resources

Review

Population–Urbanization–Energy Nexus: A Review

Ram Avtar [1,2,*], Saurabh Tripathi [2], Ashwani Kumar Aggarwal [3] and Pankaj Kumar [4]

1. Faculty of Environmental Earth Science, Hokkaido University, Sapporo 060-0810, Japan
2. Graduate School of Environmental Science, Hokkaido University, Sapporo 060-0810, Japan
3. Electrical and Instrumentation Engineering Department, Sant Longowal Institute of Engineering and Technology, Longowal, Punjab 148106, India
4. Natural Resources and Ecosystem, Institute for Global Environmental Strategies 2108-11 Kamiyamaguchi, Hayama, Kanagawa 240-0115, Japan

* Correspondence: ram@ees.hokudai.ac.jp; Tel.: +81-011-706-2261

Received: 30 June 2019; Accepted: 23 July 2019; Published: 30 July 2019

Abstract: Energy expansion and security in the current world scenario focuses on increasing the energy generation capacity and if possible, adopting cleaner and greener energy in that development process. However, too often this expansion and planning alters the landscape and human influence on its surroundings through a very complex mechanism. Resource extraction and land management activity involved in energy infrastructure development and human management of such development systems have long-term and sometimes unforeseen consequences. Although alternative energy sources are being explored, energy production is still highly dependent on fossil fuel, especially in most developing countries. Further, energy production can potentially affect land productivity, land cover, human migration, and other factors involved in running an energy production system, which presents a complex integration of these factors. Thus, land use, energy choices, infrastructure development and the population for which such facilities are being developed must be cognizant of each other, and the interactions between them need to be studied and understood closely. This study strives to analyze the implications of linkages between the energy industry, urbanization, and population and especially highlights processes that can be affected by their interaction. It is found that despite advancement in scientific tools, each of the three components, i.e., population growth, urbanization, and energy production, operates in silos, especially in developing countries, and that this complex issue of nexus is not dealt with in a comprehensive way.

Keywords: nexus; energy; urbanization; population; sustainable resources

1. Introduction

In the present world of technological advancements, breakthroughs, and innovations, industrialization is reaching new heights. While this drives commodity prices down, increased demand for high skilled labor, increased wages, and rapid industrialization have also led us into many problems and challenges, which are too big to ignore at this moment [1]. Ever-increasing pollution of all forms, resource wastage and exploitation, increasing fuel costs due to round-the-clock production, huge energy consumption due to increased automation in different sectors, etc. are just a few issues to be considered [2]. The economic progress around the world has led to various changes, for example, hundreds of millions of jobs created, improvements in life support and health, access to goods and a wide variety of foods, etc., which is particularly noticeable in emerging economies [3]. The backbone of all these developments in industrialization, globalization and market expansion, etc. is the energy sector. If the industry is the body that works to develop a nation, energy is the oxygen that keeps the body of economy and lifestyle alive. Being the power source metric of civilization, world energy consumption has profound repercussions for the socioeconomic development of society [4].

During the period 2000–2012, coal was the main source of energy and saw a large growth in the usage ratio. Coal was followed by oil, natural gas, hydropower, and renewable energy. Even though renewable energy was least among all energy sources in this period, its growth rate was much faster than at any other time in history. In the year 2011, expenditures for energy supply were more than 6 trillion USD, which accounts for approximately 10% of the world gross domestic product. Out of this world energy expenditure, the shares for Europe, North America, and Japan were about 25%, 20%, and 6%, respectively [5]. The International Energy Agency estimates that, in the year 2013 alone, the total primary energy supply (TPES) was 1.575×10^{17} Watt-hour or 13,541 Millions of Tonnes of Oil Equivalent (Mtoe) [6]. There are other issues regarding energy consumption, for example, in the year 2014, the world's primary energy supply was 13,541 MTOE; however, final energy consumption in terms of fuel was only 8328 MTOE, i.e., 29.5% less than the total supply. One of the major reasons for this difference is because part of the energy is being consumed for products such as lubricants, asphalt, gasoline, and petrochemicals, which have chemical energy content but are not used as fuel. It is reported that the world population increased by 27% from 1990 to 2008, and the average per capita energy use also increased by 10%. For the same period 1990–2008, while overall energy usage at a global scale increased by 39%, there was significant variation at the regional scale, for example, growth in energy use for the Middle East, China, India, Africa, Latin America, USA, and Europe was recorded as 170%, 146%, 91%, 70%, 66%, 20%, and 7%, respectively [7]. This ever-increasing trend of energy consumption and energy production leads to burgeoning energy programs. This is especially true for developing economies. With the energy deficit in its current state and a booming economy, countries such as Chile, China, India, etc. have been actively perusing the net energy positive state for some time now. However, there is significant lack of deep insight for different energy driven programs and their relationship with rapid urbanization and population growth. With the aforementioned gaps, this study strives to evaluate the energy–urbanization–population nexus for India. India is witnessing a swift expansion of energy plans on all fronts, e.g., solar, wind, nuclear, thermal, etc.; however, this will lead to a catastrophic situation if this aggressive energy expansion plan is uncontrolled and not given due attention.

Rationale

The rationale behind this study is that many new energy projects are being implemented every year in India, and with land in high demand, plants have to be either set up in some remote location, close to a forest, in a protected area or on agricultural land, which on one hand helps India in achieving the energy surplus goal but at the same time affects the nearby environment with both foreseen and unforeseen problems. For example, increased soil acidity, ash deposits, loss of valuable agricultural land, presence of heat island, etc. are just some of the problems faced during or after the set-up of power plants in such surroundings. This makes the study of energy industry-induced urbanization and its effect even more relevant, as population and human activity increases significantly in these regions that would not otherwise see that level of urbanization in the foreseeable future. To understand this nexus, we need to take a closer look at the workflow of this industry and analyze the parameters which drive such developments. An interconnection of energy with various domains, including climate change, food security, population, water security, urbanization, land-use, ecosystem, economic growth, etc., is shown in Figure 1. The focus of this review paper is to analyze the interconnection among energy, population, and urbanization and to understand the nexus among these three domains. For this, several quantifiable indicators are used.

The driving factors or indicators of social development, job creation, infrastructure development, lifestyle management, industrialization, urbanization, wealth creation, etc. can all be summed up in the energy, population, and urbanization nexus as illustrated in Figure 2. This gives a first view of how deeply rooted and dependent any economy is on its energy sector, which in turn depicts that how energy sector has its own working dynamics with population and urban development to sustain such a system. Not only direct but also indirect factors, e.g., education system development and health care, play a vital role in such dynamics for any given economy. It is univocally argued that energy is the key driver for economic growth, but government policies and their implementation, which encourage long-lasting coordination between these two, are also key factors. Governments usually focus only on prices, the security of energy supply, and environmental protection when formulating energy strategies; hence, integrating plans with job creation and economic prosperity can be challenging. Just increasing direct employment in the energy industry might not be the perfect solution, as it will likely increase energy prices and reduce the industry's overall productivity. Instead, the government should focus on how energy growth-related decisions will contribute to the industry's direct economic contribution as well as maximize welfare. Industrial contribution to economic growth and job creation in some countries succeed to a great extent, but in most developing countries, industry's position as the lifeblood of the modern economy dwarfs the direct effects.

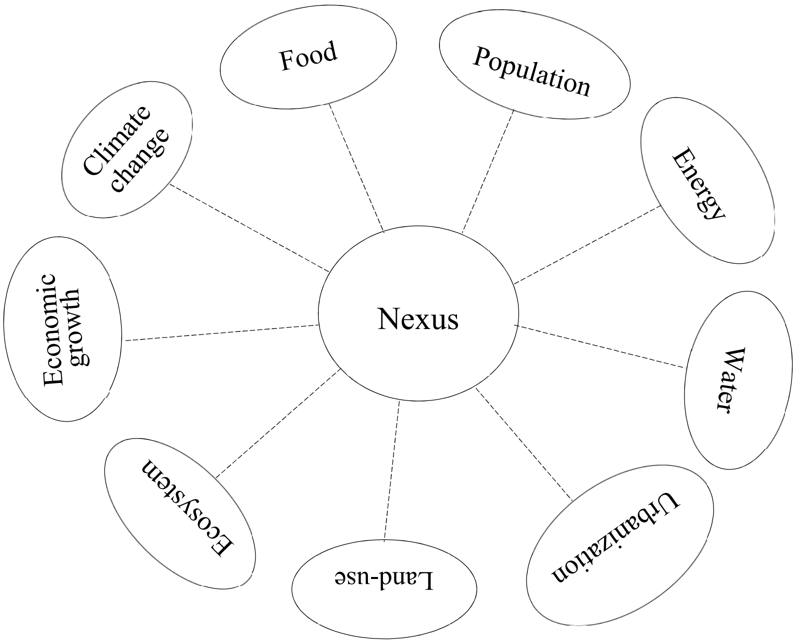

Figure 1. A nexus consisting of the interconnection of various domains.

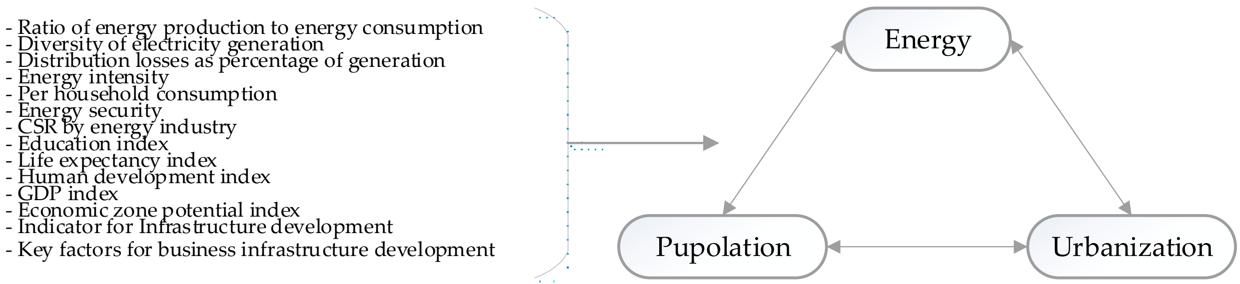

Figure 2. Population–urbanization–energy nexus.

A graphical model of the relationship between energy, population, urbanization, and other related domains is illustrated in Figure 3. Each line in this graphical model indicates a dependency. Each of the variables is dependent on the rest of the variables, and none of the variables is independent. The interconnections among energy, population, urbanization, and the related variables viz. ecosystem, economic growth, food, water, land-use, and climate change depend on several factors, such as geographic area, social structure, and other factors in the environment.

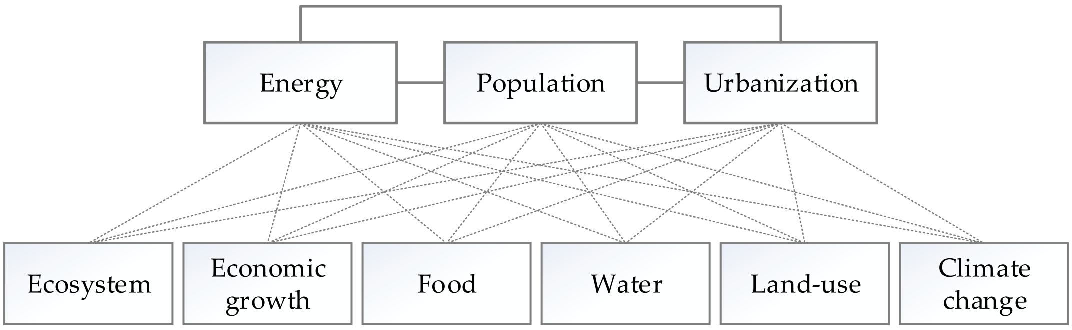

Figure 3. Graphical model of relationship between population, urbanization, energy, and other related domains.

Although the success rate for managing natural resource wealth along with promoting economic development is mixed, several countries have done so with great success [8]. Countries with less natural resources are also focusing on energy-dependent economic growth, even though it might put the scarce natural resources at a higher risk of extinction. A steady, as well as reliable, energy supply is vital for the growth of developing and emerging economic powers. Developing countries such as China and India are adopting entrepreneurship and technological innovation in nontraditional energy sectors as a further avenue to support the development of their rapidly growing economies [9]. The governments of these countries are offering incentives for the installation of energy units based on wind energy, bio-energy, and solar energy production, are promoting joint ventures and technology transfers, as well as providing avenues for research and development in these areas. Many developed countries are also looking for ways to expand their energy capacity based on renewable energy sources to contribute to achieving global sustainability goals in a timely manner.

This paper is intended towards a qualitative approach to understanding the energy–population–urbanization nexus and various correlations between the factors influencing its dynamics. The reason behind it is that extensive research on nexus issues by various scientific communities has been focused on different domains such as food–water, food–energy, real estate–energy nexus, etc., but the same level of attention has not been given to research on the energy–population–urbanization nexus.

2. Methodology

To find the most useful scientific works on nexus issues focusing on energy–population–urbanization for qualitative analysis, in this study, a title, keyword, and abstract search was made in Scopus (https://www.scopus.com), which is a citation database of peer-reviewed articles and covers around 36,000 journals. Different search queries were used viz. "nexus*" AND ("urban–energy" OR "population-energy" OR "energy-food" OR "energy-population-urbanization" OR "Energy land use-migration" OR "web 2.0"), with the intention of identifying any studies that used an energy consumption pattern, population growth, resource management, urban planning, and urbanization for their research on nexus issues. Papers that satisfied the aforementioned search criteria (n = 243) were collected and studied for qualitative analysis on nexus dynamics between energy, population growth, and urbanization.

In addition, special attention was given to papers dealing with policy-related research to identify the application of nexus issues in natural resource management. After that, we excluded irrelevant papers (n = 95) by reading their abstracts and conclusions. To extract the focus in the field of energy, population, and urbanization nexus issues, the remaining papers (n = 148) were read carefully and multiple times. Thereafter, the main outcome of each paper was noted, together with their research scale, adopted methods, nexus concepts, challenges, and opportunities.

3. Result and Discussion

3.1. Energy on Urbanization

At present, the land use pattern is very much dependent on the energy life cycle. The energy life cycle includes resource exploration, mining, refinement, distribution, usage, and distance it travels to move to the next step until the end-use. Energy development can affect urbanization in many ways, for example, mountain top removals, deforestation, clearing agricultural fields, rerouting of rivers, etc., for making way for different energy plants. The infrastructure involved in energy production, transmission, and distribution, such as railways, roads, slide rails, pipelines, refineries, electric grids, etc., has directly affected subsequent and adjoining land uses or landscapes for a long period of time, typically for more than 30–40 years. Here, the urbanization rate gets even higher in a remote location or in a farming location where such a high rate of urban development would not otherwise be seen for decades (if indeed, at all), which starts from the beginning of construction of such power generation stations. When the energy plant is set up, which is producing profitable energy, then the governing body usually puts different expansion projects in motion, which results in higher urbanization supported with various other activities such as housing development, the establishment of educational institutes, employment, etc. Therefore, during energy policy formulation, cost–benefit analysis to evaluate the relation between setting up the energy plants and its predicted benefits versus the land use land cover changes both for short and long term should be undertaken.

Land use at most of the places continues to be affected by the different stages of the energy life cycle, for example, location of use or extraction, transportation in the supply chain or end-users. More precisely, it includes materials exploration, extraction, production, refinement, distribution, and usage. Energy development can impact urbanization in many ways, ranging from an alteration in the supply of water, food, other resources, etc., through mountain top removals and surface mining, to the rerouting of rivers and flooding for hydroelectric dams, to the clearing of forest to make way for solar and wind farms, etc. The extent of dependency on land use is determined by various factors, such as location, geography, and topography. All these factors play a critical role in the energy life cycle, including the extraction of raw materials, refinement, and production of material, as well as further distribution for further usage. Human settlements have increased in places where there is sufficient wood for fuel and water for power and transport [10]. Settlements have also followed with development booms in industries in the surrounding areas, which extract, process, and transport energy supplies to users and markets. Therefore, wherever cheap, convenient energy is provided, people settle, towns spring up, and land uses change for the long term, typically for 30–40 years. The setting up of a power plant in a region is not the only infrastructure development during the energy infrastructure setup. Apart from the infrastructure needed for energy production and energy distribution, roadways and railways for material and other distribution, pipelines, refineries, grid infrastructure, housing colonies, etc. have greatly influenced the immediate and the surrounding neighboring land use and utilization. The rate of urbanization is even higher in remote or rural locations, farming locations or forest locations, where such a high rate of urban development will either not be seen for decades or even at all. Higher rates of urban development start right from the start of the project undertaking.

With ever-increasing energy demand, there is tremendous pressure on lands such as the Western Amazon, a biodiversity hotspot and one of the last remaining forest frontiers, for energy exploration and extraction. For example, in Ecuador, patterns of deforestation significantly correlated with recently developed road networks for oil exploration and development [11]. A total of 48.6% of the Peruvian Amazon was recently offered for oil and gas concessions, and the total area affected through past and current fossil-fuel concessions reached 84% of the total region [12]. The impact of the energy industry on land use is also driven by many other factors, such as the extent and duration of extraction, the intensity of availability and subsequent extraction, profitability, and the reversibility of the changes that are required for that setup. Energy-related activities act on the land cover, which may sometimes enhance the potential of land use, but more often than not, it constrains the potential land use options for a given location. Energy infrastructure such as storage tanks, distribution, and transportation systems, dams, waste management practices, and further human comfort intended development, etc. typically replaces, inundates, fragments or annihilates the vegetation across the landscape for long periods of time (typically 30–50 years). As an example, oil and gas extraction wells can have a smaller enduring footprint on the ground during normal operation periods, but an oil spill can contaminate land, surface water or groundwater, destroy vegetation, and increase hazard levels in that area significantly [13]. The case of being downstream of a dam, where there is more area available for further farming or development of new forest or vegetation, which may not have been possible previously, due to high runoff or some other issues, is one example of a positive effect on the landscape in terms of vegetation growth or increasing the diversity of the land. The barging and building of access tunnels and channels dredged through the wetlands for exploration, extraction, and distribution along with the subsidence that occurs after extraction of oil or gas are examples of the negative effects that hinder the potential of the land. These negative effects are far greater than any positive effects that could be had, such as in the above example. This might permanently affect topography and land cover with irreversible loss of ecosystems and wide-ranging legacy effects such as the loss of protective capacity from storm surges by wetlands that continue long after production operations cease [14].

The availability of relatively cheap fossil fuels has been a major driver of global land-use change such as urban sprawl, large-scale industrial set-up, and agricultural expansion [15]. Fossil fuels have been the primary source of energy for the past century, and exploration of coal, oil, and gas has reached an all-time high. From the river basins to deserts, from coastal lines to deep seas, wherever fossil fuels are to be found, humans have tried to extract them and put them to use. This uncontrolled extraction results in major environmental disasters across the lands and seas when the energy extraction or exploration goes out of control. Additionally, the method by which fossil fuel is mined also determines its impacts on the ambient environment. For example, deep mining for coal has little effect on the land surface as compared to strip mining or mountaintop removal that removes vegetation and top fertile soil. A major part of a forest in the Southern Appalachians, United States, has been converted to edge habitat because of mountain-top-removal coal mining [16]. Moreover, coal-fired power plants use extensive land areas for traditional storage of coal–ash slurries, which causes large areas of land disturbance with long-term and irreversible impacts on wildlife, air quality, water quality, and greenhouse gas emissions [17].

Additionally, cheap fossil fuel-induced energy-intensive refrigeration and transport results in drastic increases in the scale and location of food, feed, and fiber production, thereby changing land-use patterns around the world by replacing local supply chains with global trade networks. Other aspects of the construction and operation of an energy power plant can also have negative effects on the neighboring community in which the power plant is built. For example, construction of the power plant, despite being well managed, could be perceived by neighboring landowners and citizens as ugly and chaotic and might have an effect on community bonding or even business. More precisely, a typical power plant, especially in developing nations, has large areas for storage of either cooling water, or coal–ash slurries, coal and other fuel, etc., for use at different stages of the energy production. The storage area for coal–ash slurries is usually large open pits which pose a threat for leakage into the groundwater or surrounding areas. The high ash content released in any neighboring canals can cause the complete choking of a canal and also increases the acidity and salinity of water streams [18]. Further, the coal storage and burning in the boilers increases the content of the particulate matters in the air. While there are technologically-advanced systems available, which makes exhaust emissions much safer, the status quo is poor operation and maintenance, especially for aging plants, due to poor governance in energy-hungry developing countries such as India, Chile, Brazil, etc. This leads to a situation where the government of any nation needs a coal-fired plant to work continuously for overall economic and societal progress but at the same time must also mitigate coal-plant-induced problems on both the immediate and the surrounding areas.

Additionally, energy production and transmission necessitate the establishment of power-line corridors and roads. These linear features often have effects on the landscape with the excessive cutting of vegetation and topographic modification, which can affect species composition and land cover [19,20] . While these linear land-cover features are compatible with industrial or urban areas, they are not compatible with other land uses such as agriculture or forest lands, which tend to support numerous ecosystem services. Although the power line corridor's spatial extent is very limited, they can cause habitat fragmentation, which results in biodiversity loss [21]. Similarly, in the case of natural gas and petroleum products, pipelines, as well as roads, must be constructed to transport the fuels from the place of production to the consumers. In the United States alone, there are more than 4 million km of pipelines in use to transport these energy resources [22]. While pipelines are considered a safer way to transport petroleum and gas, there are still many issues involved. In countries such as Ghana, Chile, Zambia, etc., it is common for people to try and steal the oil without any proper technical knowledge or tools, which results in the breaking of the pipelines or valves and subsequent oil spills in vast areas of land and water bodies. Furthermore, pipelines have been running for decades without any problems and are therefore often neglected or forgotten in terms of maintenance, which leads to rusting, bleeding or decay of the pipes, resulting in various slow leakages and, ultimately, major oil spills and environmental disasters, such as, for example, the Keystone pipeline leakage of 2017.

Biofuel crops are one of the potential renewable energy resources but require meticulous management practices [23]. Long-term and extensive effects occur when land use is totally converted by bioenergy crops [24]. Despite extensive speculation based on numerical simulation [25], empirical evidence suggests that biofuel markets have an insignificant impact on global deforestation trends because deforestation is mainly governed by the political set-up and socioeconomic drivers [26–28]. It is reported that efficient bioenergy policies can mitigate drastic land-use change and associated adverse impacts on greenhouse gases emission [29–31]. Energy-crop demand will create incentives to manage land for higher productivity, also resulting in more CO_2 sequestration compared to unmanaged and previously disturbed land. Biofuel crops can minimize the slash-and-burn practice, a low-cost maintenance option which contributes to greenhouse gas emissions [32]. It can save a significant amount of land from 330 to 430 million ha of land which is burned every year due to slash-and-burn only in sub-Saharan Africa and along tropical agricultural frontiers. However, to promote and manage bioenergy crop planting well, a clear understanding of current land-use practices, active participation of government, growers, and industry, as well as incentives appropriate for the local situation, are required [33].

While the land-use impact of hydroelectric power extraction is quite apparent in terms of direct impact due to water accumulation for the dam in the surrounding area, other renewable energy extraction methods such as wind and solar have their own way of impacting the surrounding area. The hydroelectric power affects both aquatic and terrestrial species and also affects the resource distribution upstream and downstream of the constructed dam. The nutritious silt brought by every river that makes the lands fertile and is critical for high fertile land becomes clogged up due to the building of the reservoir of the dam, even after implementation of silt flushing is set up in some of the dams, such as the Three Gorges Dam in China, where the nutritious silt is still not distributed properly to make an impact. The reoccurring logistical problem of the relocation of people living in the affected area becomes even more apparent in developing nations where more hydroelectric plants are either constructed or pursued. The biggest example of either human resettlement or protest on a massive scale against the dam construction comes from Tehri dam in Uttarakhand India, which saw protest and delays in the project for more than 10 years and at the Three Gorges Dam in China, which resulted in the relocation of an estimated 6 million people [34].

While the impact due to hydropower extraction is clear and apparent, the effect of solar and wind power may seem far less impactful in comparison, but that may very well be because the true extent of it may not yet have been realized fully. For example, wind energy is irregular and must be backed up by another energy source. The major effect on land and the environment, once wind energy systems are fully installed, includes a change in land uses, noise pollution, the killing of birds and bats by collision to the rotating blades, and other disturbances associated with system operation and maintenance. However, the visual spatiotemporal effect on land due to wind energy is really much smaller compared to that of most of the other energy sources. Solar energy extraction, on the other hand, relies on the power of the sun to be extracted as either electricity or heat to put to various uses. The most widely used solar energy utilization method is the setup of wide and large solar electric power plants all over the world. While solar energy extraction may be limited to only some viable places due to various factors such as solar energy availability, clouds, and climate, etc., there is a tremendous amount of solar energy project implementation in the developing world, e.g., in China, Chile, and India, due to such factors as energy tariffs and countries trying to bring their carbon footprint down on the world stage. Whatever the reasons may be for such an aggressive approach towards solar energy, other areas of impact also need to be addressed. [35] stated that the temperature from urban heat islands can be utilized to grow more crops in some places, but the opposite can also be true—loss in agricultural productivity due to the presence of urban heat islands in a surrounding where the temperatures are already high due to presence of year around solar radiation rendering crop production at low yield rates. The keywords used in this search were “effect of energy on urbanization”, “influence of energy on urbanization”, “impact of energy on urbanization”, and “energy and urbanization nexus”.

3.2. Urbanization on Energy

Urbanization is the one factor that is always growing in any given condition of society or landscape. Ever-expanding cities, more elaborate and complex infrastructure development, and industrial and technological advancements are just a few examples of the progression of urbanization. All of this development is tied directly to many factors viz. resources, engineering, design, capital, etc., but the most fundamental element which influences the most is energy availability. Hence, the urbanization rate and development are tied directly to energy production and its availability in any given country. The pattern of urbanization around the world can be understood and linked to production, availability, cost, and efficiency of energy plans in various ways. The theory of ecological modernization, urban environmental transition, and the compact city has been outlined in [36]. The authors proposed that the process of urbanization triggers changes in the industrial structure and energy conservation by the inclusion of the latest technological advancement. This efficient use of energy will also stimulate economic growth. Resource availability, generation efficiency, and capital investments are a few bottlenecks faced in this co-dependency. While bigger cities demand more energy to sustain a large population, infrastructure, transportation and accompanied needs, this need also helps in the generation of capital investment and higher resource availability. Conversely, high concentration of infrastructure and need of energy in big cities also create a waste of energy situation viz. by traffic congestion, electricity waste by populous ignorance, etc., also known as energy-specific congestion diseconomies. The increasing need for all forms of energy is encouraging more use of renewable and reliable alternative energy sources. To achieve this need of energy for urban infrastructure, the first evaluation of the possibility of resource availability and extraction needs to be done in relation to the supply–demand of the current establishment as well as plausible future scenarios. The landscape also plays a vital role in the energy development process, not just to access the energy extraction but also to do so efficiently and cost-effectively with higher reliability and safety. For instance, to establish a reliable wind energy infrastructure at any location, it must have strong and steady wind flow. Along with that, the location should have either energy storage capability or the ability of the electricity grid to accommodate energy pulses [37,38].

As another illustration, landscape stability, watershed characteristics, and ease of approach determine power extraction possibilities. The industries, refineries, and thermal and hydropower plants are typically located in the vicinities of water bodies, viz. rivers or lakes, etc., where water is readily available for usage. However, once the energy plant is established, it usually leads to changes in the water table, river discharge and changes to land-use and zoning conflicts. For hydropower plants, land availability for reservoirs, hydraulic head (height of reservoir), precipitation, etc. affect the degree to which hydroelectricity can be generated as an efficient and sustainable form of energy. Furthermore, the landscape, geological stability, and land-use practices upslope of the reservoir determine sediment and erosion rates that affect the maintenance and storage capacity of the hydroelectric power generation system. Hence, land use and land cover affect the location of hydroelectric energy projects, their operating costs, and longevity, and thus, the value of a project as an energy source. The value of an energy source is highly dependent on the established infrastructure for such extraction and its location. Locations of this energy infrastructure and energy extraction are more often within remote locations or locations where there is not much infrastructure in the vicinity whatsoever. For example, setting up of a typical solar park is mostly dependent on year-round solar radiation; hence, limiting the areas where these solar projects can be set up on a large scale. Given the lower power generation efficiency of current solar cells, the only way to set up a higher generation capacity solar plant is by increasing the area of the solar power plant. The combination of all these variables can lead to the selection of a location which is in the middle of a forest, protected area, agriculture land, coastal plains or other locations, which have little to no human settlement. After the land is selected, different activities such as the clearing of large areas of forest, vegetation, conversion of agricultural land to industrial usage, setting transport and access in terms of motorway, highway and heavy-load expressway, then occur.

Urbanization also greatly affects the demand for energy. Industrial and urban areas have a relatively greater demand for energy than agricultural land, forest, or rural areas. Consequently, a steady source of energy supply in the nearby region and the efficient means to transport energy if production in a distant place is required. In addition, urban areas will also require good energy distribution networks, comprising an energy grid and transportation network, i.e., highways and expressways. As a result, most of the urban residents are still forced to use conventional energy sources if not served by natural gas pipelines or windmills for electricity in homes that are not connected to the grid. Land-use practices and priorities in the urban areas also have a significant effect in different stages of energy development. For instance, the affordable availability of energy resources depends on competing for land uses and values. The world's remaining major fossil-fuel reserves are increasingly found in remote areas or areas with very little anthropogenic disturbances such as the North Slope of Alaska, Siberia, the Western Amazon, deep underwater, or under mountaintops in Appalachia where resource exploitation can conflict with other designated uses such as biodiversity conservation, ecosystem services, watershed protection, sustainable management of productive forests and fisheries, etc. [39]. The influence of urbanization on energy consumption was investigated in [40]. Data from 78 countries, over a period from 1995 to 2012, were collected for the study. A generalized method of moments estimation was used to conclude that urbanization has a significant impact on energy consumption. It is also concluded that the impact of urbanization on energy inefficiency is greater for countries with a higher gross product per capita. The impact of urbanization on energy consumption in China was investigated in [41]. The study was based on a dataset consisting of 29 provinces of China and spanning over a period from 1998 to 2014. A nonlinear relationship between urbanization and energy consumption was estimated using STIRPAT (stochastic impacts by regression on population, affluence, and technology) framework. The influence of urbanization on energy consumption in Middle Eastern countries was studied in [42]. The dataset consisted of data from eleven Middle Eastern countries over a period of 1990–2012. Cointegrating regression analysis was carried out, and results indicated that a 1% increase in urbanization caused a 0.49% increase in energy demand. The threshold effect of urbanization on energy consumption was studied in [43]. Based on the study, suggestions were made by the authors of the paper to update the industrial structure and urbanization with low energy consumption. A suggestion to control energy consumption based on various threshold levels of urbanization was made. An aggregate analysis was carried out to identify the effect of urbanization on industrialization and energy use. The dataset contained data from 59 developing countries. The authors of the paper found that higher urbanization in a few cities as compared to more of a spread of cities affects the increase of energy consumption. The keywords used in this search were "effect of urbanization on energy", "influence of urbanization on energy", "impact of urbanization on energy", and "urbanization and energy nexus".

3.3. Population and Urbanization

Ever since the utilization of agriculture which enabled humans to make a settlement in one place, population and urbanization have gone hand in hand wherever people have gone or lived. While this process of settlement started from small camps and farming colonies, it has given way to transforming human settlements into large and megacities. Combined with the tool of industrial and technological revolutions, this has given way for a massive migration of people from rural and less populated areas, to move to big cities. Because of this migration, the urban population increased from 2% to 50% of the total world population as of 1800 and 2004, respectively [44,45]. From small to medium-size to megacities, population migration and attraction of benefits and opportunities of urbanized towns have created their own ecosystems of growth, attraction, and infrastructure expansion. The rate of energy consumption and demand of readily available energy is much higher in an urban area and is constantly going up due to always increasing demand of energy source from the population. Energy consumption for electricity, transportation, cooking, and heating is much higher in urban areas than in rural villages. There has always been a constant dependence of any society on fuel of all forms. In modern times, this dependency has been on fossil fuels, more than any other forms of energy. While cities and rural areas rely on the energy provided by fossil fuels, the rate of consumption is as high as three times that of rural areas, e.g., in China, per capita consumption of coal in towns and cities is more than three times the consumption in rural areas [46]. As any given economy grows, so does its demand for infrastructure and, hence, the energy consumption.

The dynamics of the population in any given region and urbanization of such a region are codependent in such a way that it can be said that one feeds the other, and correlation between them leads to an even wider spectrum of increased codependency. This can be understood fairly simply at the early stages of development of an urban environment. A typical expanding urban environment usually grows because of the opportunity of work and the establishment of industry nearby. This leads to a sudden migration of people to find work, which in turn leads to the establishment of the housing system, entertainment opportunities, and further industries to support such population increase [47]. As the demand for facilities, energy, transportation, etc., increases from the living population, there is a shift and surge in service sector-based industries and an increased inclination of the government and people towards more infrastructure development to sustain this growth. Migration is the prime driving factor for rapid urbanization in emerging economies. The rapid influx of people in cities big or small not only drives the city system for more infrastructure development and city expansion, but on the downside, this also leads to increasing problems of slum development social disruption and poverty etc., which by and large affect the majority of the population that are in the lower end of economic or social status.

Land conversion to urban areas is one of the most irreversible anthropogenic impacts on the earth surface. It hastens the loss of highly productive farmland, sky shooting energy demand, climate change, the frequency for extreme weather conditions, changes in hydrologic and biogeochemical cycles, habitat fragmentation, biodiversity loss, etc. [48,49]. Further urbanization will pose direct threats to biodiversity hotspots that were relatively undisturbed by urban development until the year 2000 because of lack of space [50]. The urban expansion will potentially affect CO_2 emissions, heat budgets, circulation of water, aerosols, and nitrogen in the climate system to a great extent [51]. It is predicted that urban expansion in currently developing economies of Asia and Africa alone will cause global cropland loss by approximately 80% [52]. This loss of cropland is likely to be accompanied by other sustainability risks which threaten livelihoods. Hence, good governance with relevant policy holds the key to securing livelihoods in the agrarian economies of these developing countries [53]. Other factors which are also crucial for expansion in urban areas are economic development, population growth, land-use policies, the informal economy, capital flows, and transportation costs [50]. Containing the expansion of urban areas to encourage compact, public transport-oriented urban forms, which is important for securing long-term climate mitigation goals, requires a well-executed planning approach [54]. However, the effectiveness of these containment strategies around the world is mixed because of differences in the willpower of policymakers, and geographic and institutional contexts [55]—for example, fuel taxes, an empirically and theoretically proven tool to induce more compact urban form and preserve open space [56]. Another approach involves selective protection of open space from urban encroachment, by transferring the development rights, which effectively redirects new growth from areas to be protected viz. prime agricultural fields, biodiversity hotspots, to areas where more development is desired [57,58]. The keywords used in this search were "effect of urbanization on population", "influence of urbanization on population", "impact of urbanization on population", "effect of population on urbanization", "influence of population on urbanization", "impact of population on urbanization", and "urbanization and population nexus".

3.4. Population and Energy

Population is the one factor that is the key driver for all innovation and the need for innovation. Ever since modern civilization was realized in different parts of the world, there are many things which have been in mass demand by any given society and most important of all, for almost all societies to flourish, there is almost always an ever-increasing need of energy. As the global population growth rate and life expectancy have gone up steadily, there is an exponential demand for electricity too. Availability of electricity has also become a standard for any society that wants to reap all the comforts of modern life. Electricity is demanded by every country, and the traditional means of generating this is using fossil fuels, which gives way to coal and gas-fired electricity generator plants worldwide. As the population has increased and in turn, the world has seen more consumer-driven societies, thus forming more industries, the demand for electricity is always increasing. This has led to the refinement of traditional forms of this source of energy but also to exploration of other forms viz. hydro, wind, solar, geothermal energy sources which can be utilized to fulfill the increasing energy needs.

Human population not only drives the need for energy but also wants its availability in effective price and reliability. There are a vast variety of energy needs that modern society has to fulfill to maintain a high standard of living. The ever-increasing demand for electricity is just one of the examples. There are various forms of energy that are required by the population in forms of petroleum for vehicles, gas for cooking and heating, electricity for all running electrical equipment, etc., which are now part of basic norms for a good and healthy society. This demand for energy in the form of electricity has led to the establishment of bigger power plants or further expansion of already existing ones, giving rise not only to jobs in those sectors but also driving up the real estate values in those areas where these projects are being implemented, booming the nations' GDP, increasing accessibility to higher living standards and increasing purchasing powers, etc., which are some of the positive effects fueled by the presence of ever-increasing demand of masses, especially in developing countries. It is this demand of energy that had given rise to one of the first crises of the post-industrial world, the world in which lighting up our homes at night was most important and to fulfill that, we drove several species of animals almost to the extension. Not only are the effects of that era still visible in the present world, but it also shows how the need for energy is always put on first priority, and everything gives way to fulfill that. Not only have fossil fuels given us the means to rapidly develop all sort of modern inventions, but also the demand has given the chance for a large group of people to develop skills in mining and exploration of the same energy source, giving way to an even greater scale of exploration, and hence fulfilling the supply gap. This relationship just shows how greater the bond of the population is towards a cheaper and more reliable source of energy. This increasing demand of energy has created a situation in which there is either a gap in the energy demand–supply chain or societies and nations' economies become so dependent on energy sources that people's lives are literally driven by prices of the same sources in other countries. Highly plummeting and fluctuating rates of petroleum are one of the biggest examples. While countries like the US, Russia, the UAE, etc.

depend highly on oil trades, the pricing schemes of world oil trading greatly affect the lives of millions of people across these countries as well as the rest of the world.

As the other side of technical and industrial development, energy generation acts as a catalytic factor to increase the standard of living of people of any country, making day to day life more comfortable, cultivation of crops much efficient, development of new household items on large scales by industries and, hence, more employment, etc. These are just a few examples of how energy generation is active as a background factor in the development of all facets of a given society and a nation as a whole. This, in turn, lets the situation become more favorable for the development of highly skilled labor, more facilities for the newborn, and favorable conditions for the population to grow and migrate towards areas where such facilities and situations are concentrated and available in a given country. Not only does the availability of energy help to catapult the development factors of a given economy, be it in terms of GDP or per capita income or basic standard of living, etc., but it also creates a situation where people are more inclined to migrate from one place to another in search of better facilities or employment or engaging in the activities that directly or indirectly benefit them in their life. The keywords used in this search were "effect of energy on population", "influence of energy on population", "energy of urbanization on population", "effect of population on energy", "influence of population on energy", "impact of population on energy", and "energy and population nexus".

Resource management for any nation is one of the most important commodities that play a vital role in the development of that nation, be it a human resource or natural resources. Both need to be managed and integrated in such a manner that it not only serves short-term goals such as energy availability and reliability but also works and integrates well with long-term goals of development and sustainability. It may be easier to go for short-term problem solving, but this may not be beneficial in the long term, e.g., dependence on fossil fuel for energy production. A project developed solely considering long-term gains, e.g., solar power plants supplying the majority of power, may end up not being beneficial, as peak load conditions cannot be met during night-time. Hence, an integrated approach is needed, considering demand from the population for any country or region and then developing and managing the infrastructure that is beneficial immediately and also viable for long-term sustainability. Modeling tools for landscape design need to be developed in order to facilitate energy production and utilize other services from land and climate management [39]. It is important to estimate the impact of energy production activity on climate change and landscape change and, finally, on the production of food, livestock, fodder, fiber, etc. [59].

Energy policies need to be developed based on case studies that provide a guiding path to create a system that integrates land management, infrastructure development, and energy targets to achieve multiple large-scale long-term and short-term goals for social and environmental management [60,61]. A much deeper comparison of green and renewable energy source projects and traditional fossil fuel projects needs to be done beyond common indicators, e.g., estimates of greenhouse gas emissions per unit fuel. This needs to be done for the full life cycle of these projects. When considering the energy–population–urbanization nexus, this indicator of greenhouse emission only is inadequate and incomplete. During infrastructure development of any given project, whether renewable or nonrenewable, the effects and stress on surrounding viz. development of roads, highways, seismic lines, vegetation loss to put power lines, etc. need to be considered instead of treating them as insignificant, like it was done previously by the US Environmental Protection Agency (EPA) for renewable energy fuel standard analysis and for low carbon standard regulation, because these considerations may carry heavy effects on real impact analysis of renewable energy projects, making them energy projects that are not so green. The effect on land and population integration can be better understood if they are quantified in terms of energy generation, utilization, and usage [62]. Further, the affected lands by any renewable energy project development and its associated activities need to be put under radar in terms of intensity, duration, extent, and reversibility of effects, to understand it better and to compare it with traditional energy projects, i.e., fossil fuel or nuclear power to reflect environmental and social priorities at any given time. Local government and community preferences and drivers of first-time land-use change need to be modeled for a better understanding of small-scale projects. This effort might build upon the landscape approach as presented by [63], under which regional models of secondary land change include geographic setting, land-use history, and drivers of change that represent local land use patterns were studied to trace key drivers and factors in energy-related projects. The findings of this study suggest that most of the previous studies focused on delineating the relation between either energy–population, energy–urbanization or urbanization–population growth and did not include all three components in a holistic approach.

4. Research Outcomes

A number of scientific conferences and workshops have been held throughout the world to discuss the various kinds of nexus issues since 1984, after the United Nations University organized a conference on "Food, Energy, and Ecosystems" in Brazil. A nexus interconnecting water, energy, and food was introduced at the Bonn-2011 Nexus Conference. Thereafter, a discussion paper on the water–energy—food nexus was prepared by the United Nations Economic and Social Commission for Asia and the Pacific [64]. The concept of the water–energy–food nexus has proved useful to refer to and to tackle the complicated and interconnected global resource network. According to Future Earth 2025 Vision [65], balancing the water–energy–food nexus is considered to be one of the key challenges. The vision focuses on delivering water, energy, and food for all, managing the balances among the three domains, and understanding how these interactions are influenced by environmental and economic changes.

A water–energy nexus has been studied by researchers to see the effect of energy on water and the effect of water on energy. The effect of energy for water is seen in hydropower generation and in biofuel systems. On the other hand, the effect of water on energy is seen in terms of utilizing water for irrigation and in water treatment plants which consume electric energy [66]. Table 1 shows a comparison of studies done on energy, population, and urbanization scenarios to study the interconnections between these domains.

Table 1. Summary table for various studies done on nexus interconnecting energy, population, urbanization, and others.

Sr. No.	Authors	Type of Nexus Studied	Study Area Taken	Major Findings	Year of Publication
1.	Wolman, M Gordon [67]	Population, land use, and environment	Nanticoke River, Chesapeake Bay, United States	• Historic prospective • Anthropogenic impact	1993
2.	Marilyn A. Brown and Collean G. Rizy [68]	Economic, energy, and environmental impacts of a technology commercialization program	The United States of America	• Provides a set of program metrics • Case study carried out in the paper indicates energy saving because of energy-related inventions program (ERIP) technology	1997
3.	R P S Malik [69]	Water and energy nexus	India	• Evaluation based on energy saving, greenhouse gas emissions, and new products demand • Issues in commercialization of technology studied	2002
4.	Denise Lofman, Matt Petersen & Aimée Bower [70]	Water, energy, and the environment	California and the western USA	• Water, energy, and environment connections discussed • Wide case study for understanding complex relationship among water, energy, and environment	2002

Table 1. *Cont.*

Sr. No.	Authors	Type of Nexus Studied	Study Area Taken	Major Findings	Year of Publication
5.	Seto, Karen C. Shepherd, J. Marshall [51]	Global urban land-use and climate impacts	Atlanta, Georgia	• Pathways for climate change due to urbanization • Model simulations carried out	2009
6.	Virginia H. Dale, Rebecca A. Efroymson, Keith L. Kline [39].	Land use–climate change–energy	United States, China	• Land-use, energy, and climate change can be better understood using landscape ecology • Feedback loop existing in land-use, energy, and climate change need to be calibrated	2011
7.	Hoff, Holger [71]	Water–energy–food	Brazilian Cerrado, Masdar City in UAE, Jordan, Ningxia region in China, Gujarat in India, Blue Nile basin in Ethiopia, Kenya's Tana River, Australia, Mauritius	• Opportunities explored for improving security of food, energy and water • Geopolitical features considered	2011
8.	Phetkeo Poumanyvong, Shinji Kaneko, Shobhakar Dhakal [36]	Urbanization–national transport–road energy use	Low, middle and high-income countries during 1975–2005	• Positive correlation between urbanization and road energy use • Influence of urbanization is less in middle income countries than in low income countries	2012
9.	Seto, Karen C., Güneralp, Burak, Hutyra, Lucy R [50].	Urban expansion—biodiversity hotspots—tropical carbon biomass	Eastern Afromontane, the Guinean Forests of West Africa, the Western Ghats and Sri Lanka hotspots	• There is significant effect of urbanization on carbon pools • Above ground carbon calculated using probabilistic urban expansion maps	2012
10.	Hardy, L., Garrido, A., Juana, L. [66]	Water–energy	Spain	• No threat of water scarcity on increasing use of renewable energy sources • Legislative steps required in water allocation	2012
11.	FAO [72]	Water, energy, and food	Red River Basin in Vietnam	• Repercussions of bioenergy on water, land, and energy • Effect of sectoral policies with other sectors	2014
12.	Berkman, M. [73]	Electricity–water	United States	• Electricity generation demand is not a primary concern. • Infrastructure and conservation are a primary concern	2015
13.	Felix Creutzig, Giovanni Baiocchi, Robert Bierkandt, Peter-Paul Pichler, and Karen C. Seto [56].	Global typology of urban energy and urbanization mitigation wedge	274 cities representing all city sizes and regions worldwide	• Urban mitigation of global climate change is not well understood • Transport cost and geographic factors have more effect on urban transport energy use than on urban direct energy use	2015
14.	Eloise M. Biggs, Eleanor Bruce, Bryan Boruff, John M.A. Duncan, Julia Horsley, Natasha Pauli, Kellie McNeill, Andreas Neef, Floris Van Ogtrop, Jayne Curnow, Billy Haworth, Stephanie Duce, Yukihiro Imanari [74]	Water, energy, and food	Indo-Gangetic plains, South-East Asia and Oceania, Caribbean island nations, Mekong Region	• A framework on nexus–livelihood proposed • Environmental livelihood security assessed	2015

Table 1. *Cont.*

Sr. No.	Authors	Type of Nexus Studied	Study Area Taken	Major Findings	Year of Publication
15.	Golam Rasul [75]	Water–energy–food	South Asia	• Lack of sectoral coordination has threatened food, water, and energy security • Improved policy coherence among food, water, and energy bis required	2016
16.	Giupponi, C.; Gain, A.K. [76]	Water–energy–food	Ganges-Brahmaputra-Meghna (GBM) River Basin in Asia and the Po River Basin in Europe	• Water, energy and food security is less in Ganges–Brahmaputra–Meghna river basin in Asia than in Po river basin in Europe • Intersectoral linkages to water, energy, and food need to be given attention	2016
17.	Aiko Endo, Izumi Tsurita, Kimberly Burnett, Pedcris M. Orencio [77]	Water–energy–food	Asia, Europe, Oceania, North America, South America, Middle East, and Africa	• A review on water, energy, and food nexus taking study area of Asia, Europe, North America, South America, Oceania, Middle East, and Africa • New hydrological insights	2017
18.	Catherine L. Kling, Raymond W. Arritt, Gray Calhoun, and David A. Keiser [78]	Water–energy–food	US, Brazil, Chesapeake Bay, Kinta River in Malaysia, Iowa	• Integrated assessment models discussed • Research needs in food, energy, and water nexus reviewed	2017
19.	Delin Fang, Bin Chen [79]	Water–energy	Beijing	• Linkage analysis for water and energy of Beijing investigated • Key sectors for the nexus identified	2017
20.	Niclas Bieber, Jen Ho Ker, Xiaonan Wang, Charalampos Triantafyllidis, Koen H. van Dam, Rembrandt H.E.M. Koppelaar, Nilay Shah [80]	Water–energy–food	The Greater Accra Metropolitan Area (GAMA), the capital city of Ghana	• Climate change has significant effect on CO_2 emission • Higher fossil fuel price caused decrease in emission factor	2018
21.	Jiangyu Dai, Shiqiang Wu, Guoyi Han, Josh Weinberg, Xinghua Xie, Xiufeng Wu, Xingqiang Song, Benyou Jia, Wanyun Xue, Qianqian Yang [81]	Water–energy	Taihu Basin	• Macroassessment of water energy nexus done • 35 case studies involving 70 tools reviewed	2018
22.	Floor Brouwer, Lydia Vamvakeridou-Lyroudia, Eva Alexandri, Ingrida Bremere, Matthew Griffey and Vincent Linderhof [82]	Energy and resource efficiency for policy assessments	Europe, The Netherlands, Latvia, Southwest UK	• Macroeconometric model does not consider connections between energy, water, and land • Alternate fuels in transportation have repercussions on land-use	2018
23.	Noruzi, M M and Yazdandoost F [83]	Water–energy	Arid Basin and Kashan Basin	• Estimation of desired volume of nonconventional water • Maximum capacity of nonconventional water is not necessarily the optimal point	2019

Table 1. *Cont.*

Sr. No.	Authors	Type of Nexus Studied	Study Area Taken	Major Findings	Year of Publication
24.	Meng, Fanxin Liu, Gengyuan Liang, Sai Su, Meirong Yang, Zhifeng [84]	Energy–water–carbon	France, Spain, Australia, US, UK, China	• Systematic review of energy, water and carbon dioxide nexus • Energy, water nexus has been focused more by researchers among energy, water, and carbon dioxide nexus	2019
25.	Jill B. Kjellsson and Michael E. Webber [85]	Energy and water nexus	Texas, USA	• Optimal locations for installing photovoltaic systems in Texas identified • Negative effects of Carbon emissions can be reduced using photovoltaic systems to power pumping processes	2015
26.	Gary M. Gold, Michael E. Webber [86]	Energy and water nexus	Texas, USA	• Photovoltaic thermal hybrid solar systems can be used as a heat exchanger for solar panels and brackish groundwater • Heat transfer from photovoltaic panels to water is advantageous both in solar power production and in water treatment	2015
27.	Wen-Tien Tsai [87]	Waste-to-energy (WTE) plants	Kaohsiung Municipality (Taiwan)	• Operational efficiencies in waste to energy plants analyzed • Bathtub curve pattern followed by operational efficiencies	2019
28.	Catherine I. Birney, Michael C. Jones, and Michael E. Webber [88]	Geothermal powered multieffect brackish water distillation	Texas, USA	• The salinity of groundwater has a small impact on brackish groundwater desalination with multieffect distillation • A framework for optimal locations for geothermal powered desalination facilities provided	2019

Several researchers have focused on various domains viz. water, food, energy, climate change, land-use, etc. to understand the nexus among these domains. In this paper, although the focus is on the population, urbanization, and energy nexus, papers on this nexus are lacking in spite of its significant importance to framing development policies and strategies. To carry out a rational nexus analysis, more than 70 papers were reviewed, covering domains including water, food, and climate change. It has been noticed that among several domains, the water, food, and energy nexus has been studied exhaustively by many researchers.

There are many papers which discuss the relationship among three variables viz. energy, population, and urbanization. Some of the papers also discuss the causal relationship between these variables. Figure 4 depicts a quantitative analysis of papers focusing on relationship between the three variables and describing the causal relationship between these variables. It has been found that out of 28 papers on the energy–population relationship, 7 papers presented a causal relationship between these variables. Similarly, for the population–urbanization relationship, only 3 papers describe the causal relationship among 21 papers on their relationship and for the energy–urbanization relationship, 6 papers describe the causal relationship among 34 papers on their relationship.

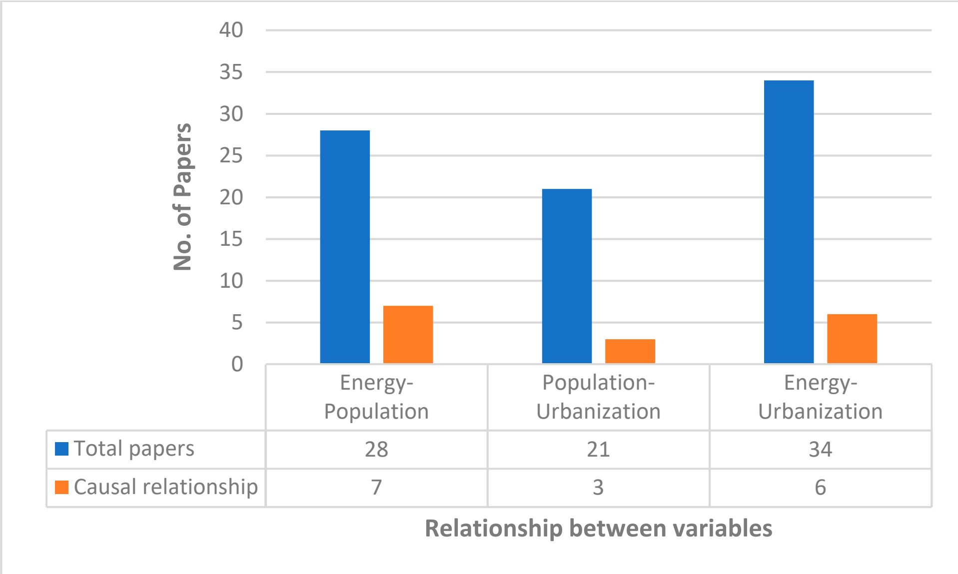

Figure 4. Quantitative analysis of papers on relationship among three variables and describing their causal relationship.

5. Conclusions

In this paper, based on the findings of several studies, it was found that there exists an intertwining connection between energy, population, and urbanization which need to be addressed in a holistic way. Although different integrated assessment tools like water evaluation and planning (WEAP), long-range energy alternatives planning (LEAP), etc. are already available, which can be used to assess nexus between urbanization, population growth, and energy, these have hardly been utilized to explore the issue at the science-policy level. Therefore, quantitative tools need to be further developed that can estimate the relation of rapid land-use change with dynamics of population growth and energy consumption of any given region along with climate change to rationale scales to visualize its foreseen and unforeseen implications. For example, using landscape ecology and utilization as an approach can provide information on cost–benefit analysis resulting from different choices made about the spatial and geographical location of energy resources in terms of impact intensity, utilization, extent, longevity, sustainability, and likely interactions that may compound or offset some effects. Opportunity costs must also be considered while deciding where and whether to use the land for energy production, agriculture, housing or other usages and if and when to stop relying on traditional energy resources and when to switch to renewable energy resources. The decision should be based on scientific evidence for environmental, social, and economic tradeoffs and benefits for both the short term and long term. Further, a transdisciplinary approach including all three components of these complex nexus issues can be a subject of future study. This review paper will impart direction to researchers to explore the energy, population, and urbanization nexus using various indicators depending on their study area.

Author Contributions: Conceptualization, R.A., S.T., A.K.A., and P.K.; methodology, R.A., S.T., and A.K.A.; formal analysis, S.T., P.K., and A.K.A.; investigation, R.A., S.T., and A.K.A.; writing—R.A., S.T., P.K., and A.K.A.; writing—review and editing, R.A., S.T., P.K., and A.K.A.

Funding: This research received no external funding.

Acknowledgments: Authors would like to thank Hokkaido University for providing research facilities. Saurabh Tripathi would like to thank Monbukagasho Japanese Government Scholarship to pursue his studies at Hokkaido University.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Brown, O.; Crawford, A.; Gibson, J. *Boom or Bust: How commodity price volatility impedes poverty reduction, and what to do about it*; IISD: Winnipeg, MB, Canada, 2008; ISBN 9781894784047.
2. Prasad, M.N.V. Recovery of Resources From Biowaste for Pollution Prevention. *Environ. Mater. Waste* **2016**, 1–19. [CrossRef]
3. Luo, Y.; Tung, R.L. International expansion of emerging market enterprises: A springboard perspective. *J. Int. Bus. Stud.* **2007**, *38*, 481–498. [CrossRef]
4. Bilgen, S. Structure and environmental impact of global energy consumption. *Renew. Sustain. Energy Rev.* **2014**, *38*, 890–902. [CrossRef]
5. International Energy Agency. *World Energy Investment 2018: Executive Summary*; IEA Publishing: Paris, France, 2018; pp. 1–12.
6. International Energy Agency. *World Energy Outlook Executive Summary*; IEA Publishing: Paris, France, 2016.
7. Tanaka, N. *World Energy Outlook 2010*; IEA Publishing: Paris, France, 2010.
8. Jones, D.W. How urbanization affects energy-use in developing countries. *Energy Policy* **1991**, *19*, 621–630. [CrossRef]
9. Müller-Kraenner, S. *China's and India's Emerging Energy Foreign Policy*; German Development Institute: Bonn, Germany, 2008; p. 29.
10. Greller, A.M.; Perlin, J. A Forest Journey: The Role of Wood in the Development of Civilization. *Bull. Torrey Bot. Club* **2006**, *120*, 77. [CrossRef]
11. Viña, A.; Echavarria, F.R.; Rundquist, D.C. Satellite change detection analysis of deforestation rates and patterns along the Colombia-Ecuador border. *Ambio* **2004**, *33*, 118–126. [CrossRef] [PubMed]
12. Finer, M.; Orta-Martínez, M. A second hydrocarbon boom threatens the Peruvian Amazon: Trends, projections, and policy implications. *Environ. Res. Lett.* **2010**, *5*. [CrossRef]
13. Jager, H.I.; Efroymson, R.A.; Sublette, K.L.; Ashwood, T.L. Unnatural landscapes in ecology: Generating the spatial distribution of brine spills. *Environmetrics* **2005**, *16*, 687–698. [CrossRef]
14. Giglio, L.; Randerson, J.T.; Van Der Werf, G.R.; Kasibhatla, P.S.; Collatz, G.J.; Morton, D.C.; Defries, R.S. Assessing variability and long-term trends in burned area by merging multiple satellite fire products. *Biogeosciences* **2010**, *7*, 1171–1186. [CrossRef]
15. Wind, B.D.; Wallender, W.W. Fossil-fuel carbon emission control in irrigated maize production. *Energy* **1997**, *22*, 827–846. [CrossRef]
16. Wickham, J.D.; Riitters, K.H.; Wade, T.G.; Coan, M.; Homer, C. The effect of Appalachian mountaintop mining on interior forest. *Landsc. Ecol.* **2007**, *22*, 179–187. [CrossRef]
17. Parks, N. The price of tar-sands oil. *Front. Ecol. Environ.* **2009**, *7*, 232–237. [CrossRef]
18. Mahur, A.K.; Gupta, M.; Varshney, R.; Sonkawade, R.G.; Verma, K.D.; Prasad, R. Radon exhalation and gamma radioactivity levels in soil and radiation hazard assessment in the surrounding area of National Thermal Power Corporation, Dadri (U.P.), India. *Radiat. Meas.* **2013**, *50*, 130–135. [CrossRef]
19. Luken, J.O.; Hinton, A.C.; Baker, D.G. Response of woody plant communities in power-line corridors to frequent anthropogenic disturbance. *Ecol. Appl.* **1992**, *2*, 356–362. [CrossRef] [PubMed]
20. Ahmad, S.; Avtar, R.; Sethi, M.; Surjan, A. Delhi's land cover change in post transit era. *Cities* **2016**, *50*, 11–118. [CrossRef]
21. Dobkin, D.S.; Rich, A.C.; Niles, L.J. Defining forest fragmentation by corridor width: the influence of narrow forest-dividing corridors on forest-nesting birds in southern New Jersey. *Conserv. Biol.* **1994**, *8*, 1109.
22. Kusakana, K.; Vermaak, H.J. Hydrokinetic power generation for rural electricity supply: Case of South Africa. *Renew. Energy* **2013**, *55*, 467–473. [CrossRef]
23. Dale, V.H.; Kline, K.L.; Wiens, J.; Fargione, J. Biofuels: Implications for land use and biodiversity. In *ESA Biofuels and Sustainability Reports*; Ecological Society of America: Washington, DC, USA, 2010; p. 13.
24. Fargione, J.; Hill, J.; Tilman, D.; Polasky, S.; Hawthorne, P. Land Clearing and the Biofuel Carbon Debt. *Science* **2008**, *319*, 1235–1238. [CrossRef]
25. Keeney, R.; Hertel, T.W. The indirect land use impacts of United States biofuel policies: The importance of acreage, yield, and bilateral trade responses. *Am. J. Agric. Econ.* **2009**, *91*, 895–909. [CrossRef]
26. Geist, H.J.; Lambin, E.F. Proximate Causes and Underlying Driving Forces of Tropical Deforestation. *Bioscience* **2006**, *52*, 143. [CrossRef]

27. Lambin, E.F.; Geist, H.J.; Lepers, E. Dynamics of Land-Use and Land-Cover Change inTropical Regions. *Annu. Rev. Environ. Resour.* **2003**, *28*, 205–241. [CrossRef]
28. Kline, K.L.; Dale, V.H.; Fargione, J.; Hill, J.; Tilman, D.; Polasky, S.; Hawthorne, P.; Searchinger, T.D. Biofuels: Effects on Land and Fire. *Science* **2008**, *321*, 199–202.
29. Kline, K.; Dale, V.H.; Lee, R.; Leiby, P. In Defense of Biofuels, Done Right. *Issues Sci. Tech.* **2009**, *25*, 75–84.
30. Avtar, R.; Kumar, P.; Oono, A.; Saraswat, C.; Dorji, S.; Hlaing, Z. Potential application of remote sensing in monitoring ecosystem services of forests, mangroves and urban areas. *Geocarto Int.* **2017**, *32*, 874–885. [CrossRef]
31. Avtar, R.; Yunus, A.P.; Kraines, S.; Yamamuro, M. Evaluation of DEM generation based on Interferometric SAR using TanDEM-X data in Tokyo. *Phys. Chem. Earth Parts A/B/C* **2015**, *83*, 166–177. [CrossRef]
32. Edwards, T.; Creary, M.; Russell, D.; Aiken, K.; Fisher, E.; Espeut, P. *FAA 118/119 Tropical Forests and Biodiversity Assessment*; USAID: Washington, DC, USA, 2008.
33. IUCN. *Implementing Sustainable Bioenergy Production: A Compilation of Tools and Approaches*; International Union for Conservation of Nature: Gland, Switzerland, 2008; ISBN 9782831711317.
34. Gleick, P.H. The World's Water 2008–2009: Three Gorges Dam Project, Yangtze River, China. Water Brief 3. 2009. Available online: https://sswm.info/sites/default/files/reference_attachments/GLEICK%202009%20Three%20Gorges%20Dam%20Project%20Yangtze%20River%20China.pdf (accessed on 10 November 2017).
35. Waffle, A.D.; Corry, R.C.; Gillespie, T.J.; Brown, R.D. Urban heat islands as agricultural opportunities: An innovative approach. *Landsc. Urban Plan.* **2017**, *161*, 103–114. [CrossRef]
36. Poumanyvong, P.; Kaneko, S.; Dhakal, S. Impacts of urbanization on national transport and road energy use: Evidence from low, middle and high income countries. *Energy Policy* **2012**, *46*, 268–277. [CrossRef]
37. Johnson, F.M.; Sharma, A. GCM simulations of a future climate: How does the skill of GCM precipitation simulations compare to temperature simulations? In Proceedings of the 18th World IMACS MODSIM Congress, Cairns, Australia, 13–17 July 2009; pp. 2618–2624.
38. Ackermann, T.; Soder, L. Wind energy technology and current status: a review. *Renew. Sustain. Energy Rev.* **2000**, *4*, 315–374. [CrossRef]
39. Dale, V.H.; Efroymson, R.A.; Kline, K.L. The land use-climate change-energy nexus. *Landsc. Ecol.* **2011**, *26*, 755–773. [CrossRef]
40. Sheng, P.; He, Y.; Guo, X. The impact of urbanization on energy consumption and efficiency. *Energy Environ.* **2017**, *28*, 673–686. [CrossRef]
41. Wang, Q.; Yang, X. Urbanization impact on residential energy consumption in China: the roles of income, urbanization level, and urban density. *Environ. Sci. Pollut. Res.* **2019**, *26*, 3542–3555. [CrossRef] [PubMed]
42. Topcu, M.; Girgin, S. The impact of urbanization on energy demand in the Middle East. *J. Int. Glob. Econ. Stud.* **2016**, *9*, 21–28.
43. Liu, X.; Peng, D. Study on the Threshold Effect of Urbanization on Energy Consumption. *Theor. Econ. Lett.* **2018**, *8*, 2220–2232. [CrossRef]
44. United Nations, Department of Economic and Social Affairs. World Urbanization Prospects 2018. Available online: https://population.un.org/wpp/Graphs/ (accessed on 12 December 2018).
45. Serageldin, I.; Barrett, R.; Martin-Brown, J. *The business of sustainable cities: Public-private partnerships for creative technical and institutional solutions*; The World Bank: Washington, DC, USA, 1995; ISBN 0821333194.
46. International Energy Agency. *World Energy Outlook 2017*; International Energy Agency: Paris, France, 2018.
47. WHO Kobe. Available online: https://extranet.who.int/kobe_centre/en (accessed on 21 August 2018).
48. Jiang, X.; Xia, B.; Guo, L. Research on urban heat island and its environmental effects of rapidly urbanized regions. *Ecol. Sci.* **2006**, *2*, 171–175.
49. Kaufmann, R.K.; Seto, K.C.; Schneider, A.; Liu, Z.; Zhou, L.; Wang, W. Climate response to rapid urban growth: Evidence of a human-induced precipitation deficit. *J. Clim.* **2007**, *20*, 2299–2306. [CrossRef]
50. Seto, K.C.; Güneralp, B.; Hutyra, L.R. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 16083–16088. [CrossRef]
51. Seto, K.C.; Shepherd, J.M. Global urban land-use trends and climate impacts. *Curr. Opin. Environ. Sustain.* **2009**, *1*, 89–95. [CrossRef]
52. D'Amour, C.B.R.; Reitsma, F.; Baiocchi, G.; Barthel, S.; Güneralp, B.; Erb, K.-H.; Haberl, H.; Creutzig, F.; Seto, K.C. Future urban land expansion and implications for global croplands. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 8939–8944. [CrossRef]

53. Creutzig, F.; Agoston, P.; Minx, J.C.; Canadell, J.G.; Andrew, R.M.; Le Quéré, C.; Peters, G.P.; Sharifi, A.; Yamagata, Y.; Dhakal, S. Urban infrastructure choices structure climate solutions. *Nat. Clim. Chang.* **2016**, *6*, 1054–1056. [CrossRef]
54. Daniels, S.; Endfield, G.H. Narratives of climate change: introduction. *J. Hist. Geogr.* **2009**, *35*, 215–222. [CrossRef]
55. Dawkins, C.J.; Nelson, A.C. Urban containment policies and housing prices: an international comparison with implications for future research. *Land Use Policy* **2002**, *19*, 1–12. [CrossRef]
56. Creutzig, F.; Baiocchi, G.; Bierkandt, R.; Pichler, P.-P.; Seto, K.C. Global typology of urban energy use and potentials for an urbanization mitigation wedge. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 6283–6288. [CrossRef] [PubMed]
57. Angel, S.; Parent, J.; Civco, D.L.; Blei, A.; Potere, D. The dimensions of global urban expansion: Estimates and projections for all countries, 2000–2050. *Prog. Plann.* **2011**, *75*, 53–107. [CrossRef]
58. Johnston, R.A.; Madison, M.E. From land marks to landscapes: A review of current practices in the transfer of development rights. *J. Am. Plan. Assoc.* **1997**, *63*, 365–378. [CrossRef]
59. Opdam, P.; Luque, S.; Jones, K.B. Changing landscapes to accommodate for climate change impacts: A call for landscape ecology. *Landsc. Ecol.* **2009**, *24*, 715–721. [CrossRef]
60. Wander, M.M.; Parton, W.J.; Adler, P.R.; Barney, J.N.; Cruse, R.M.; Duke, C.S.; Fearnside, P.M.; Follett, R.F.; Gibbs, H.K.; Goldemberg, J. Sustainable biofuels redux. *Science* **2008**, *322*, 49–50.
61. Bogdanski, A.; Dubois, O.; Jamieson, C.; Krell, R. *Making Integrated Food-Energy Systems Work for People and Climate*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2010; ISBN 9789251067727.
62. Termorshuizen, J.W.; Opdam, P. Landscape services as a bridge between landscape ecology and sustainable development. *Landsc. Ecol.* **2009**, *24*, 1037–1052. [CrossRef]
63. Sohl, T.L.; Loveland, T.R.; Sleeter, B.M.; Sayler, K.L.; Barnes, C.A. Addressing foundational elements of regional land-use change forecasting. *Landsc. Ecol.* **2010**, *25*, 233–247. [CrossRef]
64. Adnan, H. *Water-Food-Energy Nexus in Asia and the Pacific*; United Nations ESCAP: Bangkok, Thailand, 2013; p. 72.
65. Future Earth. *Future Earth 2025 Vision*; Future Earth: Paris, France, 2014.
66. Hardy, L.; Garrido, A.; Juana, L. Evaluation of Spain's Water-Energy Nexus. *Int. J. Water Resour. Dev.* **2012**, *28*, 151–170. [CrossRef]
67. Wolman, M.G. Population, land use, and environment: A long history. In *Population and Land Use in Developing Countries*; National Academy Press: Washington, DC, USA, 1993.
68. Brown, M.A.; Rizy, C.G. Evaluating The Economic, energy and environmental impacts of a technology commercialization program. In Proceedings of the Energy Evaluation Conference, Chicago, IL, USA, 27 August 1997; pp. 1–11.
69. Malik, R.P.S. Water-energy nexus in resource-poor economies: The Indian experience. *Int. J. Water Resour. Dev.* **2002**, *18*, 47–58. [CrossRef]
70. Lofman, D.; Petersen, M.; Bower, A. Water, Energy and Environment Nexus: The California Experience. *Int. J. Water Resour. Dev.* **2002**, *18*, 73–85. [CrossRef]
71. Hoff, H. *Understanding the Nexus*; Background Paper for the Bonn2011 Conference: The Water, Energy and Food Security Nexus; Stockholm Environment Institute: Stockholm, Sweden, 2011; pp. 1–52.
72. Food and Agriculture Organization of the United Nations (FAO). The water-energy-food nexus- A new approach in support of food security and sustainable agriculture. *Environ. Sci. Policy* **2016**, *68*, 97–106.
73. Berkman, M. The electricity-water nexus: Is a crisis imminent? *Water Policy* **2015**, *17*, 1163–1175. [CrossRef]
74. Biggs, E.M.; Bruce, E.; Boruff, B.; Duncan, J.M.A.; Horsley, J.; Pauli, N.; McNeill, K.; Neef, A.; Van Ogtrop, F.; Curnow, J.; et al. Sustainable development and the water-energy-food nexus: A perspective on livelihoods. *Environ. Sci. Policy* **2015**, *54*, 389–397. [CrossRef]
75. Rasul, G. Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia. *Environ. Dev.* **2016**, *18*, 14–25. [CrossRef]
76. Giupponi, C.; Gain, A.K. Integrated spatial assessment of the water, energy and food dimensions of the Sustainable Development Goals. *Reg. Environ. Chang.* **2017**, *17*, 1881–1893. [CrossRef]
77. Endo, A.; Tsurita, I.; Burnett, K.; Orencio, P.M. A review of the current state of research on the water, energy, and food nexus. *J. Hydrol. Reg. Stud.* **2017**, *11*, 20–30. [CrossRef]

78. Kling, C.L.; Arritt, R.W.; Calhoun, G.; Keiser, D. Integrated Assessment Models of the Food, Energy, and Water Nexus: A Review and an Outline of Research Needs. *Ssrn* **2017**, 143–166. [CrossRef]
79. Fang, D.; Chen, B. Linkage analysis for the water–energy nexus of city. *Appl. Energy* **2017**, *189*, 770–779. [CrossRef]
80. Bieber, N.; Ker, J.H.; Wang, X.; Triantafyllidis, C.; van Dam, K.H.; Koppelaar, R.H.E.M.; Shah, N. Sustainable planning of the energy-water-food nexus using decision making tools. *Energy Policy* **2018**, *113*, 584–607. [CrossRef]
81. Dai, J.; Wu, S.; Han, G.; Weinberg, J.; Xie, X.; Wu, X.; Song, X.; Jia, B.; Xue, W.; Yang, Q. Water-energy nexus: A review of methods and tools for macro-assessment. *Appl. Energy* **2018**, *210*, 393–408. [CrossRef]
82. Brouwer, F.; Vamvakeridou-Lyroudia, L.; Alexandri, E.; Bremere, I.; Griffey, M.; Linderhof, V. The nexus concept integrating energy and resource efficiency for policy assessments: A comparative approach from three cases. *Sustainability* **2018**, *10*, 4860. [CrossRef]
83. Noruzi, M.M.; Yazdandoost, F. Determining the Optimal Point In Arid Basins Using Water-Energy Nexus Approach. *Iran Univ. Sci. Technol.* **2019**, *9*, 423–435.
84. Meng, F.; Liu, G.; Liang, S.; Su, M.; Yang, Z. Critical review of the energy-water-carbon nexus in cities. *Energy* **2019**, *171*, 1017–1032. [CrossRef]
85. Kjellsson, J.; Webber, M. The Energy-Water Nexus: Spatially-Resolved Analysis of the Potential for Desalinating Brackish Groundwater by Use of Solar Energy. *Resources* **2015**, *4*, 476–489. [CrossRef]
86. Gold, G.; Webber, M. The Energy-Water Nexus: An Analysis and Comparison of Various Configurations Integrating Desalination with Renewable Power. *Resources* **2015**, *4*, 227–276. [CrossRef]
87. Tsai, W.-T. An Analysis of Operational Efficiencies in the Waste-to-Energy (WTE) Plants of Kaohsiung Municipality (Taiwan). *Resources* **2019**, *2*, 125. [CrossRef]
88. Birney, C.; Jones, M.; Webber, M. A Spatially Resolved Thermodynamic Assessment of Geothermal Powered Multi-Effect Brackish Water Distillation in Texas. *Resources* **2019**, *8*, 65. [CrossRef]