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Use of Sustainable Energy Systems in Educational Institutions

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ABSTRACT: Educational institutions like other public and private organizations should try to eliminate their carbon footprint for the achievement of the ambitious 2050 target of net-zero carbon emissions. Several mature, reliable and cost-effective sustainable energy technologies can be used in these institutions replacing the use of fossil fuels and reducing their carbon emissions. Solar energy, wind energy and biomass can be used for heat and electricity generation replacing the use of oil, gas and grid electricity. Additionally, various low-carbon emission technologies including heat pumps, co-generation systems, fuel cells, district heating systems and power storage technologies can be also used in them. The combined use of these technologies in schools, colleges and universities can replace the current use of conventional energy sources reducing or completely eliminating their carbon emissions. The abovementioned benign energy technologies are already used commercially in several sectors proving their reliability and cost-effectiveness. It has been indicated that a plethora of green energy technologies can be used in educational institutions eliminating their carbon footprint achieving the desired global 2050 target of net-zero carbon emissions. Our results could be useful to policy makers and to the authorities of schools, colleges and universities who are willing to promote their environmental sustainability, achieving economic benefits and offering valuable educational opportunities to students.

KEYWORDS: educational institutions, energy efficiency, energy saving, renewable energies, schools, zero carbon emissions

1. INTRODUCTION

Use of sustainable energies, including renewable energies and low-carbon emissions technologies, in several sectors nowadays is of paramount importance for achieving the 2050 target for net-zero carbon emissions. Educational institutions including schools, colleges and universities should be sent in this global effort. The use of renewable energies in educational institutions has been studied extensively [1], [2], [3], [4], [5], [6]. The use of low-carbon emission technologies in schools and universities has been also studied [7], [8], [9], 10]. The net-zero energy transition of education institutions has been also analyzed [11], [12], [13], [14], [15].

The aim of the current research is to examine the use of mature, reliable and cost-effective sustainable energies in educational institutions including the use of renewable energy as well as the use of low-carbon emissions energy technologies.

The text is structured as follows: After the literature review the importance of energy sustainability and energy saving in educational institutions is stated. Next, the renewable energy and the low-carbon energy technologies which can be used in schools and universities are analyzed. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used.

Our work is innovative presenting the mature, reliable and cost-effective benign energy technologies which can be used to zero the net-energy use and the net-carbon emissions in schools and universities. It could be useful to educational authorities and to policy makers who are willing to decrease or zero the net-energy use and the net-carbon emissions in educational institutions.

2. LITERATURE SURVEY

The impacts of wind power development on Oklahoma's USA public schools have been studied [1]. The authors stated that wind turbines in western Oklahoma generated in 2016 around 20% of the county's power demand. They also mentioned that the development of wind farms can positively contribute in funding public schools located nearby them. The use of solar power in education has been reviewed [2]. The authors stated that the integration of solar power in education is transforming campuses and curricula worldwide. They also mentioned that solar power integration in educational Institutions has multiple environmental, economic, educational and societal benefits. The use of solar-PV systems in three California's school districts has been studied [3]. The author stated that schools present a unique opportunity for deployment of renewable energies and use of energy efficient technologies. He also mentioned that usually educational institutions have large surfaces for the installation of solar panels while they can educate their students in these benign energy technologies. The use of solar-PVs in public schools in Palestine has been studied [4]. The authors estimated that installation of solar-PV systems in 3,074 schools in Palestine with nominal power 57.16 KW_p each could generate 5.12% of the total annual energy demand in Palestine while the payback period of the investment would be 4.38 years. The use of renewable energies and energy storage systems in university campuses has been studied [5]. The authors proposed a multiple energy generation system comprising solar-PV panels, wind turbine, fuel cell and hydrogen production. Due to intermittent energy sources used they also suggested the use of an electric battery and a hydrogen storage system. The energy efficient and renewable energy systems in higher education facilities have been reviewed [6]. The authors stated that integration of renewable energy technologies in higher education facilities empowers the localized generation of electricity ensuring a reliable and sustainable energy source. They also mentioned that educational institutions investing in energy efficient technologies experience substantial reductions in utility bills leading to long-term cost savings. The development of an electricity and a thermal storage system in a high school building in Greece have been studied [7]. The authors stated that after refurbishment of a high school a solar-PV system was installed which, according to the regulations, was not allowed the infuse electricity into the grid during the day. They proposed the installation of an electric battery to store the generated electricity during the day time and to infuse it into the grid in the night. The use of small- and medium-scale co-generation of heat and power (CHP) systems has been studied [8]. The authors stated that biofuels such as biogas, bioethanol and biodiesel enhance the sustainability and the efficiency of CHP systems. They also mentioned that the use of CHP systems in coastal regions has many benefits particularly when combined with renewable energy resources such as solar energy, wind energy and water energy. The connection of the university buildings in Tallin, Estonia with the local district heating network has been analyzed [9]. The authors stated that the annual heat demand of the university's buildings is around 20 GWh. They mentioned that the connection of the buildings with the city's district heating network will reduce the annual CO_2 emissions by 765 tons. A report related with the use of heat pumps which reduce the energy demand in the university of Leeds has been released, [10]. The heat pumps are going to replace the old boilers which were using oil and wood pellets electrifying the heating system. The new system significantly reduces the carbon emissions helping the university to achieve the 2050 net zero target. The carbon neutrality in schools has been investigated [11]. The authors stated that school buildings offer some of the most cost-effective carbon abatement opportunities. Studying for a period of two years thirteen schools in Perth, Western Australia, they mentioned that the average carbon emissions have been reduced by around 20% while the most of the implemented actions had low or zero cost. The energy improvement of school buildings in England decreasing their energy and carbon emissions has been examined [12]. The authors stated that there is a large potential for emissions' reduction in British schools particularly by switching from gas to electric heating combined with installation of solar-PV systems. However, they mentioned, a considerable effort is required for retrofitting school buildings in the country, at a rate 650 schools per year, for achieving the target of carbon neutrality by 2050. The cost-effective options for the renovation of an existing building with covered surface 6,517 m^2 at College Park, Maryland, USA has been studied [13]. The author stated that investing in energy efficient retrofitting techniques was more cost-effective than investing in renewable energy technologies. He also mentioned that the payback period of the green energy investments was in the range of 1.4 years to 4.1 years. Two models for nearly-zero energy schools in Belgium have been developed [14]. The authors stated that the average energy intensity per school was at 59 KWh/m^2 year and 42 KWh/m^2 year. They also mentioned that nearly zero energy schools were cooling and electricity dominated. The energy behavior of school buildings in Canada has been studied [15]. The authors stated that the mean energy consumption in Canadian schools is 213.9 KWh/m^2 year while the share of electricity in the energy mix is 54%. They also mentioned that there are several successful LEED certified schools in Canada and a few of them can be considered as net-zero energy schools. The biomass cookstoves in rural Kenyan schools have been studied [16]. The authors compared two types of biomass-feed cookstoves used for the preparation of midday school meals. The use of wind energy in schools in USA has been examined [17]. The author stated that the use of wind turbines in schools will: a) introduce teachers and students to wind energy, b) engage America's communities in wind energy applications, and c) Equip college students with an education in wind energy. A report regarding the use of heating systems in schools in Bhutan has been published [18]. The report investigated the use of several sustainable heating technologies in schools comprising: a) the use of geothermal heat pumps, b) the use of air-source heat pumps, and c) the use of solar water heating systems. The development of zero carbon emissions school buildings in Crete, Greece has been studied [19]. The author stated that school buildings in Greece have low energy demand at 68 KWh/m^2 year and carbon emissions at 28 $kgCO_2/m^2$ year. He also mentioned that using several renewable energy technologies school buildings can zero their net carbon footprint. The energy consumption and the carbon emissions in an Academic institution in Greece has been evaluated [20]. The author estimated its specific annual energy consumption at 164.96 KWh/m^2 and its carbon emissions at 110.64 $kgCO_2/m^2$. He also mentioned that the combined use of solar thermal energy, solar-PV energy and high efficiency heat pumps could eliminate all the energy-related carbon emissions in the Institution. The use of a solar-PV system in a school building located in Izmir, Turkey has been studied [21]. The covered area of the school was 1,356.6 m^2. The authors stated that the installation of 180 solar-PV panels in the school could generate electricity covering all its annual power demand including the power used for the operation of a heat pump with COP at 2.5. They also mentioned that the payback period of the energy investments was lower than 10 years. The energy saving potential in university buildings in Hong Kong in the case of constructing green roofs on their rooftops has been assessed [22]. The authors stated that the most of energy savings are due to lower cooling demand in the buildings during the summer. They also mentioned that university buildings with poor thermal insulation benefit more from the construction of green roofs regarding energy and economic aspects. The effect of green roofs on energy performance in school buildings in USA has been assessed [23]. The authors stated that the recommended soil thickness is 15 cm. They also mentioned that the optimal plants’ height in green roofs for cooling dominated climates is 30 cm while for heating dominated climates at 10 cm. The energy saving potential in higher educational institutions in Portugal has been evaluated [24]. The authors characterized each university buildings according to its typology and implemented energy performance benchmarking. They estimated the potential energy saving in the range of 10% to 34% in final energy consumption. The performance of a local heating system powered by biomass in a university campus in Spain has been assessed [25]. The authors stated that before renovation the specific energy consumption in the university’s buildings was in the range of 60 KWh/m^2 year – 430 KWh/m^2 year. After the renovation and the installation of centralized heating system in the campus the specific energy consumption in the buildings has been significantly reduced while the carbon emissions were at 1.57 $kgCO_2/m^2$ year. The current status of energy production from solid biomass in North-West Italy has been examined [26]. The authors categorized 28,167 existing biomass plants according to their typology. They stated that biomass is used for power generation and co-generation of heat and power in thermoelectric plants as well as for heat production and for district heating in thermal plants. The energy consumption of five different school buildings in the city of Matera (Southern Italy) has been analyzed [27]. The authors stated that their energy behavior was poor. Four school buildings were categorized in the energy class G while the fifth in the energy class D. The energy consumption in one university in the city of Guangzhou, China has been analyzed [28]. The authors estimated its annual energy consumption for three years in the range of 60.83 KWh/m^2 to 82.14 KWh/m^2. The energy consumption of a middle school in Daegu, South Korea has been estimated [29]. The authors stated that its average annual energy consumption was 133 KWh/m^2. They also mentioned that the share of electricity in the energy mix was 82% while the rest 18% was attributed to LNG and kerosene. A reported related with the use of geothermal energy for heating and cooling universities has been released, [30]. It is stated that the Oxford Brooks University, UK, in 2022 announced the installation of a new geo-exchange heating system which was the first for a UK university. It is also mentioned that these systems have high efficiency because they do not generate energy but they transfer it.

1. The Importance of Energy Sustainability in Educational Institutions

Energy sustainability in educational institutions is crucial for both environmental and educational reasons. As centers of learning, schools and universities have a responsibility to lead by example in addressing the global energy crisis and reducing their carbon footprints. By adopting sustainable energy practices, these institutions can significantly reduce their reliance on fossil fuels, cut greenhouse gas emissions, and contribute to combating climate change. Sustainable energy practices, such as using solar panels, wind turbines, and biomass for heating, offer financial benefits. Educational institutions often have large campuses with high energy demands. By investing in renewable energy, they can reduce their operational costs, freeing up resources for other essential academic activities, infrastructure, or student services. The cost savings from energy efficiency measures can also help offset budget constraints faced by many schools and universities. Beyond cost and environmental impact, incorporating energy sustainability into educational institutions offers a rich educational opportunity. It allows students to observe and learn from real-world examples of renewable energy technologies, sustainable building practices, and resource conservation. This hands-on exposure to sustainability efforts helps raise awareness among students about the importance of environmental stewardship and prepares them to become future leaders in the fight against climate change. Energy sustainability in educational institutions is not only an environmental necessity but also an educational imperative. By adopting sustainable energy practices, schools can save money, reduce environmental impacts, and inspire the next generation to embrace and innovate sustainable solutions.

2. Energy saving in educational institutions

Energy saving in academic institutions is crucial for both environmental sustainability and cost-efficiency. Universities and colleges often operate large campuses with diverse facilities, such as classrooms, laboratories, libraries, and dormitories, all of which consume significant amounts of energy. By implementing effective energy-saving measures, these institutions can reduce their carbon footprint and operational costs while setting a positive example for students and the community. Several strategies can help academic institutions conserve energy. First, improving the energy efficiency of buildings is key. This can be achieved through better insulation, energy-efficient lighting, and the use of smart heating and cooling systems. Many universities are transitioning to LED lighting and motion-sensor technology, which ensures that lights are only on when needed. In laboratories, where energy consumption is particularly high, efforts such as optimizing ventilation systems, using energy-efficient equipment, and encouraging responsible energy practices among researchers can make a big difference. Reducing standby power consumption from electronic devices, installing energy-efficient appliances, and encouraging the use of renewable energy sources, such as solar panels, are other impactful strategies. Beyond infrastructure upgrades, promoting energy-saving behaviors among students, faculty, and staff is essential. Awareness campaigns that encourage turning off lights, reducing water usage, and minimizing waste can foster a culture of sustainability. Therefore, energy-saving efforts in academic institutions not only reduce costs but also help mitigate climate change, while promoting sustainability education and leadership in the community

3. USE OF PASSIVE ENERGY AND RENEWABLE ENERGY SYSTEMS

5.1 The Use of Green Roofs in Educational Institutions

Green roofs, which involve covering a building's roof with vegetation, offer significant environmental and educational benefits, making them a valuable addition to educational institutions. These roofs improve insulation, helping to reduce energy consumption and lower heating and cooling costs. They also mitigate urban heat island effects by cooling surrounding areas and contribute to better air quality by filtering pollutants. In educational settings, green roofs serve as living laboratories where students can study ecology, sustainability, and environmental science firsthand. They provide opportunities for hands-on learning, fostering awareness of biodiversity and climate change solutions. Schools and universities can use green roofs to support curriculum development in subjects such as biology, chemistry, and environmental engineering, helping to connect theoretical knowledge with practical applications. Furthermore, green roofs promote mental well-being by creating green spaces in urban environments, which have been shown to reduce stress and improve focus. These areas can serve as peaceful retreats for students and staff, contributing to a more conducive learning environment. Overall, incorporating green roofs in educational institutions enhances sustainability efforts while enriching the academic experience and fostering environmental stewardship among students.

5.2 The Use of Solid Biomass for Heating in Educational Institutions

Using solid biomass for heating in educational institutions presents a sustainable and cost-effective energy solution. Biomass refers to organic materials, such as wood chips, agricultural residues, and other plant-based matter, that can be burned to produce heat. In schools and universities, biomass heating systems offer several advantages over conventional fossil fuel-based systems. One of the primary benefits of biomass heating is its lower environmental impact. Biomass is a renewable energy source that reduces carbon emissions compared to fossil fuels, as it releases only the amount of CO_2 that plants absorb during their growth cycle. This makes biomass a carbon-neutral energy solution that helps educational institutions reduce their carbon footprints, aligning with global sustainability goals. Additionally, the use of biomass can significantly lower heating costs for schools, especially in regions where wood and agricultural by-products are readily available. This cost efficiency can free up budget resources for other educational needs. Beyond energy savings, biomass systems provide opportunities for students to learn about renewable energy technologies and sustainable resource management. By adopting biomass for heating, educational institutions not only contribute to environmental sustainability but also create educational opportunities that promote awareness of renewable energy sources.

5.3 The Use of Small Wind Turbines in Educational Institutions

The installation of small wind turbines in educational institutions offers a sustainable and practical energy solution, contributing to both environmental and educational goals. These turbines generate clean, renewable energy by converting wind into electricity, helping schools and universities reduce their reliance on fossil fuels and lower carbon emissions. One of the major advantages of small wind turbines is their potential to cut energy costs. By harnessing wind power, educational institutes can supplement their energy needs, reducing electricity bills and freeing up financial resources for academic and infrastructural improvements. This energy independence is particularly beneficial in rural or windy areas where wind energy can be consistently harnessed. In addition to the economic and environmental benefits, small wind turbines serve as valuable educational tools. They offer hands-on learning opportunities for students, allowing them to study renewable energy technology, engineering principles, and sustainability practices. Wind turbines can become a focal point for lessons in science, physics, and environmental studies, inspiring students to explore careers in green energy and engineering fields. Educational institutes that invest in renewable energy also demonstrate a commitment to sustainability, fostering environmental responsibility among students and staff. Moreover, by adopting small wind turbines, educational institutions contribute to a broader cultural shift towards renewable energy, setting an example for their communities. These turbines not only reduce environmental impact but also promote awareness of climate change solutions, empowering the next generation to engage with global sustainability challenges. Overall, small wind turbines provide a forward-thinking, environmentally conscious energy option that enriches the academic experience.

5.4 The Use of Solar Thermal Systems for Hot Water Production in Educational Institutions

Solar thermal systems offer an efficient and eco-friendly solution for hot water production in educational institutions. These systems use the sun's energy to heat water, reducing the need for conventional fossil fuel-based energy sources. By harnessing solar power, schools and universities can significantly lower their energy costs while minimizing their carbon footprint. One of the key advantages of solar thermal systems is their ability to provide a consistent and renewable source of hot water. Whether used for showers, kitchens, laboratories, or dormitories, these systems can meet a large portion of an institution's hot water demands. In areas with abundant sunlight, solar thermal technology is particularly effective, and its low maintenance requirements make it a cost-efficient long-term investment. The environmental benefits of solar thermal systems are substantial. By replacing or supplementing traditional water heating methods, educational institutions can reduce greenhouse gas emissions, helping them contribute to sustainability goals and climate action plans. Solar thermal technology also raises awareness of renewable energy solutions among students and staff. Moreover, solar thermal systems provide hands-on educational opportunities. Students can learn about solar energy technologies, renewable energy science, and sustainable practices through direct interaction with the system. This practical exposure helps foster environmental stewardship and encourages students to think critically about energy use and conservation. Overall, the integration of solar thermal systems in educational institutes aligns with both financial savings and environmental responsibility, while also offering valuable educational opportunities to students.

5.5 The Use of Solar-PV Systems in Educational Institutions

The installation of solar photovoltaic (solar-PV) systems in educational institutions offers numerous environmental, economic, and educational benefits. Solar-PV systems generate electricity by converting sunlight into usable energy, providing a clean, renewable alternative to fossil fuels. For schools and universities, adopting solar-PV technology is a sustainable way to reduce energy costs and carbon emissions while promoting a culture of environmental responsibility. One of the primary advantages of solar-PV systems is their ability to significantly lower electricity bills. Educational institutions, which often have large campuses with high energy demands, can use solar energy to meet a substantial portion of their electricity needs. By reducing reliance on the grid, schools can save on energy costs, allowing more funds to be directed towards academic and infrastructural improvements. Additionally, solar-PV systems have a long lifespan and require minimal maintenance, making them a cost-efficient investment over time. Beyond the financial and environmental benefits, solar-PV systems serve as excellent educational tools. They offer students real-life examples of renewable energy technologies and sustainability practices, providing opportunities for hands-on learning in fields such as physics, environmental science, and engineering. Schools can integrate solar energy data into their curriculum, allowing students to monitor energy production and learn about the importance of clean energy solutions. By adopting solar-PV systems, educational institutions not only reduce their carbon footprint but also foster environmental awareness and responsibility among students. This forward-thinking approach helps prepare students to tackle future sustainability challenges while contributing to a greener, more sustainable future. The use of passive energy and renewable energy systems in educational Institutions is presented in table 1.

Table 1. Use of passive energy and renewable energy systems in educational Institutions

Energy system	Energy source	Cost of energy source	Carbon emissions	Generated energy
Green roof	-	-	No	Energy reduction
Solar-PV	Solar energy	zero	No	Electricity
Solar thermal	Solar energy	zero	No	Domestic hot water
Wind turbine	Wind energy	Zero	No	Electricity
Biomass burning	Biomass	Yes	Yes, on-site	Heat

Source: own estimations

4. USE OF EFFICIENT AND LOW-CARBON EMISSIONS ENERGY SYSTEMS IN EDUCATIONAL INSTITUTIONS

6.1 The Use of Heat Pumps in Educational Institutions

Heat pumps have emerged as a transformative technology for heating and cooling in educational institutions, offering an efficient and environmentally friendly solution. These systems transfer heat from one place to another, utilizing electricity to move heat instead of generating it through combustion, which significantly reduces energy consumption and carbon emissions. One of the primary advantages of heat pumps is their energy efficiency. For every unit of electricity consumed, heat pumps can produce multiple units of heating or cooling, resulting in lower operational costs. This is particularly beneficial for schools and universities, which often face tight budgets and high energy demands. By reducing heating and cooling costs, institutions can allocate more resources to academic programs and facility improvements. In addition to their economic benefits, heat pumps contribute to sustainability goals. By utilizing renewable energy sources, such as ambient air, ground, or water, they help educational institutions decrease their reliance on fossil fuels. This transition not only reduces greenhouse gas emissions but also aligns with global efforts to combat climate change. Furthermore, the installation of heat pumps provides an excellent educational opportunity. Students can learn about energy efficiency, thermodynamics, and renewable energy technologies, gaining hands-on experience in a growing field. This exposure fosters awareness of sustainable practices and encourages future generations to engage with environmental challenges. The integration of heat pumps in educational institutes represents a significant step towards energy efficiency and sustainability. By investing in this technology, schools and universities can lower costs, minimize environmental impact, and inspire students to embrace renewable energy solutions.

6.2 The Use of Heat and Power Co-generation Systems in Educational Institutions

Co-generation systems, also known as combined heat and power (CHP) systems, represent a highly efficient approach to energy management in educational institutions. These systems simultaneously produce electricity and useful thermal energy from a single fuel source, maximizing the overall efficiency of energy use. By harnessing waste heat generated during electricity production, co-generation systems can significantly reduce energy costs and carbon emissions. One of the primary benefits of co-generation in educational institutes is its economic advantage. Institutions typically have substantial energy demands for heating, cooling, and electricity. By integrating co-generation systems, schools and universities can generate their own electricity while meeting heating requirements, thereby lowering utility bills. The reduction in energy costs allows educational institutions to allocate more funds toward academic programs, infrastructure, and student services. In addition to financial savings, co-generation systems contribute to sustainability efforts. By improving energy efficiency and utilizing renewable fuel sources, such as biomass or biogas, these systems help reduce greenhouse gas emissions. Educational institutions can serve as models for sustainability, demonstrating a commitment to environmental responsibility and inspiring students to engage with energy conservation initiatives. Co-generation systems are an effective solution for enhancing energy efficiency and sustainability in educational institutes. By adopting this technology, schools and universities can lower costs, reduce environmental impact, and prepare students to tackle the energy challenges of the future.

6.3 The Use of Fuel Cells in Educational Institutions

Fuel cells are an innovative technology that holds great potential for educational institutions, offering a clean and efficient energy source for various applications. These devices convert chemical energy directly into electricity through an electrochemical reaction, typically using hydrogen as fuel. By integrating fuel cells into their energy systems, schools and universities can significantly enhance their sustainability efforts while providing valuable educational opportunities for students. One of the primary advantages of fuel cells is their environmental benefits. As they produce electricity with water and heat as the only by-products, fuel cells contribute to reducing greenhouse gas emissions compared to traditional fossil fuel-based energy sources. By adopting fuel cell technology, educational institutions can lower their carbon footprint and align with global sustainability goals, demonstrating a commitment to environmental stewardship. In addition to their ecological benefits, fuel cells can provide a reliable and resilient energy source. Educational institutions often require continuous power for classrooms, laboratories, and other essential services. Fuel cells can serve as a backup power source, ensuring uninterrupted operations during grid outages. Moreover, the implementation of fuel cells in educational settings presents a unique opportunity for hands-on learning. Students can engage with cutting-edge technology, gaining insights into renewable energy systems, electrochemistry, and engineering principles. The use of fuel cells in educational institutes represents a forward-thinking approach to energy management. By embracing this technology, schools and universities can reduce environmental impact, enhance energy reliability, and empower students with the knowledge and skills needed to address future energy challenges.

6.4 The Use of District Heating and Cooling Systems in Educational Institutions

District heating systems represent an effective solution for providing reliable and efficient heating in educational institutions. These systems distribute thermal energy generated from a centralized source to multiple buildings within a designated area, allowing schools and universities to benefit from reduced energy costs and enhanced sustainability. One of the primary advantages of district heating is its efficiency. By generating heat at a central location—often using renewable energy sources such as biomass, geothermal, or waste heat—district heating systems can optimize energy production and minimize losses that typically occur in decentralized heating systems. This centralized approach not only reduces the carbon footprint of educational institutions but also helps them meet sustainability goals by utilizing cleaner energy sources. Moreover, district heating systems can lead to significant cost savings for educational institutions. By sharing a common heating source, schools can reduce infrastructure costs associated with individual heating systems. The savings on maintenance and operational costs can then be redirected to enhance educational programs and facilities, benefiting students and staff alike. In addition to economic and environmental benefits, district heating systems offer educational opportunities for students. They can learn about energy systems, sustainability, and the importance of energy efficiency through practical experiences associated with these systems. District heating systems provide educational institutions with a sustainable, cost-effective, and efficient method for meeting their heating needs.

6.5 The Use of Energy Storage Systems in Educational Institutions

Energy storage systems are increasingly recognized as vital components in enhancing the sustainability and efficiency of educational institutions. These systems store excess energy generated from intermittent renewable energy sources, such as solar and wind, for later use, ensuring a reliable power supply and reducing reliance on the grid. By integrating energy storage into their energy management strategies, schools and universities can reap numerous benefits. One of the primary advantages of energy storage systems is their ability to balance energy supply and demand. During peak production periods, such as sunny or windy days, excess energy can be stored for use during high-demand times, like evenings or cloudy days. This capability not only enhances energy reliability but also helps institutions manage energy costs by reducing dependence on peak electricity pricing. Additionally, energy storage systems contribute to sustainability efforts by maximizing the use of renewable energy. By storing excess energy, educational institutions can reduce their reliance on fossil fuels, lowering their carbon footprint and aligning with global climate goals. This commitment to sustainability sets a positive example for students and the surrounding community. Moreover, the implementation of energy storage systems provides unique educational opportunities. Students can engage in hands-on learning experiences related to renewable energy technologies, energy management, and environmental science. Energy storage systems offer educational institutions a practical solution for enhancing energy efficiency and sustainability. By adopting these technologies, schools and universities can ensure reliable energy supply, reduce costs, and inspire future generations to embrace renewable energy solutions. The use of efficient and low carbon emissions energy systems in educational institutions is presented in table 2.

Table 2. Use of efficient and low carbon emissions energy systems in educational institutions

Energy system	Energy source	Generated energy	Cost of energy source	Carbon emissions
Heat pumps	Ambient heat and electricity	Heat, cooling	Yes	Yes
Co-generation systems	Natural gas, diesel oil, biogas	Heat, electricity	Yes	Yes, no when biogas is used
Fuel cells	Hyrdogen, natural gas	Heat, electricity	Yes	Yes, no when green hydrogen is used
District heating systems	Natural gas, biogas, biomass	Heat	Yes	Yes, no when biomass or biogas are used
Power storage	Electricity	Electricity	Yes	No

Source: own estimations

The electricity generation using hybrid energy systems in several universities is presented in table 3 while the payback time of energy saving and renewable energy systems in several universities in table 4.

Table 3. Electricity generation using hybrid energy systems in several universities

University/Location	Peak load (KW)	Hybrid energy system	LCOE ($/KWh)
University of Victoria/Canada	-	Solar-PV/wind/Biomass/Battery	0.129
Hitit University in Corum/Turkey	94.2-157.5	Solar-PV/H_2/Gas	0.061-0.065
American University in Beirut/Lebanon	15,300	Solar-PV/Battery/Diesel	0.088-0.144
Ouargla University, Algeria	1,916	Solar-PV/H_2/Fuel Cell	0.016-0.100

Source: [30]

Table 4. Payback time of energy saving and renewable energy systems in several universities

University/Location	Payback time (years)	Energy system
University of Coimbra/Portugal	3.8	Energy efficient lighting
Northeastern Greece/Greece	2-8	Energy saving
Ain Shams University/Egypt	4-5	Energy saving
Tokio University of Agriculture/Japan	2-4	Biomass heating
University Polytechnic Madrid/Spain	11	Solar-PV
Technical University of Crete/Greece	4.2	Solar-PV
Lappeenranta University of Technology/Finland	10-15	Ground source heat pump
Seoul National University/South Korea	8-10.2	Renewable energy microgrid

Source: [30]

5. DISCUSSION

Several mature, reliable and cost-effective renewable energy technologies as well as low-carbon energy technologies can be used in educational institutions including schools, colleges and universities. They can replace the use fossil fuels helping their clean energy transition and the achievement of the 2050 net-zero carbon emission target. These energy technologies can cover all the energy demand of the educational institutions in heat, cooling, hot water and electricity eliminating the use of fossil fuels and their CO_2 emissions. Taking into account that these energy technologies are already broadly commercialized in various sectors their combined use in educational institutions can zero all the energy-related carbon emissions achieving the desirable target of net-zero carbon emissions.

Our work does not indicate the different combinations of the abovementioned benign energy technologies which can be used in educational institutions for the elimination of their carbon footprint. It does not indicate either the installation cost of the benign energy systems neither the existing barriers for the promotion of these green energy investments.

Future work should be focused in the implementation of various case studies related with the achievement of net-zero emissions educational institutions describing the benign energy technologies which can be used in them as well as their size and capacity.

6. CONCLUSIONS

The use of sustainable energies in educational institutions including schools, colleges and universities has been studied. It has been found that several mature, reliable and cost-effective benign energy technologies can be used in them reducing or zeroing their carbon emissions. These comprise:

a) The use of green roofs,
b) The use of solar thermal and solar-PV systems,
c) The use of solid biomass,
d) The use of wind turbines,
e) The use of heat pumps,
f) The use of heat and power co-generation systems,
g) The use of fuel cells,
h) Their connection to local district heating systems, and
i) The power storage in their premises.

Our findings indicate that educational institutions can use a plethora of mature, reliable and cost-effective benign energy technologies replacing the use of fossil fuels and eliminating their carbon footprint achieving the ambitious 2050 target of net-zero carbon emissions.

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