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The Need for the Nexus Approach

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ABSTRACT

The water, energy, and food resources share a lot in common; they have strong interdependencies and are inadvertently affected by action in any one of them. Therefore, the nexus approach (integrated policies related to water, energy, and food) is required in the face of growing concerns over the future availability and sustainability of these resources. The nexus approach can help achieve at least some of the "Sustainable Development Goals (SDGs)" (e.g., SDG 2, 6, 7, 12, 13, 15). This chapter discusses trends in availability and consumption of the three key resources (i.e., water, energy, and food) and interactions between them, and finally provides some reasons why the nexus approach can help achieve social and economic development goals.

1.1. INTRODUCTION

The water, energy, and food resources share a lot in common, including inaccessibility to billions of people, rapidly growing demand, strong interdependencies with climate change, different regional availability, and variations in supply and demand [*Bazilian et al.*, 2011; *Walsh et al.*, 2015]. Apart from the similarities, there is a growing sense of awareness of the linkages among water, energy, and food sectors (Figure 1.1) and that the actions in one sector would inadvertently affect one or both of the other sectors. The growing population, rapid economic growth, and changing consumption trends has increased the urgency to act through the utilization of integrated approaches that encompasses all three sectors. This ensures that there is a proper balance among the different user goals and interests while at the same time protecting the ecosystem.

It was acknowledged at the Bonn 2011 Nexus Conference that integrated policies related to water, energy, and food are required in the face of growing concerns over the future availability and sustainability of these resources. The continuation of isolated policies which are predominant in developing countries will unavoidably affect other sectors and eventually lead to the acceleration of ecosystem degradation. Hence, a better understanding of the strong linkages and trade-offs with respect to the water-energy-food (WEF) nexus is important for sustainable long-term development growth as well as for human well-being. A nexus approach is based on three guiding principles [*Bonn 2011 Conference*, 2011]:

1. Placing people and their basic human rights as the basis of the nexus
2. Creating public awareness and the political will for successful implementation
3. Involving local communities in the planning and implementation processes in order to create a sense of participation and ownership

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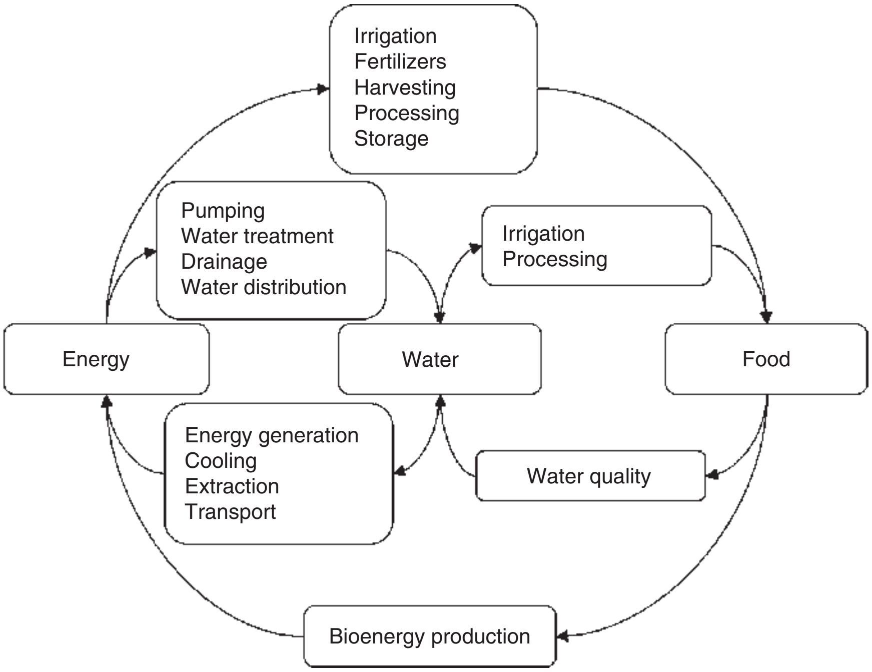

Figure 1.1 Interactions of the water-energy-food nexus. Source: *IRENA* [2015], "Renewable Energy in the Water, Energy & Food Nexus."

The practical implementation is proven as difficult mainly due to the vastness of the individual sectors, the multidimensional interlinkages among the sectors, and the fact that stakeholders in all disciplines and at all levels need to be involved. In addition, significant financial investment would also be required in the restructuring of existing infrastructure to suit the nexus approach. The development of robust analytical tools, conceptual models, and robust data sets which can be used to supply information on the future use of energy, water, and food is vital toward making the WEF nexus a reality [*Bazilian et al.*, 2011].

The Sustainable Development Goals (SDGs) have set targets for each of the nexus sectors explicitly under SDG 2 (zero hunger), SDG 6 (clean water and sanitation), and SDG 7 (affordable and clean energy). In order to satisfy the stipulated goals, a shift to more sustainable production and consumption patterns (SDG 12) will be required while tackling climate change (SDG 13) and ensuring a balance in ecosystem both on land and water (SDG 14 and SDG 15). The interconnection between the SDGs emphasizes the need for a nexus approach in achieving the individual goals.

1.2. AVAILABILITY AND CONSUMPTION TRENDS OF THE NEXUS COMPONENTS

The growing demand for water, energy, and food are driven by common factors: population growth and mobility, sustainable development, international trade, urbanization, changing lifestyles, cultural and technological changes, and climate change [*FAO*, 2014]. The exploitation of more resources will definitely be required to meet the growing demand. However, it is possible to slow down this growing demand by reducing wastage and loss incurred in the water, energy, and food stream, which would also help in saving embedded resources during production and reducing environmental impacts. Reduction of water and energy through conservation and efficient use will be crucial in the coming decade.

1.2.1. Water

The world has enough freshwater to supply the global demand but nonuniform distribution of these reserves and other reasons have led to shortages in certain locations. The United Nations (UN) estimates indicate that there are 1.2 billion people living in areas of physical water scarcity and another 1.6 billion people facing economic water shortage [*Walsh et al.*, 2015]. In terms of water quality, there are 748 million people who lack access to an improved drinking water source [*UNESCO*, 2015]. The shortage in both quantity and quality may likely spread and become more acute due to growing demands, unsustainable withdrawal rates, degradation of source water quality, and changing climate patterns. Understandably, the main impact of water shortage is on direct human consumption but other indirect impacts include those on energy supply, food production, and ecosystem.

Traditionally, the expansion of water resources mainly depended on the need of the expanding population for food, clothing, and modern energy. More recently, the rising standards of the middle-income group has led to sudden and sharp increases in the water consumption in both production and use. Economic growth coupled with higher living standards could be the reason that the growth of water demand is double that of population growth in the twentieth century.

The global water withdrawals in 2009 stood at 4500 billion m^3 (BCM) of which 70% was used for agriculture, 17% for industry, and 13% for municipal and domestic purposes [*2030 Water Resources Group*, 2009]. According to the *2030 Water Resources Group* [2009], the projected demand of 6900 BCM in 2030 under the business-as-usual scenario is 40% more than the currently assessed water supplies (ground and surface) that are accessible, reliable, and sustainable. In another report by UN Water, the water demand is projected to increase by around 55% in 2050, which will mainly be attributed to growing demands in the manufacturing sector, thermal power plants, and domestic use [*UNESCO*, 2015].

The gap between future availability and demand can be closed not through the discovery of more water supplies but through effective demand-side management, which will definitely need effective policy interventions.

1.2.2. Energy

Energy demand is increasing primarily due to drivers like growth in population and gross domestic product (GDP). Though there are diverse sources of energy, fossil fuels are expected to continue as the dominant fuel source and would account for almost 80% of the total energy supplies in 2035 [*BP*, 2016]. Gas is expected to gain popularity along with renewable energy though the share of the latter would still be below 10% in 2035. On the other hand, coal will exhibit a decreasing trend while oil remains steady. The additional energy demand will come from growing and emerging economies while Organization for Economic Cooperation and Development (OECD) countries will hardly show any growth. Apart from the need of energy to support the increased GDP in the developing countries, the push for global electrification will drive the steady growth for power generation. China will be a key player in the future energy demand as Figure 1.2 indicates that they will move toward a more sustainable rate compared to the past.

Most energy projections by various organizations follow the trend as depicted in Figure 1.2. There are international initiatives which look at reducing the demand and dependency on fossil fuels. One such initiative is the Sustainable Energy for All (SE4ALL), which was launched by the UN Secretary-General in 2011. The SE4ALL has set three main objectives to be achieved by 2030: ensure universal access to modern energy services, double the global rate of improvement in energy efficiency, and double the share of renewable energy in the global context.

1.2.3. Food

There are concerns on whether the world would be able to produce enough food for the growing population. The amount of arable land and water required for agriculture is declining and at the same time has to compete with urbanization and industrialization for the same resources. The most popularly used indicator for measuring and monitoring the world food status is food consumption in kcal/person/day. The world average per capita availability

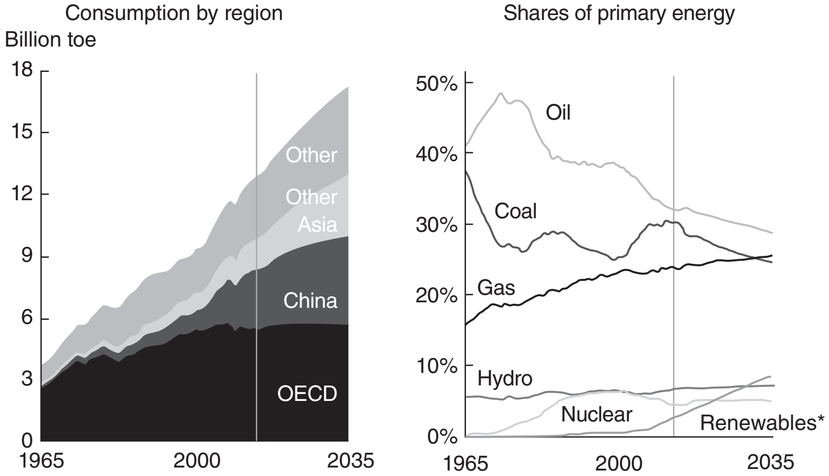

Figure 1.2 Projected growth in energy consumption. Toe is ton equivalent. * includes biofuels. Source: Reproduced with permission of *BP* [2016]. (*See insert for color representation of the figure.*)

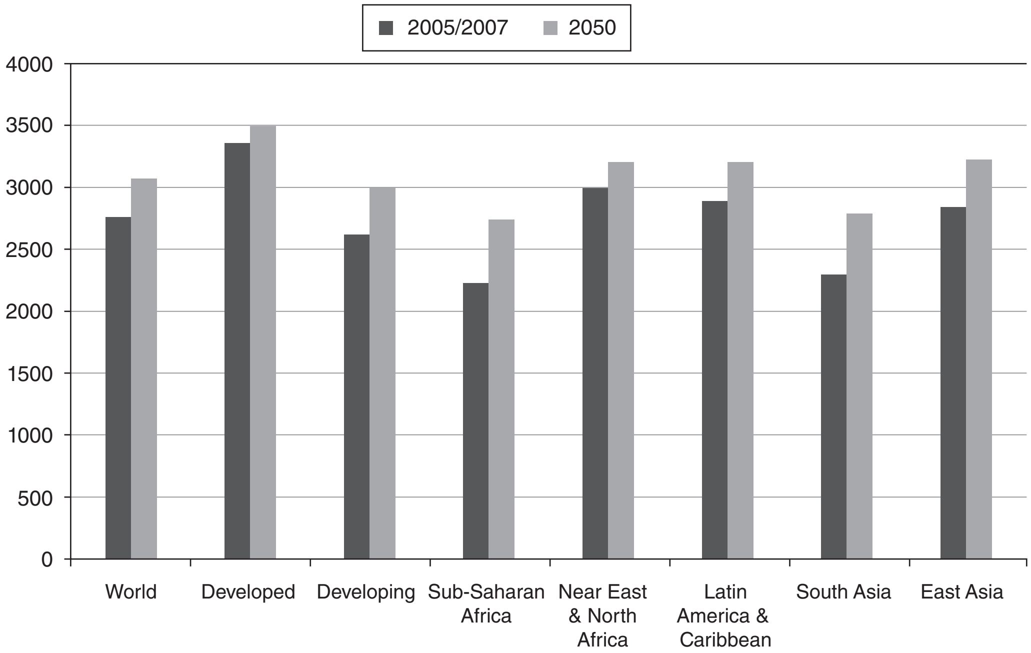

Figure 1.3 Per capita food consumption (kcal/person/day). Source: *Alexandratos and Bruinsma* [2012]. Reproduced with permission of FAO.

of food for direct human consumption was 2770 kcal/person/day in 2005/2007 (Figure 1.3). This world average is, however, misleading as there are areas where the value falls below 2500 kcal and other areas where it is way above 3000 kcal.

By 2050, food production in the global context and for developing countries will need to be increased by 60 and 100% respectively from 2005/2007 figures [*UNESCO*, 2015]. This translates into a 1.1% annual growth rate increment of total world consumption [*Alexandratos and Bruinsma*, 2012]. The projected values in million tons for some of the major food groups with respect to 2005/2007 figures are illustrated in Figure 1.4. The drivers for increase will mainly result from increasing population and income as well as structural changes in diet (i.e., shifting to a meat-based diet) and overnutrition.

1.3. SECTORAL INTERACTIONS

Water, energy, and food are interlinked in many ways. Water is required to produce energy and food. Energy is required to produce water and food. Food can be a source of energy (e.g., biofuel). Therefore, action in one sector will have implications on the others.

1.3.1. Water–Energy Interactions

The water intensity in the energy sector varies depending on the choice of technology, source of water, and type of fuel. Water is used for the production of fuels originating from fossils, growing of biomass-related fuel stocks, and generation of energy (e.g., electricity from fossil fuels). Thermal power plants utilize large amounts of water for cooling, of which a fraction is lost to evaporation depending on the type of cooling system employed. On the other hand, hydropower plants utilize a large area, which in turn increases the surface area of the water body, further facilitating evaporation. In 2010, energy production accounted for 15% (580 BCM of water annually) of global freshwater withdrawals, of which 66 BCM was consumed [*Walsh et al.*, 2015]. In the United States, power plants account for the largest share (41%) of freshwater withdrawal [*Union of Concerned Scientists*, 2010]. The global energy demand is projected to increase by 35% in 2035, which would increase water withdrawal in the energy sector by 20% and water consumption by 85% [*IRENA*, 2015]. The life cycle water consumption (gallons/MWh) for some selected electricity generation technologies is illustrated in Figure 1.5.

Renewable energy is very slowly replacing fossil fuels, especially in the power sector, but it is still projected that 75% of the expected energy increase by 2030 will be from fossil fuels [*ADB*, 2013]. Renewable energy alternatives may be climate-change-friendly but may not be favorable when considering water and land requirements. As illustrated in Figure 1.6, the water requirement for biofuel production is much higher than that required for fossil-fuel-based products. The promotion of biofuels in the

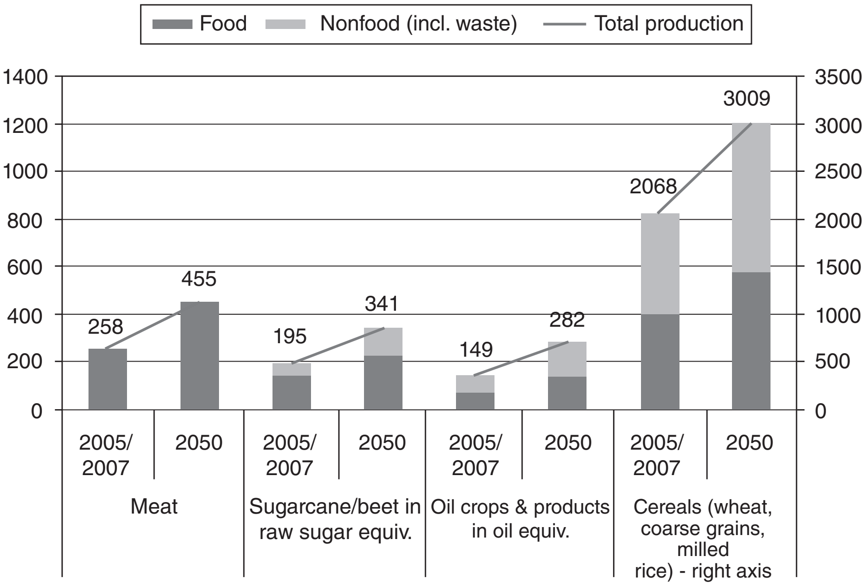

Figure 1.4 World production and use of major agricultural products (million tons). Source: *Alexandratos and Bruinsma* [2012]. Reproduced with permission of FAO.

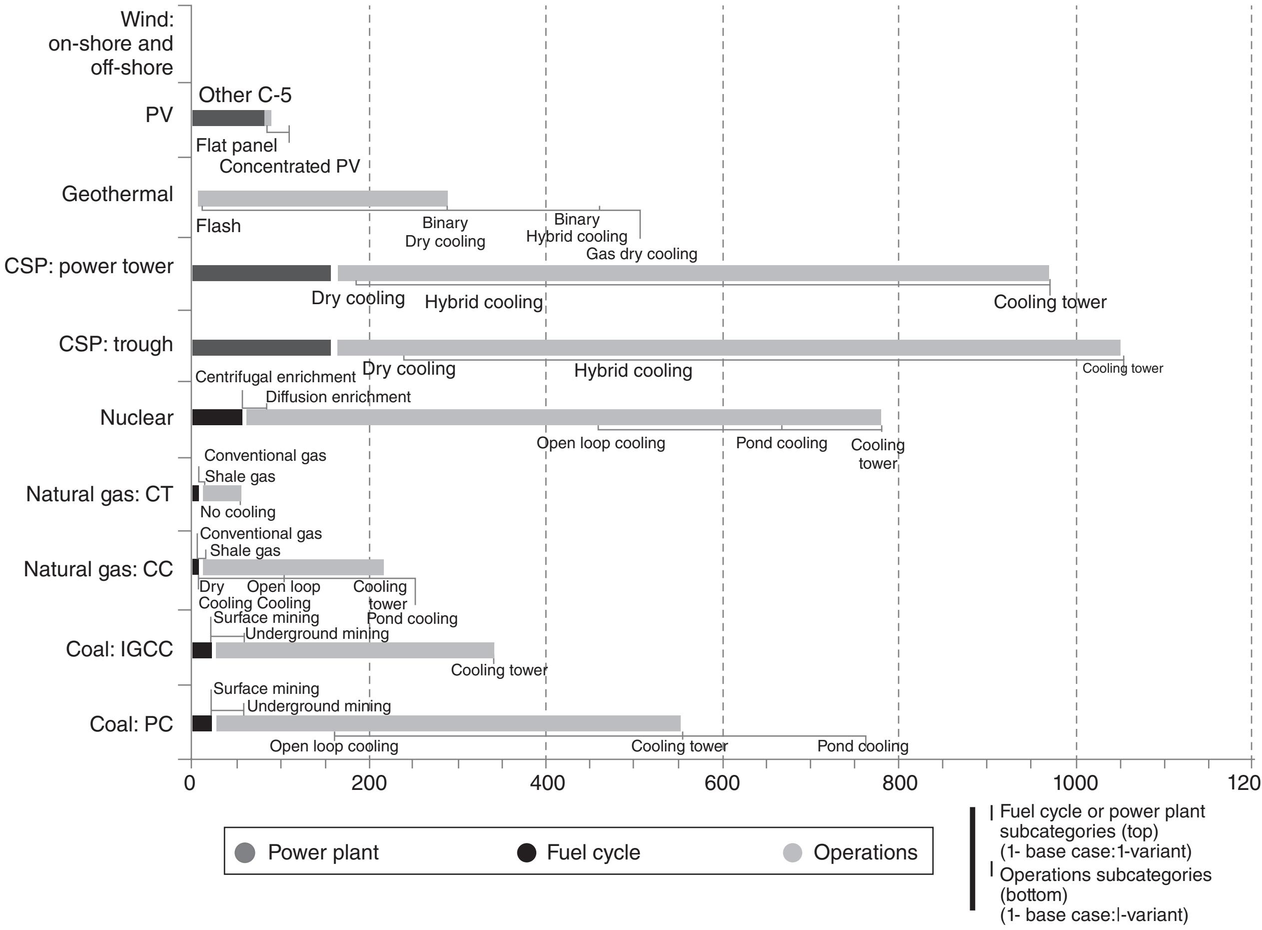

Figure 1.5 Life cycle water consumption for selected electricity generation technologies (gal/MWh). Source: *IRENA* [2015], "Renewable Energy in the Water, Energy & Food Nexus."

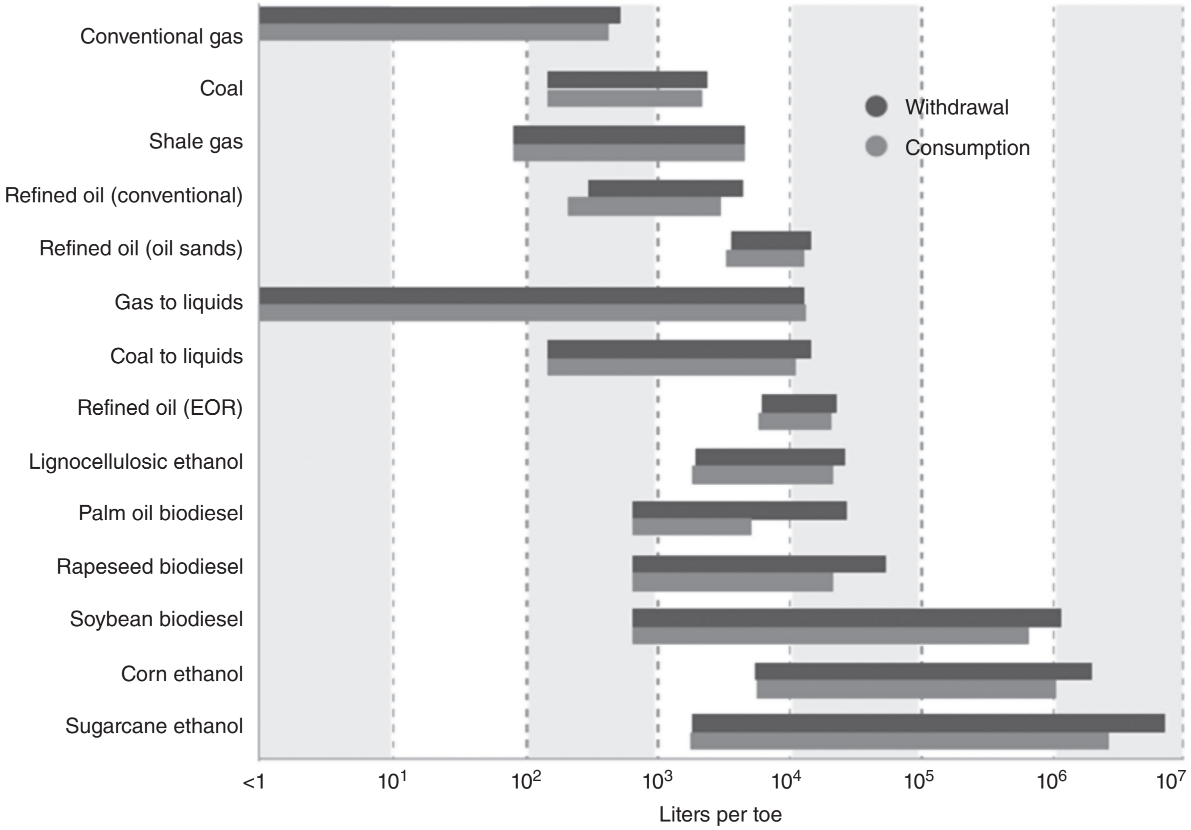

Figure 1.6 Water withdrawal and consumption for primary fuel extraction, processing, and transportation. Source: *IRENA* [2015], "Renewable Energy in the Water, Energy & Food Nexus."

transport sector through subsidies has led to greater competition for land and water use [*ADB*, 2013].

Energy is required for the extraction, transportation, and treatment of water. The energy intensity for water will vary depending mainly on the source of water, quality of water, and efficiency of the water system. For example, desalination of seawater would be more energy-intensive than utilizing surface or groundwater. Surface water was traditionally used for agricultural irrigation but with advances in technologies and inaccessibility to surface water, the use of groundwater has increased steadily. This shift to groundwater use comes with increased energy demand and lowered groundwater levels.

Energy is a dominant cost factor in the provision of water and wastewater facilities with estimates of 55% of water utilities operating budget being attributed to the energy cost [*IRENA*, 2015]. Water purification for industrial processes and human consumption requires energy and the amount of energy required depends on the source of water. For example, the purification of lake, river, or groundwater consumes less than 1 kWh/m^3 of potable water while purification of seawater can be as high as 8 kWh/m^3 [*IRENA*, 2015].

1.3.2. Water–Food Interactions

The accessibility and availability of water determine the agricultural characteristics of a given locality and the world as a whole. Water is necessary for food production, preparation, and consumption while changes in food consumption patterns or agricultural practices can create a strain on water security. Agriculture can be considered as the largest consumer of freshwater supplies, accounting for approximately 70% of consumption [*Ooska News*, 2011]. Water is not only used for growing food crops (i.e., irrigation) but also for processing, distribution, retailing, and consumption [*IRENA*, 2015]. Agricultural practices also affect water resources via water pollution through fertilizers and pesticides, which in turn affects agriculture itself, thus forming a vicious cycle. Though agriculture accounts for a large share of freshwater withdrawal, most of the water is returned to the surface or groundwater along with pollutants [*IRENA*, 2015].

The generation of waste or polluted water is unavoidable whenever food is handled, processed, packed, distributed, or stored. It was estimated that the consumption of water in the food industry in England is around 250 million m^3

(MCM) for 2006 [*Klemes et al.*, 2008]. The cost incurred during supply and disposal could be minimized by reducing the amount of wastewater, which can also lead to saving the loss of potential revenue.

1.3.3. Energy–Food Interactions

The energy–food interaction is more visible and easily felt in the modern context as the variations in food prices are strongly linked to oil price variations [*Bazilian et al.*, 2011]. This is not surprising as the agri-food supply chain accounts for 30% of the world's energy consumption [*IRENA*, 2015]. The main share of the energy consumed in the food sector is required for activities related to processing, distribution, preparation, and cooking. Energy is also accounted for in energy-intensive products such as pesticides and fertilizers. High-yield agriculture is heavily dependent on synthetic nitrogen-based fertilizers, which are almost entirely produced using natural gas [*ADB*, 2013].

The growing demand for food will be due to the growing population, improved lifestyle, and further mechanization of the food supply chain. The main challenge in the food sector with meeting the growing demand is not actually an increase in food production but rather a reduction in food wastages. The Food and Agricultural Organization (FAO) reported that approximately one-third of edible food produced for human consumption is lost or wasted [*IRENA*, 2015]. This accounts for a loss in not only embedded energy but also embedded water and contributes to greenhouse gas (GHG) emissions.

Food-processing industries also consume a significant amount of energy for heating and cooling during processing and storage of food products. For example, 20% of energy in the dairy industry is used for cooling and 80% for heating purposes. Energy consumption of the food industry in the United Kingdom is estimated at 126 TWh/year, which is equivalent to 14% of energy consumption in the country [*Klemes et al.*, 2008]. Similarly, the premium energy in the form of biogas can be produced from the effluent of food-processing plants by running anaerobic digestors. The quality and quantity of gas production depends on the balance of organic materials and process management ranges from 150 to 600 L/kg of volatile solids [*Burton and Turner*, 2003]. Pure methane has a thermal energy of 53 MJ/kg. Studies show that fuel can be generated from the utilization of organic waste [*Bianchi et al.*, 2006].

1.4. THE NEED FOR THE WATER-ENERGY-FOOD (WEF) NEXUS

There are still 1.2 billion people who lack access to electricity, 783 million people without access to potable water, and 842 million people who suffer from chronic hunger [*IRENA*, 2015]. Developing countries are expected to see a rise in population and consumption in both developing and developed countries is becoming more resource-intensive. By 2050, it is expected that global energy demand will double, with water and food demand increasing by over 50% [*IRENA*, 2015]. Climate change impacts such as global temperature increase and extreme weather conditions further compound the challenge of meeting the growing demand.

As the planet approaches the sustainable limit of its resources, competition and scarcity of the resources will become more predominant. There is a likely possibility that economic growth will soon be constrained by shortages of one or more of these resources. Therefore, water security, energy security, and food security have already been on national and international agendas for quite some time.

The amalgamation of water, energy, and food in a "nexus" framework in order to increase resource efficiency can be considered as a necessary way forward in achieving the SDGs. It enables us to take into consideration the impacts of a decision for one sector on itself as well as on the other sectors.

The best case example of a complex interaction of the nexus is the emerging trend of biofuels as an energy source in the transport sector. Biofuel production raises the conflict of the use of limited water and land against growing food for human consumption.

1.5. STRUCTURE OF THIS BOOK

In the context of the need to better understand, operationalize, and practice the nexus approach for resource use efficiency vis-à-vis the lack of adequate knowledgebase and publications in the arena, this book aims to contribute to the global debate on WEF nexus through knowledgebase generation. A single volume of the book covers theoretical and/or conceptual aspects of the WEF nexus, ways to overcome operational challenges of the nexus approach to resources management, cases of the nexus approach in practice from different regions of the world, and opinions on the future of the nexus agenda. The book is divided into four sections and 19 chapters. The first section on "understanding the nexus" contains five chapters focusing on the need of a nexus approach; its evolution as a policy and development discourse; its contribution to better water management and limitation; the emergence of a new paradigm in the nexus approach; and the urban nexus. The second section "operationalizing the nexus" contains six chapters focusing on modeling techniques; available tools/models in practice; governing the nexus; the role of international cooperation in operationalizing the nexus; framing nexus cooperation issues in the transboundary context; and cases of energy-centric operationalization of the nexus. The third section on the theme of "nexus in practice" covers seven chapters and focuses on various types of case studies of WEF nexus in various geographical regions of the world. Finally, the fourth section called "future of the nexus agenda" contains only one chapter focusing on how the nexus approach can help achieve the SDGs or the 2030 Agenda.

REFERENCES

2030 Water Resources Group (2009), Charting our water future: Economic frameworks to inform decision-making.

ADB (Asian Development Bank) (2013), Thinking about Water Differently: Managing the Water-Energy-Food Nexus, ADB, Bangkok.

Alexandratos, N., and J. Bruinsma (2012), *World Agriculture Towards 2030/2035: The 2012 Revision*, FAO, Rome.

Bazilian, M., H. Rogner, M. Howells, S. Hermann, D. Arent, D. Gielen, P. Steduto, A. Mueller, P. Komor, R. S. J. Tol, and K. K. Yumkella (2011), Considering the energy, water and food nexus: Towards an integrated modelling approach, *Energy Policy*, *39*(12), 7896–7906, doi:10.1016/j.enpol.2011.09.039.

Bianchi, M., F. Cherubini, A. De Pascale, A. Peretto, and B. Elmegaard (2006), Cogeneration from poultry industry wastes: Indirectly fired gas turbine application, *Energy*, *31*(10), 1417–1436.

Bonn2011 Conference (2011), Messages from the Bonn2011 Conference: The water, energy and food security nexus—solutions for a green economu.

BP (2016), BP energy outlook 2016: Outlook to 2035.

Burton, C. H., and C. Turner (2003), *Manure Management: Treatment Strategies for Sustainable Agriculture*, Editions Quae ed., Silsoe Research Institute, Bedford.

FAO (Food and Agricultural Organization) (2014), *The Water-Energy-Food Nexus: A New Approach in Support of Food Security and Sustainable Agriculture*, FAO, Rome.

IRENA (The International Renewable Energy Agency) (2015), Renewable energy in the water, energy and food nexus, IRENA, Abu Dhabi.

Klemes, J., R. Smith, and J.-K. Kim (2008), *Handbook of Water and Energy Management in Food Processing*, Elsevier, Burlington, MA.

Ooska News (2011), Conference synopsis, paper presented at the Bonn2011 conference: The water, energy and food security nexus—solutions for the green economy, Bonn, Germany.

UNESCO (United Nations Educational, Scientific and Cultural Organization) (2015), *The United Nations World Water Development Report 2015: Water for a Sustainable World*, UNESCO, Paris.

Union of Concerned Scientists (2010), The energy-water collision: 10 things you should know.

Walsh, B. P., S. N. Murray, and D. T. J. O'Sullivan (2015), The water energy nexus, an ISO50001 water case study and the need for a water value system, *Water Resour. Ind.*, *10*, 15–28, doi:10.1016/j.wri.2015.02.001.