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Land Use and Energy Nexus

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SUMMARY

In this research, the connection between land use and energy has been discussed from two points of view, i.e., the impacts of energy on land use and the impacts of land use on energy. This research identified several direct and indirect land use changes that occur by clearing vegetation, destroying top soils, and relocating human populations during the different stages of extraction, deposition, and transportation of fossil fuels and uranium ore; and during the establishment of renewable energy sources including wind turbines, hydro-power plants, and associated structures (highways, dams, culverts, tunnels, power station infrastructure, and energy transmission networks). Likewise, feedstock cultivation, processing, and transportation to biomass plants, as well as the production of biodiesel from municipal solid waste, require accessible land resources that further contribute to global land-use change. In the case of the impacts of land use on energy, mixed use development was found to be one of the most efficient approaches to achieve energy efficiency. Similarly, energy demand for motorized travel can also be reduced with the development of urban blocks and transit-oriented development. Furthermore, integrated combined heat and power systems, green space, and energy-supporting land use regulations were identified as energy savings strategies that may aid in achieving energy efficiency and ensuring sustainable development.

KEY WORDS

Land use, energy efficiency, fossil fuels, renewable energy, mixed use, green spaces

1. INTRODUCTION

Land is considered as a physical entity by means of topographical and spatial characteristics. It is the utmost gift of nature and is categorized as the fundamental resource of human society [1]. Land formed between 480 and 360 million years ago during the mid-Palaeozoic era [2]. It supports population growth, economic and societal development. Land use is usually defined as the human utilization of land. It is also considered as the modification, alteration, and management of natural environments into built environments such as settlements, agriculture, transportation, industry, recreation, and open space [1], [3], [4]. Land use change or land transformation is a major concern for the betterment of the healthy wellbeing of human society. It is the outcome of environmental conditions and socio-economic, cultural, political, and institutional conditions as well as the interaction of the determinants [5], [6]. However, anthropogenic alteration that is for socio-economic wellbeing has been reported as the most influential for land use change through the processes of demographic change, industrialization, urbanization, economic and technological improvement, institutional factors, cultural factors, and globalization [5], [7]–[11].

Energy has been considered as the central determinant for smooth economic development and people's livelihood in Bangladesh and many other countries [12], [13]. However, the world's energy systems are evolving with new smart energy and grid technologies [14]. This energy can be derived from oil, gas, hydropower, solar, nuclear, geothermal, and other types of energy with the aim of generating electricity for lighting homes, offices, industries, etc. and operating/charging appliances; powering automobiles; and running the industry [15]. Extraction of fuel (oil/coal/gas), storage, construction of production infrastructure, the production and distribution processes, including uses of neighboring land and waste disposal, have different land use impacts and environmental implications [16]. By 2050, the global urban population is expected to grow by almost 2.5 billion people. Asia and Africa will house nearly 90% of the newly added population. These additional populations need more new and improved housing and associated infrastructure, leading to a significant increase in energy consumption [17], [18]. To meet these challenges, people need to go for energy efficiency or efficient energy use, which basically defines using less energy to carry out similar work, and this way energy waste can be eliminated. The main aim of energy efficiency is to diminish the amount of energy required for producing goods and services [19]. The tools and techniques of land use have impressive potential to reduce a community's energy consumption and are also required for improving the economy and mitigating climate change [20]. Hence, this chapter focuses on the nexus between land use and energy.

2. METHODS

Researchers searched related literature using different academic databases and search engines, including Scopus, ScienceDirect, Web of Science, PubMed, Google Scholar, and ScienceOpen. For considering the aspects relevant to the nexus between land use and energy, various search combinations were performed using different keywords such

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as land use, energy, fossil fuels, renewable energy, nuclear power, mixed use, transit-oriented development, green spaces, hydro-power, biomass, biodiesel, combined heat and power systems, urban block development, and energy-supporting land use plans and policies. Searching was done in the early 2022 and considered literature written in English. The outputs were manually screened, and duplicates were removed. After that, researchers finalized the relevant literature to perform the review after rereading abstracts, and in some cases, methodology and conclusion parts. The results of this review are presented in Section 3 (land use and energy nexus). In the sub-sections (3.1 and 3.2), a detailed description of the consequences of energy sources and their associated infrastructure on land use as well as implications of land use on energy, particularly energy efficiency, is provided. Finally, in Section 4, some concluding remarks are presented.

3. FINDINGS: LAND USE AND ENERGY NEXUS

There are two different views on the nexus between land use and energy, i.e., (a) energy significantly alters the landscape during its different processes (excavation to waste disposal) and (b) land use has substantial impacts on energy and its efficient use. Researchers reviewed academic articles, books, and institutional reports and made them in an understandable manner in the aspects of land use and energy connection for both the effects of the source and its associated infrastructure on land use and the impacts of human use of land on energy efficiency.

3.1 Impacts of Energy on Land Use

Energy has been considered as one of the most crucial determinants for smooth economic development and people's livelihoods. The per capita energy consumption rate is a basic indicator for determining the economic modernization of a country. Hence, it is well said that countries are more developed when per capita energy consumption is higher. Fossil fuels are a type of energy that has been around for a long time and is still frequently used. People are, however, shifting away from fossil fuels and toward nuclear and renewable energy in order to achieve greater energy efficiency. These energies' production, transmission, and distribution processes have a significant impact on land use [21].

3.1.1 Fossil Fuels and Nuclear Energy

Fossil fuels are forms of organic carbon formed beneath the earth's surface due to excessive heat and pressure of the earth's crust. The most available and easy-to-use fossil fuels are coal, oil, and natural gas. Around 70%-80% of global energy comes from these non-renewable sources. Global output of these fuels grew by almost 67.5 percent in 2019 compared to 1990 [22]. On the other hand, the use of nuclear reactions to generate energy is known as nuclear power. In 2018, nuclear energy produced around 10% of the world's electricity [23]. Fossil fuels such as coal mining, oil and natural gas extraction, and nuclear power generation all have significant impacts on land use in the production and service sectors [16], [19].

Coal

Land transformation occurs both directly and indirectly during the different stages of the coal-fuel cycle. On one hand, coal mines alter land use directly by destroying top soil and cleaning vegetation. On the other hand, as fuel for power plant operations and associated infrastructure, waste indirectly affects land use. Mining excavation, mining methods (surface/underground), coal extraction, waste disposal, and other related processes can convert land from one use to another, with numerous environmental consequences [16], [19], [24]. Several studies have identified coal mining subsidence as a major human geological disaster in China [25], [26], India [27], Greece [28], Korea [29], and elsewhere. Scholars argue that land subsidence causes damage to cultivable land, forest areas, urban neighborhoods, and the overall landscape ecology nearby the mining area. Direct and indirect land use transformation, for example, occurred at and/or near the Barapukuria coal mine in Bangladesh [30].

Coal-fired power stations are established due to the abundance and effectiveness of coal for producing electricity. Hence, coal as fuel indirectly alters the land uses. It is estimated that 6–33 m2/GWh of land transformation required for the entire operation including powerhouse, switchyard, coal storage, stack, walkways, cooling towers etc. of a 1000 MW coal-fired power plant [31]. Coal-fired power plants produce almost 10 Gt of carbon dioxide per year (IEA, 2018), identified as the single most contributor of global greenhouse gas emission in 2018 [32].

Another indirect effect of coal-mining is related to its fuel for mining operation. Wood usage for mine operation that accounts for huge land transformation by both deforestation and afforestation process [31]. Indirect forest losses have been identified almost five times more due to coal mining than direct land use change in Appalachia [33]. It is also examined that about 40% of fly ash and bottom ash are deposited in land or mine filling (indirect effect) in Europe [34] which have several negative effects including contamination in the groundwater and disruption of aquatic systems [35], [36].

Natural Gas and Oil Extraction

The technologies used in extracting natural gas and oil have significant indirect and direct effects on land utilization. Natural gas is extracted from deep wells using fracking methods. In this method, water, sand, and chemicals are injected into the deep well, which makes cracks in the rock layer and withdraws natural gas through the cracks to fill up the well. Although a small amount of land is required for deep wells, usually 28–36 square meters [37], [38], but provision of infrastructure and creation of a vehicle network is needed to maintain the supply chain, supply raw materials to the gas fields, for example, sand for fracking, and supply gas to the potential users [39], [40]. Both technologies (creation of deep wells) and facilities (creation of infrastructure and vehicle networks) have the potential to transform land use patterns in the associated areas [40]–[42]. In addition, injecting wastewater into the wells poses some risk of seismic activity, which may cause land use alteration, but the seismic risk related to injecting wastewater is much smaller than the carbon capture and storage systems have [40], [43].

Oil and gas exploration and exploitation have been causing significant impacts on land use and cover change. For example, about 59,078 sq.km of bare land was converted between 2001 and 2008 to other uses, including oil and gas infrastructure, associated settlement of the newly migrated population due to employment in the industries, agriculture to meet the demand for additional foodstuffs, vegetation increased by afforestation projects etc. in the oil and gas production community of Kwale in Delta State of Nigeria [44], [45].

Furthermore, oil development has other negative consequences, including contamination of water, air, and land; health effects; and road wear and tear. The main concerns are that restoring land from oil activities takes a very long time and that the removed forest area may not recover when the operations are decommissioned [46]. The boreal forest in Canada, for example, is changing as a consequence of oil and gas exploration, transportation, and human settlement expansion. However, oil infrastructure expansion had a greater impact on forests than on water, farming land, or barren land. From 1975 to 2017, they discovered 0.234% deforestation in north-eastern British Columbia [47].

Nuclear Energy

Land is required in the different phases of nuclear power generation, such as mining ore, establishing power stations, management, transportation, and waste disposal [48], [49]. A nuclear power station with a 1000-Megawatt electrical power output requires approximately 330000 tons of uranium ore (0.1% uranium oxide) per year [48]. These amounts of ore can be obtained from underground, surface, or solution mining based on the geological setting of the neighborhood [49]. Approximately 7 ha of land is required to be ore mined to produce 1000-Megawatt electrical power for one year. Land transformation is higher in the case of nuclear power production than coal-fired energy in the USA [31]. In addition, a large buffer area is needed for transporting fuel and waste. The areas are isolated and free from usual development but are being used as wildlife habitats through biodiversity and conservation programs by many nuclear energy operators. Moreover, reprocessing of spent fuel needs further land transformation through establishing transportation systems, operation of reprocessing plants, etc. [40], [48].

3.1.2 Renewable Energy

The decision makers around the world are well aware of our limitations regarding the fossil fuels we have. In addition, oil price fluctuations, increasing changes in climatic conditions and their associated impacts on the world economy have motivated many countries in the world to produce renewable energy both on a small and large scale [16]. Renewable energy is the source of energy that is naturally replenishing and virtually inexhaustible in duration. The energy is acquired from naturally regenerated sources over a human timespan. The most common renewable energy sources are wind energy, solar energy, biomass, hydropower, and deriving energy from waste, etc. These renewable energy sources have significant implications for natural landscape change.

Wind Energy

Wind energy is becoming more familiar as a non-conventional source of energy in many parts of the world. China has the highest installed wind capacity, 221 gigawatts (GW), and the largest wind farm, 7965 megawatts (MW), in the world. The United States is the second largest wind capacity country (96.4 GW), while Germany (59.3 GW) is the third largest. Besides, with 35 GW of wind capacity, India's position is fourth, followed by

Spain (23 GW) and the United Kingdom (20.7 GW) [50]. Agricultural land, livestock grazing, fallow land, etc. are the most compatible land uses for wind energy production because of height and noise issues for establishing wind turbines. Situated in residential or commercial areas, wind turbines are not feasible because adjacent buildings impede the wind on one hand. On the other hand, the noise created due to turbines crosses the recommended noise level (25–40 dB at night, with 10 dB higher for daytime) of the International Standards Organization (ISO). The noise created by wind turbines may vary depending on the power capacity and types of turbines used, as well as available wind speed. The usual range of noise created by wind turbines is 96-108 dB [51]. Therefore, establishing wind turbines needs to change the present land use of agricultural, livestock grazing, and fallow land. Although these changes happen on a small scale, they have significant impacts. In addition, establishing infrastructure for the construction of wind turbines, operation and maintenance, and energy supply systems needs alteration of land uses in the production and service areas [52].

Solar Energy

The demand and use of solar energy have been increasing around the world using two popular methods, i.e., photovoltaic (PV) and concentrated solar power (CSP) systems. In 2015, the total capacity of solar-powered electricity reached 227 gigatons (GWe), accounting for about 1% of global electricity production. PV farms and CSP are large-scale centralized methods of solar energy production that require a huge volume of insolation as well as land use concern. The National Renewable Energy Laboratory (NREL) reported that the average required land area (direct use) for producing 1 MW of electricity in the United States is about 7.3 acres [40]. About 114–261 square meters of land are usually needed depending on available insolation to fulfil a person's energy demands using PV methods [53]. Land use changes (through forest clearance, construction activities, etc.) for solar energy production are observed at different rates in many countries like the United States, China, etc., which have several potential effects on soil erosion [40].

Biomass

Biomass is considered the fourth largest source of energy while the first, second, and third sources are oil, coal, and natural gas, respectively. It uses about 6.41% of total global energy consumption [54]. It is the largest source of renewable energy that can be produced from different sources of raw materials such as agricultural crops, forestry and wood processing residues, algae, household wastes, industrial wet wastes, etc. Biomass energy, such as biogas and biofuel, can be used for cooking, heating, and electricity generation, as well as transportation fuel [55]–[57]. Like other developing countries in South and Southeast Asia, biomass energy is being used as the main source of household energy in Bangladesh [58]. Global demand for biomass energy has doubled in the last four decades and is still increasing [59]. Although only 0.5% to 1.7% of agricultural land is currently used to grow biofuel raw materials, there is significant potential for small-scale and large-scale production [60]. Biomass production is heavily reliant on available cultural land and land use policies, which may increase land transformation [55], [60]–[62]. The effect of biomass on land use is largely due to the cultivation and processing of feedstock, as well as transporting fuel to the power plant. For biomass energy production to work, there needs to be a lot of planning over a long period of time that takes into account competing uses of land and resources [63].

Waste Energy

The water-to-energy (WTE) process has a strong significance for land use alteration. Agricultural or commercial uses of land can be transformed into solid waste disposal sites in order to generate utility and industrial fuel [64]. According to the origin of waste, solid waste can be categorized as (a) municipal solid waste (MSW) includes food-kitchen-green waste, paper waste, product packaging waste, appliance waste, etc.; (b) industrial solid waste (ISW) includes inert industrial waste (chemically or biologically non-reactive) and non-hazardous waste; and (c) healthcare solid waste (HSW), also called solid medical waste (SMW), includes plastic discarded gloves, syringes, bandages, human or animal tissues, clothes, etc. [65]. However, the magnitude of economic or agricultural losses caused by solid waste dumping varies by location, but in most cases, all biodiversity is destroyed in such territory [64]. Particularly, biodiesel generation from municipal solid waste requires available land surface, ignoring food feedstocks that contribute to global land-use change [66].

Hydropower

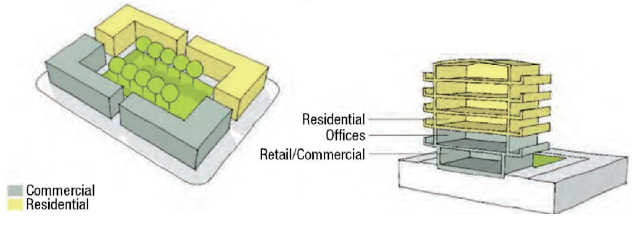
Hydropower is the most abundant form of renewable energy, accounting for more than 70% of all green energy and more than 16% of global electricity supply from across all energy sources [40]. In contrast to electricity derived from fossil fuels, increasing hydropower energy output has the potential to reduce greenhouse gas emissions [67]. Hydropower is often touted as a low-cost, low-carbon, advanced technology for satisfying growing energy needs and boosting economic growth [68]. River basin management and reservoir creation for establishing a hydropower plant as well as its associated economic activities may trigger the changing nature of social status and economic well-being as a result of changes in land use and land cover (LULC) and hydrologic patterns in the water basin area. In addition, a hydropower project can contribute to increased urbanization through reducing flood risk and improving development activities [69]. And, of course, urbanization has been one of the leading causes of land use change in recent decades. A large-scale hydropower plant includes the construction of structures such as roads, dams, culverts, tunnels, power station infrastructure, and electricity power grids, leading to the clearing of forest and the relocation of human settlements. In addition, the reservoir's inundation on land could kill ecosystems, destroy infrastructure and settlements, harm livelihoods, etc. [70]. The World Commission on Dams reported that about 40-80 million people were displaced due to the socio-economic consequences of dam establishment activities [71]. Later, research on ‘‘land use and renewable energy planning'' estimated that indirect deforestation rises between 11.3% and 59% and land use for agriculture increases between 7% and 50% due to hydropower development in any given site for any given year [69].

3.2 Impacts of Land Use on Energy Efficiency

Isolated land use patterns make housing scattered, sparse population densities, average distance traveled for commuting or personal trips, etc. are directly related to increasing vehicle miles traveled [72]. Vehicle miles traveled or VMT is a performance measure widely used in land use and transportation planning with a view to sufficient energy use. It is defined by measuring the total amount of distance traveled by all vehicles in a spatial unit over a fixed period of time, usually one year. VMT is considered as a crucial proxy data for identifying vehicle emissions, energy consumption, etc. [73]–[75]. Energy efficiency (EE), or efficient energy use, is basically defined as using less energy to carry out similar work, and in this way, energy waste can be eliminated. The main concern of EE is to reduce the required amount of energy for producing goods and services. The most efficient way of achieving energy efficiency in the built environment can be obtained through means of land use planning with a view to lowering energy requirements and consumption is by reducing VMT [20], [76]. Sustainable development and energy conservation can be achieved through reducing vehicle miles travelled using a variety of methods, including mixed-use development, urban block development, and encouraging transport-oriented development. In addition, establishing a combined heat and power system, ensuring available green spaces, and energy-supporting land use policies can unlock energy efficiency and ensure sustainable development.

3.2.1 Mixed or Blended Land Use Development

Mixed or blended land use development in the sense of urban development combines at least two distinct types of compatible land uses, such as residential-commercial, residential-commercial-institutional, etc., into one space. It may be in the same building or in close proximity to each other. To some extent, the functions of these blended land uses are physically and functionally integrated [15], [17], [77]. For instance, mixed use development can be vertical where a single building could include a business on the first floor and residential uses on the upper floors, or can be horizontal where a range of different structures on the same site each perform a definite objective, such as a neighborhood area that has housing buildings, office buildings, a playground, a park, a shop, and other facilities (Figure-1). Mixed land use development increases the neighborhood's liveliness and makes the urban environment more attractive. In order to reduce energy demand for motorized travel, average travel distances (commuting or personal trips), and promote walking and other non-motorized travel, mixed land use development is more realistic than monofunctional neighborhoods [15], [78].



Source: North Shore City [79]

Figure 1: Mixed land use on the Block and Building Scale

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One of the earliest cities in North America that adopted mixed-use development policies is Toronto, Canada. City planners started to promote high-density development by blending land uses near to metro stations during the rapid expansion of the city's transit network in the 1960's. In 1980, the regional government of Toronto came up with a plan called Metroplan to promote the use of aligned transit networks. In 1986, the municipal administration took the initial step with a zoning bylaw under the Toronto legal framework that allowed for commercial, residential, and institutional use to be blended and formed a new dimension of land use. The zoning bylaw was revised in 2013 and continues to focus on accommodating a blended land use. Although mixed-or blended-use developments may be found all throughout the city, the majority of Toronto's blended-use zones are concentrated in the city center. City center dominated blended development occurred due to the city's political legacy and developmental history, which has also prioritized combining land uses near transportation networks. The concept of mixed land use in Toronto has been adopted by other Canadian and American cities to effect similar changes[80]–[83].

3.2.2 Urban Block Development

Scholars define an urban block as a part of an urban area that is spatially isolated by road network from the surrounding parts. It is also called the residential cluster encompassed by the road network [84]. There are three types of urban blocks, such as tower blocks, linear blocks, and perimeter blocks. The same amount of floor space could be arranged in towers, linear, and perimeter blocks, but there is a need to control its height. It is estimated that the same result can be achieved in a fifteen-story tower, five-story linear, and three-story perimeter block [85]. There is no fixed size for an urban block, it may vary across the cities around the world. The appropriate extent of a block is up to 120 m considering walkable, active, and livable urban space, but sometimes it may be accepted up to 500 m in high-rise urban areas. In Tokyo-Japan, the size of a typical urban block is 50 m wide, while it is 70-100 m in Vienna or Paris, and 100-120 m in New York and Washington D.C. Urban blocks represent mixed uses and public shops exist on the ground floor, usually in a linear pattern and connected with the road network [17]. Hence, energy savings can be achieved through decreasing energy demand for motorized travel [78].

3.2.3 Transit Oriented Development

The Intergovernmental Panel on Climate Change stated that energy generation and consumption are the key contributors that emit almost two-thirds of greenhouse gas emissions. Cities, particularly their transport systems and household requirements (heating and cooling), are the dominant sources of energy consumption [86]. It is estimated that world energy demand will rise by about 1.3% yearly up to 2040 [87]. Transit-oriented development (TOD) can contribute to reducing a certain amount of greenhouse gas emissions from urban areas. TOD is a tool for urban land use and transportation planning that focuses on mixed-use development within walking distance of transit stops in order to maximize transportation service efficiency [88]–[90]. The distance between origin and destination is a key factor in TOD that influences whether users use transit or not. Many scholars identify that the standard walking distance is 10 minutes from a house, business, or leisure spot to public transport [88], [91]. However, this distance may vary depending on the location and user specific needs.

3.2.4 Combined Heat and Power (CHP)

A country can achieve energy efficiency by introducing and incorporating combined heat and power (CHP) systems at an individual and/or district level. CHP is a system that makes both heat and electricity in a single step [20]. Combined heat and power (CHP) at district level, usually called district heating with combined heat and power (CHP-DH), is a system or process of generating heat at a central level and distributing it to the users' premises through insulated pipes [92]. The actual benefit of CHP-DH, on the other hand, is greater in mixed-use development than in single-use neighborhoods [20], [76]. However, CHP at an individual level also provides an outstanding opportunity to supply heat and power to many buildings, like hotels, educational institutions, medical centers, residential houses, etc.

3.2.5 Green Spaces

Most urban areas are considered the centers of heat generation and are commonly called "urban heat islands" [93] They largely depend on solar insolation, wind speed, cloud cover, humidity, vegetation coverage, construction materials, etc. [94], [95]. Urban heat islands consume vast amounts of cooling energy during the summer season [96]. Sufficient green space in urban areas reduces air temperature on both the horizontal [97] and vertical [96] scales, as well as cooling energy requirements within the urban area and its periphery [17], [94]–[97]. Some scholars explain green spaces as the "natural air conditioner" that can reduce building energy [98], [99] and create barriers to release carbon dioxide, nitrogen dioxide, and ozone gases into the air [100].

3.2.6 Energy Support Land Use Plan and Policies

Land-use planning is "the systematic assessment of land and water potential, alternatives for land use, and economic and social conditions in order to select and adopt the best land-use options" [101]. Land use planning and regulations are public policy exercises that designate and regulate land use in terms of enhancing the environmental, financial, and sociocultural efficiency or well-being of a community. These regulations are also involved in achieving energy efficiency or diminishing marginal energy demand. Many scholars [20], [102], [103] identified land use policies as the root cause of land use change. Land use policies can attain energy conservation by incorporating several sections regarding mixed use development, urban block formation, transport-oriented structural development, establishment of combined heat and power systems, green field development, improvement of mass transport, walking, cycling access, etc. [17].

4. CONCLUSIONS

Land use is the human utilization of land, which is considered the modification, alteration, and management of the physical environment into built environments such as settlements, agriculture, transportation, industry, recreation, and open space. The changing pattern of land use is a major concern for the improvement of the healthy well-being of human society. Energy has been considered as the central determinant for smooth economic development and people's livelihoods. The nexus between land use and energy can be discussed as the impacts of energy on land usage and, conversely, the impacts of land use on energy. It is recognized that direct and indirect land use changes occur during the different stages of extraction, deposition, and transportation of fossil fuels and uranium ore. Mining for fossil fuels and uranium ore has a direct impact on land usage by clearing vegetation and destroying top soil. Furthermore, supplying fuel for mining operations, establishing associated infrastructure, and disposing of waste all have an indirect impact on the land uses of the associated areas. Moreover, generating renewable energy also has several direct and indirect impacts on land usage. The installation of wind turbines necessitates a direct change in the current land use of agricultural, animal grazing, and fallow land. In addition, creating infrastructure for wind turbine construction, operation, and maintenance, as well as an energy supply system, requires land use changes in the production and service areas. Furthermore, the effects of biomass on land usage are primarily attributable to feedstock cultivation and processing as well as fuel transportation to power plants. Likewise, the production of biodiesel from municipal solid waste requires available land surface, ignoring food feedstocks, which contribute to global land-use change. In a similar way, the building of highways, dams, culverts, tunnels, power station infrastructure, and energy transmission networks for large-scale hydropower plants leads to the destruction of forests and the relocation of people.

This research found blended land use development as the most efficient approach to achieve energy efficiency through land use planning. This form of development, which is more practical than a monofunctional neighborhood, mixes at least two different types of compatible land uses to minimize energy demand for motorized travel, average commute or personal trip distances, and encourage non-motorized modes of transportation like walking. Furthermore, urban block and transit-oriented development can significantly lower the energy demand for vehicle trips. Moreover, an integrated heat and power system, green space in the neighborhood, as well as energy-supporting land use plans and regulations, may help to achieve energy efficiency and ensure long-term development.

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