it must be broader, taking into account the particularities and complexity of human activity systems. Due to the three subsystems that constitutes the Norwegian water-energy-food nexus, the hierarchized interactions of its stakeholders and the numerous operations, functions, and processes that occur among them, a conventional risk analysis is not adequate to identify the particular threats and vulnerabilities that could hinder its functioning.

Although the methodology and application of systemic risk modelling and management of single systems can serve as a basis for managing and modelling risk in complex socioecological systems such as the water-energy-food nexus, it is imperative to adapt the strategies and models to manage systemic risk to the interconnectedness of complex systems.

The analysis of systemic risk within the water-energy-food nexus requires a change from conventional systemic risk analysis applied to single systems. In this context, information collected, and historical assessments are not as reliable, and an approach where awareness of the tacit sources of risk.

In the water-energy-food nexus, for example, an initiating event that causes the failure of the water supply system would result in adverse consequences for the energy supply system, negatively affecting the subsystem that ensures food supply. The interdependence existing among the resources, processes and infrastructures that make possible the availability of water, energy and food makes it necessary to analyze systemic risk with a clear understanding of the systemic configurations not only at a technical level but also at a social level.

This means that not only aspects such as the optimization of supply systems and process engineering are necessary to avoid systemic risk in the context of the water-energy-food nexus; but factors such as changes in the economy, the society and the environment need special attention in order to model and manage systemic risk in such context. A particularity of the Norwegian water, energy, and food nexus is that key decision makers and actors that define the social infrastructure for water, energy and food security in Norway collaborate closely with actors from the productive infrastructure to coordinate their decisions. This dynamic has a positive effect on the overall management and effectiveness of the Norwegian water-energy-food nexus.

All water-energy-food nexuses are subjected to many sources of systemic risk, and the Norwegian water-energy-food nexus is not the exception. In such case, uncertainty and vulnerability analysis becomes imperative when modelling and managing systemic risks. Robust decision-making processes cannot be attained without proper representation and assessment of vulnerabilities and uncertainties.

Adequate systemic performance is dependable on the robustness of decisions, and both factors are the basis for characterizing technical, technological, economic, or environmental issues that could create vulnerabilities within the water-energy-food nexus. The main sources of uncertainty when modelling systemic risk in such cases are related to knowledge and variability. In the first instance, incomplete or faulty knowledge of the complex system in consideration can lead to uncertainty related to incorrect decisions regarding appropriate models and parameters to use.

Uncertainty related to variability, on the other hand, can manifest through relevant initiating events that require particular attention. In the context of complex systems, sources of uncertainty are present in the majority of decision-making processes. The lack of understanding of the complexity of the confluence of water, energy and food supply systems can lead to uncertainty associated to the creation of incorrect assumptions around the vulnerabilities of the water, energy, and food nexus. Even if exact assessment of uncertainties and vulnerabilities is not possible to achieve, an analysis that is close to the real implications of the vulnerabilities of the system can be carried out.

Robust functioning of water, energy and food supply systems can be achieved through modelling and managing of systemic risk, using a multi-dimensional approach that can cover the specificities of a complex system. Modelling and managing systemic risk within a complex system must be based on four fundamental objectives:

- Identification of Key Actors for the Activities of the Complex System
- Identification of Main Systemic Threats and Vulnerabilities
- Robust Decision making Under Uncertainties Associated to Systemic Risk
- Robust System Resilience

The achievement of these four objectives can significantly mitigate systemic risk and aid the process of bouncing back after a systemic disruption. Methodologies and strategies to achieve such objectives vary depending on the specific type of complex system and the nature of the activities that it performs. Initiating events associated to systemic risk have different effects in the interactions of the subsystems. In the case of the water-energy-food nexus in Norway, each subsystem has different decision-makers and since the activities of the three subsystems present a high degree of interdependence, decisions taken regarding a water supply system, may affect negatively or positively the energy and food supply systems.

Complex systems are affected by several initiating events associated to systemic risk from two different angles: from within the system (endogenous systemic risk) and from outside the system (exogenous systemic risk). When it comes to analyzing systemic risk within a complex system with a socioecological nature such as the water-energy-food nexus, both dimensions must be taken into account when modelling systemic risk.

The Norwegian water-energy-food sustains productive and logistical activities to provide with quality of water, energy, and food supply to a population of 5.328 million people that are fragmentally dispersed through 385,207 km². The close interconnectedness of the interactions that characterize this water-energy-food nexus is a contributing factor to a systemic risk analysis that requires more than only one conceptual or analytical to model both endogenous and exogenous systemic risk within the nexus.

In the case of the Norwegian water-energy-food nexus, the activities are divided into the three sectors to understand the specificities and vulnerabilities of the subsystems. Water, energy, and food supply systems are broken down under technical and social criteria and delimited by political and geographical boundaries. In systemic risk analysis in this context aspects such as the geographic region and the activity sectors must be clearly stated.

Considering the Water-Energy-Food Nexus from the overlapping perspectives of water, energy, and food security; geography and governance as well as the objectives of the nexus, the sources of systemic risk and main vulnerabilities may arise from multiple factors. Especially, the sources of systemic risk within the different counties, cities and municipalities in Norway, an instance where proper allocation of shared resources is crucial.

Considering the particular concerns of the water-energy-food nexus, systemic risk management in Norway responds to the objectives of reducing environmental footprints, protection of the natural environment and fish and wildlife, and supply water, energy, and food needs.

All modelling representations in accordance to these factors within the subsystems of the water-energy-food nexus in Norway present systemic risk sources that would be more difficult to identify through an approach where just a single system is taken into consideration. In sum, a complex system such as the Norwegian water-energy-food nexus must be managed and modelled under the objectives of the system itself, of systemic risk management, according to the needs of the population the nexus is meant to supply with water, energy and food.

The main sources of systemic risk for the water, energy, and food nexus arise mainly from the food interlinkage of the system. Norway presents very low systemic risk in terms of water and energy security in the country, and although the food supply interlinkage in the Norwegian nexus is wicker due to Norway's high reliance on food imports, especially vegetable origin products, factors such as the proper planning and decision making resulting from robust governance actions make it possible to have an efficient food supply for all inhabitants in the country.

The exploration and visualization of the extent of systemic risk and the implications it may have in current and future scenarios within the Norwegian water-energy-food nexus highly depends on the identification of both internal and external initiating events, this aids the process of avoiding negative impacts in the system. Both internal and external initiating events to water-energy-food nexus

In conclusion, the multidimensionality of the Norwegian water-energy-food nexus is a clear representation of a complex system. The multiple, associated stakeholders, decision-makers, productive and social actors represent heterogeneous constituencies in terms of production, supply, regulation and provision of water, energy and food supply, accounting for the importance of systemic risk modeling and analysis process.

6.2. Optimization within the Norwegian Water-Energy-Food Nexus through Resilience Improvement

Highly resilient complex systems have been proven to adapt and survive to the negative implications of systemic risk. System resilience and flexibility are the key characteristics to ensure that human activities can adapt to change and recover from ruptures. A crisis within a water-energy-food nexus may arise when disturbances exceed a certain threshold and affect or disrupt water, energy, or food supply. Based on this reality, the water-energy-food nexus must seek to activate reorganization strategies in order to regain stability after a disturbance.

Although the subsystems of the water-energy-food nexus are easily identifiable, they are difficult to decompose for practical and analytical purposes. The perspective of resilience is useful to understand the dynamics of water-energy-food nexus, which represent the sum of the social system and the ecological system. Water, energy, and food supply systems are influenced by the changes in the capacity of ecosystems to maintain that adaptation and cause breaking points in the resilience of the water-energy-food nexus.

Considering the resilience of complex systems can be understood as an approach to organize and manage water-energy-food nexus by emphasizing the capacity for renewal, and development, where disturbances are part of the dynamics of the system and represent opportunities for change or innovation.

In chapter 2, different principles were presented to improve resilience within a complex system. Hereafter, a set of strategies as how to apply relevant principles to the Norwegian water-energy-food nexus will follow:

Maintaining Diversity and Redundancy in the Water-Energy-Food Nexus in Norway

The management of water, electricity and food supply systems must recognize and incorporate the value of diversity and redundancy in the management of the nexus. This can be achieved by paying attention to the following factors:

Conserve and value redundancy: Redundancy is rarely conserved or managed in complex systems similar to the water-energy-food nexus. Special attention should be paid to important functions or services that have low redundancy, such as those controlled by key actors. In the case of the water-energy-food nexus in Norway, through the application of the MACTOR method, these actors are government institutions that draw up policies in favor of water, energy and food security such as the Norwegian water resources and energy directorate, Statkraft, the Norwegian food safety authority and the Norwegian Ministry of Agriculture and Food.

Increasing the redundancy associated with these nexus functions can be accomplished through maintaining activity diversity. Diversity is essential for the ecosystem services of water, energy, and food supply. Furthermore, diversity can improve the resilience of these services by providing a repository of redundancy and response to systemic risk. Recommended strategies to maintain or enhance ecological diversity include: maintaining the structural complexity of the system, establishing buffer zones around vulnerable areas, creating corridors for connectivity, and controlling frequent disruptions.

Developing diversity and redundancy in governance systems is also useful to strengthen resilience in the water-energy-food nexus. During the management of water, energy and food supply systems, the value of the different sources of knowledge should be better recognized and incorporated. As long as this is balanced with respect to uncertainties, vulnerabilities and systemic risk of conflicting interests, diversity of perspectives can enhance problem solving and aid in learning and innovation, allowing for faster recovery after a disturbance. Also, focusing less on maximum efficiency, even if it is more expensive is important. Traditional cost-effectiveness thinking promotes maximum efficiency, while resilient thinking encourages policies that can better deal with resource sourcing processes.

Managing Connectivity in the Water-Energy-Food Nexus in Norway

Connectivity can enhance and also reduce the resilience of the water-energy-food nexus and the services that it produces. A well-connected system can overcome disturbances and recover from them more quickly, but a system that is too connected can lead to a rapid spread of disturbances throughout the entire system, so that all components of the system are affected.

Therefore, mapping connectivity to understand the degree of interdependence is important to understand the effect of connectivity on the resilience of the water-energy-food nexus, the first step is to identify the relevant parts, their scale, their interactions, and the strength of the connections. Once this is done, actor mapping, network analysis and/or visualization tools can help reveal the structure of the network, identifying the important elements and interactions. In order to guide potential interventions and optimize connectivity, it is important to identify core interactions among the actors of the system. This helps to identify vulnerable parts and resilient parts of the system.

Managing Variables and Feedback in the Norwegian Water-Energy-Food Nexus:

In a rapidly changing world, managing slow variables and feedbacks is often crucial to keeping the water-energy nexus well-structured and functioning in ways that water, energy, and food supply are performed effectively. If these systems switch to a different setting or regimen, it can be extremely difficult to reverse.

Strengthening the feedbacks that maintain desirable regimes and monitoring important nexus variables is essential to detect slow changes that could cause the system to cross a threshold that can have negative implications in the system. Understanding the role of slow variables and feedbacks can help managers to recognize that sources of systemic risk focus on the variables that underlie within the functioning of the system. Establishing governance structures that can respond to monitoring information based on the knowledge and information from monitoring are not sufficient to avoid systemic risk that may threaten water, energy, and food supply. Establishing governance structures that can respond effectively to monitoring information is equally critical. If the follow-up indicates that a critical threshold has been reached or is about to be reached, a formal process is triggered in which a decision is required to be made on whether to take corrective action or adjust the presumed threshold to a new level.

Expanding the Participation of Key Actors in the Norwegian Water-Energy-Food Nexus

Well-functioning and broad participation can build trust, create shared understanding, and uncover perspectives that cannot be acquired through more traditional scientific processes.

Enhancing efficient participatory process within the water-energy-food nexus is highly dependent on the actors that are involved in the system and choosing appropriate tools and methods to use is challenging. Some of the most common sources of systemic risk can derive from underestimating how important is to place focus in the key actors of the nexus that are essential to carry out successful participation. Insufficient or faulty knowledge of the system and lack of clarity about roles and rules for participation of the stakeholders have a significant impact.

There are several guidelines that may contribute to more effective key actor participation within the Norwegian water-energy-food nexus:

- Promote Communication Among Key Actors of the Nexus
- Clarify Objectives, Expectations, and Implications of Roles within the Water-Energy-Food Nexus
- Involve Relevant Actors of the Water-Energy-Food Nexus
- Identify Synergies and Conflicts Among Key Actors
- Obtain Sufficient Resources to Allow Effective Participation

Chapter 7

Chapter 7: Conclusions and Key Recommendations for Future Research

7.1. Conclusions

Based on the research process that was carried out for this study, it is possible to conclude that:

All engineered complex systems that carry out vital human activities are subjected to systemic risk. It is necessary for procedures and regulatory governance strategies to be in place for systemic risk to be modelled and managed. In order to analyze systemic risk within the Norwegian water-energy-food nexus it is important to incorporate both system engineering and risk analysis. An approach that is based on the particularities of systemic risk will account for negative initiating events that represent a threat for the nexus.

The Norwegian water-energy-food nexus is characterized by multiple shared circumstances and essential entities, and plentiful of technological and organizational subsystems; multiple objectives, agencies, stakeholders, and decisionmakers. All these elements come from the three domains (water, energy, food supply systems) of the nexus, where multiple horizons associated with each subsystem and the entire nexus intertwine.

Modelling and managing systemic risk in the context of the Norwegian water-energy-food nexus must be carried out with close understanding of the criticality of each subsystem for water, energy, and food security. Oftentimes, proper systemic risk analysis within the water-energy-food nexus will require the use of diverse methods and models and a proper comprehension of their critical role in identifying and managing vulnerabilities and uncertainties.

In the same context, systemic risk analysis within the nexus must make an end for uncertainties and vulnerabilities. In the context of the water-energy-food nexus, uncertainties are commonly perceived as the lack of capacity of determine the current status of a system. In such situation, in order to guarantee water, energy and food security, decision-making associated to systemic risk must take into consideration all relevant and important initiating events.

The water-energy-food nexus methodology is useful to characterize water-energy-food nexuses. However, based on the research process carried out through this study, it is fair to state that a complementary application of a methodology that can serve as a diagnostic tool can bring a better outcome of analysis, especially when the objective is to model or manage systemic risk. In the case of this research study, such tool was the MACTOR methodology.

In order to comprehend the complexity of the interrelationships of the water, energy and food supply systems as a nexus and complex system, it is important to identify the key actors that are of upmost relevance for the ecosystem services that the water-energy-food nexus performs. For that purpose, the MACTOR methodology was applied to identify the main stakeholders of the Norwegian water-energy-food nexus. Through the MACTOR methodology it is possible to take into account the synergies and trade-offs among the interactions of the stakeholders.

In modelling systemic risk within a complex system, it is imperative to make an account for systemic risk with low probability and extreme consequences. This approach to systemic risk in complex systems has played an important role in decision-making of productive processes. Systemic risk is inherent to complex systems; in the case of the Norwegian water-energy-food nexus, systemic risk modelling can be achieved through agent-based models to identify vulnerabilities within the system.

Systemic risk analysis within complex systems must have a holistic approach, where all the specificities, technicalities and complexities of the system are considered to the higher degree that is possible.

Lastly, Norway presents high levels of water, energy, and food security. The Norwegian water-energy-food nexus is a robust complex system. The particular characteristics that contribute to this reality are: the large amount of natural resources of the country, good administration of such resources and strong governance practices concerning water, energy, and food security.

7.2. Key Recommendations for Future Research

Based on the application of the Water-Energy-Food Nexus and MACTOR methodologies in the context of the water-energy-food nexus in Norway, it is possible to make the following recommendations to give continuity to future research on this topic:

1. In reference to the results obtained, it is established that there are numerous research areas related to the water-energy-food nexus in Norway to be explored in the field of risk and complexity science.

2. As stated before, although the water-energy-food nexus methodology is a useful tool to characterize specific water-energy-food nexus, there are methodologies, models and tools that can add value to the research when it comes to the diagnostic part. A similar research study utilizing the multi-scale integral analysis of socioecological metabolism can be a diagnostic tool that can lead to useful findings that can be useful to model and manage systemic risk.

3. Due to the intricate nature of complex systems, research conducted on a complex system has to be properly delimited, A recommendation for future research on water-energy-food supply systems in Norway is to perform the study to a specific region of the country. An analysis conducted in more vulnerable areas may be more effective as to ascertain more specific sources of systemic risk with the Norwegian water-energy-food nexus.

4. For the purpose of this research study, governance dynamics in Norway were analyzed at a national level. Governance strategies at a more particular level, like a specific municipality, is recommended to carry out in the future.

5. The proposals presented in this research study as to how the Norwegian water-energy-food nexus can improve mitigate systemic risk have been based on strengthening resilience within the system. For a future research, an approach where stochastic optimization models are applied to the Norwegian water-energy-food nexus is recommended.

6. Although the Norwegian Water-Energy-Food Nexus was evaluated in a general manner, research that is more focused on the food interlinkage of the nexus in Norway would be a useful point of research. This is because the food interlinkage in the Norwegian water, energy, food nexus is the weakest out of the three. Even id this weakness does not represent major vulnerabilities to the food security dynamic in Norway, I would be a valuable contribution.

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