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Use of Sustainable Energy Sources and Technologies in Primary and Secondary School Buildings in Greece. Can They Eliminate their Carbon Footprint?

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ABSTRACT: School buildings consume energy covering their energy demand. The most of them utilize fossil fuels and grid electricity while the use of renewable energies is rather limited. School buildings should eliminate their carbon emissions in order to achieve the global target for net-zero carbon emissions by 2050. The energy consumption and the carbon emissions in schools have been evaluated. School buildings in Greece consume less than 100 kWh/m^2 year. Solar thermal energy, solar photovoltaic energy and high efficiency heat pumps can cover all the energy demand in school buildings in Greece replacing the use of conventional energy sources. These energy technologies are reliable, mature and cost-effective. There are 7,756 primary and secondary school buildings in Greece consuming 1.67 TWh/year. The total cost of energy renovation eliminating their carbon emissions is estimated at 1,156,000 €/school or 8.96 billion € for the 7,756 schools in the country. For achieving the target of net-zero carbon emissions by 2050, 310 Greek schools should be energy refurbished every year eliminating their carbon footprint in the next 25 years. Taking into account the availability of benign energy sources and technologies the main barrier for eliminating the carbon emissions in school buildings in Greece by 2050 is the high investment cost. Our results could be useful for the development of the required policies for decarbonization in school buildings.

KEYWORDS: carbon emissions, energy consumption, Greece, schools, sustainable energies

1. INTRODUCTION

The challenge of mitigating the current climate crisis requires the sharp reduction in fossil fuels use and the clean energy transition in all sectors of the economy. Educational buildings consume significant amount of energy while the use of zero-carbon energy sources and technologies is rather limited so far. Many studies in several countries with different climate conditions have estimated the energy consumption in primary and secondary schools [1], [2], [3], [4], [5]. Several studies have been also realized evaluating the carbon emissions in school buildings [6], [7], [8], [9], [10] as well as in schools' commuting [11], [12], [13]. The energy consumption in Greek schools has been also estimated by several authors [14], [15], [16], [17]. Several sustainable energy technologies are nowadays mature, reliable and cost-effective while they are extensively used in many daily applications.

The aim of the current work is to investigate the possibility of eliminating the carbon emissions in primary and secondary school buildings in Greece using sustainable energy sources and technologies.

The structure of the text is as follows: After the literature survey the energy consumption and the carbon emissions in schools are analyzed. Next, the energy renovation in schools in Greece reducing their carbon footprint and the sustainable energy technologies that can be used for that are stated. In the next section the sizes of the benign energy systems required for zeroing the carbon emissions in a Greek school are evaluated. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used.

The work is innovative since there are limited studies related with the elimination of the carbon footprint in primary and secondary school buildings. It fills a gap regarding the clean energy transition in primary and secondary schools in Greece. The work could be useful to policy makers and to local authorities who are willing to promote the clean energy transition in schools in Greece achieving the Greek and EU target for net-zero carbon emissions by 2050. It could be also useful to energy companies which are going to participate in the design and installation of the required sustainable energy systems zeroing the carbon footprint in Greek school buildings.

2. LITERATURE SURVEY

The energy consumption in schools has been reviewed [1]. The authors presented data regarding the energy consumption in primary and secondary school buildings in several countries as well as the average energy use profile in schools in USA. The energy consumption in 68 school buildings in Luxembourg has been evaluated [2]. The authors estimated the average electricity consumption at 32 kWh/m^2 year and the average heat energy consumption at 93 kWh/m^2 year. The energy consumption in 121 secondary school buildings in Hong Kong has been studied [3]. The authors estimated that the average energy consumption is 105.61 kWh/m^2 year while they mentioned that electricity was the primary energy source used. The energy consumption in 270 schools in Tianjin, China has been evaluated [4]. The authors stated that electricity consumption varied in the range 21-27 kWh/m^2 year while the average heat energy consumption was 68.64 kWh/m^2 year. They also mentioned that the heat energy consumption corresponded at 64%-79% of the total primary energy consumption. The energy consumption in middle schools in Daegu, Korea has been estimated [5]. The authors stated that the annual energy consumption in the schools studied was in the range of 67-240 kWh/m^2 year with mean value at 133 kWh/m^2 year. They also mentioned that the share of electricity in the energy mix was at 82% followed by LNG at 14% and kerosene at 4%. The carbon emissions in Montgomery County public schools have been analyzed [6]. The author stated that the average annual emissions were at 11.74 kgCO_2/student. He also mentioned that electricity contributes to about 70-75% of the total energy-related carbon emissions. A study of carbon emissions from British schools has been published [7]. The study mentioned that CO_2 emissions in schools are divided in four categories as follows: a) the use of energy in school buildings, b) the commuting of staff, pupils and school trips, c) the goods and services procured by schools, and d) the produced wastes. The carbon footprint from school activities in Indonesia has been studied [8]. The authors estimated that the carbon footprint of school activities was 83.04 tonCO_{2eq}/year while the largest portion was related to transportation of students, staff and teachers, followed by electricity, paper and LPG use. They also mentioned that the existing vegetation in schools was absorbing 3 tonCO_{2eq}/year. The carbon footprint in a vocational technical school in the Black Sea Region of Turkey has been quantified [9]. The authors stated that the students emitted 7.43 tnCO_{2eq}/year which is higher than the average emissions in Turkey at 4.1 tnCO_{2eq}/year. They mentioned that the reasons for the high emissions were the use of coal in the region and the limited use of public transport. The carbon neutral schools have been investigated [10]. The authors stated that school buildings offer some of the most cost-effective opportunities for carbon abatement. They examined 13 schools in Perth, Australia which had participated in an innovative two-years low-carbon school program. The authors mentioned that the schools reduced their CO_2 emissions per student on average by 20% while more than 70% of the realized actions had low or zero cost. The low-carbon trips in schools have been studied [11]. The authors stated that carbon emissions produced in school trips are increasing year by year. The impact of home-school commuting mode choice on carbon footprint in Northwest Italy has been evaluated [12]. The authors stated that students at high schools have lower CO_2 emissions than teachers, staff and students of primary and middle schools because of the higher intensive use of public transport. They also mentioned that a shift from car use to walking for home-school distances up to 2 km and use of public transport for distances between 2-10 km would reduce the CO_2 emissions by 60-67%. The creation of zero CO_2 emissions school buildings due to energy use in Crete, Greece has been investigated [13]. The author stated that school buildings in Greece consume 68 kWh/m^2 year and emit 28 kgCO_2/m^2 year. He also mentioned that the cost of installing renewable energy systems in school buildings generating green energy replacing the use of fossil fuels varies in the range of 47.42 €/m^2 to 87.71 €/m^2 while the cost of carbon emissions savings is in the range of 1.69 €/kgCO_2 to 3.13 €/kgCO_2. The energy performance in Hellenic schools has been studied [14]. The authors made an energy survey in 135 Hellenic schools stating that they consume energy for heating, lighting and operation on various equipment. They also mentioned that schools consume less energy than other types of buildings since during the peak heating and cooling periods they are closed for students' holidays. The energy consumption in Hellenic school buildings has been studied [15]. The authors have analyzed 238 school buildings stating that their average total annual energy consumption was at 93 kWh/m^2 year. They also mentioned that 72% of their annual consumption was used in space heating while the energy conservation potential corresponded at around 20% of their energy use. The energy consumption in school buildings has been reviewed [16]. The authors analyzed the electricity consumption in 50 primary and secondary school buildings in Scotland. They stated that the power demand in these schools varied in the range of around 2 W/m^2 in the morning and the evening to around 23 W/m^2 at noon. The possibility of assessing the carbon emissions in schools by the students has been investigated [17]. The authors developed a methodology allowing to students to evaluate their school footprint related to mobility, heat and electricity consumption, food in the school canteen and to various consumables (paper et cetera). An analytical description of the existing schools in Greece has been

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presented, Eurydice, EU [18]. The number of different types of primary and secondary Greek schools are given. The energy consumption in six Portuguese secondary schools which have upgraded their heat, ventilation and air-conditioning (HVAC) systems has been estimated [19]. The authors stated that electricity had a share at 76% in the total energy mix while the remaining was attributed to natural gas. They also mentioned that the energy consumption varied in the range of 32 kWh/m^2 year to 70 kWh/m^2 year. The energy consumption and the thermal comfort in public primary schools in Egypt have been studied [20]. The authors stated that thermal comfort plays a major role in educational buildings in hot-arid climate. They used simulation models to estimate their energy consumption at 1.5 kWh/m^2 year. Their findings indicated that lighting represented the largest proportion in energy consumption while the pupils were staying more than 36.5% of their daily time in classrooms under thermal stress conditions. Two benchmark models for nearly-zero energy schools have been developed [21]. 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 zero-energy schools are cooling and electricity dominated. The net-zero energy school buildings in Canada have been studied [22]. The authors stated that the number of net-zero energy schools is increasing in USA. They also mentioned that significant energy efficiency strategies are needed to achieve the net-zero energy status in cold climates like in Canada. The authors stated that the size of Canadian schools varies in the range of 930 m^2 to 4,650 m^2 while their average energy consumption is at 213.9 kWh/m^2 year. The pathways to improve the school building stock in England towards net-zero have been investigated [23]. The authors stated that there is a large potential for emissions reduction across English schools particularly when shifting from gas to electric heating using heat pumps. They also mentioned that for achieving the net-zero emissions target by 2050 around 650 schools should be retrofitted annually. The zero-energy and zero-carbon buildings have been studied [24]. The author stated that during the recent years zero-energy and zero-carbon buildings have attracted much attention. He also mentioned that zero-carbon buildings achieve the greatest carbon saving while they are more expensive and there is limited practical experience regarding their construction and behavior. The use of sustainable energy systems in educational institutions has been studied [25]. The author stated that several mature, reliable and cost-effective sustainable energy technologies can be used in these institutions replacing the use of fossil fuels. He also mentioned that the combined use of these technologies in educational institutions can totally eliminate their carbon footprint.

3. ENERGY CONSUMPTION IN SCHOOLS

Energy consumption in schools is a significant factor in both operational costs and environmental impact. Schools, as large institutions with varied energy needs, consume substantial amounts of energy daily. This includes lighting, heating, cooling, powering technological devices, and running various educational facilities. Understanding and addressing energy consumption in schools is essential for both economic and environmental sustainability.

The primary contributors to energy use in schools are the HVAC systems. These systems account for a significant portion of energy expenditure, especially in regions with extreme climates. Additionally, lighting represents a large share of electricity consumption, particularly in schools that have long operational hours and extensive indoor spaces. Classrooms, gyms, and computer labs also require considerable energy to power computers, projectors, and other electronic devices used in education. The average energy use per sector in schools in USA is presented in table 1.

Table 1. Average energy use profile in schools in USA

Sector	%, energy use
Space heating	47
Lighting	14
Cooling	10
Ventilation	9
Water heating	7
Others	5
Computers	4
Refrigeration	2
Cooking	1
Office equipment	1
Total	100

Source: [1]

The energy consumption in school buildings depends on many factors comprising the local climate, the type of school building, the quality of building construction and their age, the operating months per year, the type of the equipment and the energy systems used, the thermal comfort in the class rooms, the behavior of the students, teachers and the staff et cetera. The energy consumption in schools in several countries is presented in table 2 while the energy consumption in Greek schools is presented in table 3.

Table 2. Energy consumption in schools in several countries

Country	Energy consumption (kWh/m^2 year)	Reference
EU	90-272	Dias-Pereira et al, 2014 [1]
Luxemburg	145	Thewes et al, 2014 [2]
Hong Kong	105.61	Chung et al, 2020 [3]
Greece	93	Santamouris et al, 1994 [15]
China	173.08-1,425.9 (primary energy consumption)	Xing et al, 2015 [4]
Canada	213.9	Hakim et al, 2019 [22]
Belgium	42-59	Attia et al, 2020 [21]
South Korea	133	Kim et al, 2019 [5]
Portugal	50-53	Dias Pereira et al, 2017 [19]
England	119-223	Kilpatrick et al, 2011 [16]
Franch	197	Kilpatrick et al, 2011 [16]
Egypt	1.5 (electricity only)	Saleem et al, 2016 [20]

Source: various authors

Table 3. Energy consumption in Greek school buildings

Energy consumption (kWh/m^2 year)	Reference
53-69	Dias-Pereira et al, 2014 [1]
49.5-90.8	Dascalaki et al, 2011 [14]
93	Santamouris et al, 1994 [15]
68	Vourdoubas, 2016 [13]
57	Kilpatrick et al, 2011 [16]

Source: various authors

The high levels of energy consumption in schools lead to significant financial costs. For many educational institutions, energy expenses are second only to personnel costs. In underfunded schools, this can place a heavy burden on already tight budgets. Moreover, excessive energy use contributes to the environmental footprint of schools by increasing greenhouse gas emissions, which negatively impacts climate change.

4. CARBON EMISSIONS AT SCHOOLS

Carbon emissions from schools, though often overlooked, play a considerable role in contributing to environmental challenges like climate change. Schools, as large, active institutions, generate carbon emissions through various sources such as energy consumption, transportation, waste production, and even food services. Understanding these sources and adopting measures to reduce carbon emissions is essential for creating more sustainable learning environments.

One of the primary sources of carbon emissions in schools is energy use. Heating, cooling, and lighting classrooms, gyms, and offices require substantial energy, much of which is still derived from fossil fuels. Schools that rely on non-renewable energy sources for electricity contribute to carbon dioxide and other greenhouse gases being released into the atmosphere. The transportation sector is another significant contributor, as buses, cars, and other vehicles that bring students and staff to and from school emit carbon dioxide and other pollutants. Waste management, including food waste from cafeterias and paper waste, adds to the overall carbon footprint. Even activities like school trips or deliveries of supplies contribute to carbon emissions. A net-zero carbon emissions school building is conceived as a building in which the energy consumption by on-site or off-site fossil fuel use is equal to the amount of on-site or off-site renewable energy production. The operational carbon footprint in British schools is presented in table 4 while the operational greenhouse gas footprint in British schools in table 5.

Table 4. The operational carbon footprint in British schools (2004)

Category	%, of carbon footprint	Key components
Buildings	41	Energy use in buildings, electricity for ICT
Procurement	42	Furniture, materials, equipment, food, ICT, electrical equipment
Transport and travel	17	Transport of pupils and staff from/to school, various trips
Waste	<1	Paper and food waste

Source: [7]

Table 5. The operational greenhouse gas footprint in British schools (2004)

Category	%, of greenhouse gas footprint	Key components
Buildings	37	Energy use in buildings, electricity for ICT
Procurement	45	Furniture, materials, equipment, food, ICT, electrical equipment
Transport and travel	16	Transport of pupils and staff from/to school, various trips
Waste	2	Paper and food waste

Source: [7]

The environmental impact of carbon emissions from schools is significant, as it contributes to global climate change. In the long term, climate change can disrupt local ecosystems, affecting agricultural production, water supply, and public health, all of which are critical for future generations of students.

5. ENERGY RENOVATION IN GREEK SCHOOLS TO REDUCE OR TO ELIMINATE THEIR CARBON FOOTPRINT

Primary and secondary schools in Greece should be energy retrofitted to achieve the national, EU and global target of net-zero carbon emissions by 2050. Many school buildings in Greece have been constructed with the old building codes without proper thermal insulation. Therefore, they are not energy efficient while the most of them use grid electricity and fossil fuels. The use of renewable energies in school buildings in Greece is so far rare. There are several types of elementary and high schools in Greece which are presented in table 6.

Table 6. Number of primary and secondary schools in Greece

Type of school	Number of schools
Single-type all day primary schools	3,709
Single-type all day primary schools with limited number of teachers	621
Minority primary schools	26
Total number of primary schools	4,356
Day lower secondary schools	1,570
Day lower secondary schools with upper secondary classes	188

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Evening lower secondary schools	48
Evening lower secondary schools with upper secondary classes	26
Day general upper secondary school	1,100
Evening general upper secondary school	52
Day vocational upper secondary school	334
Evening vocational upper secondary school	82
Total number of secondary schools	3,400
Total number of primary and secondary schools	7,756

Source: [18]

Energy renovation of Greek schools is a critical step toward eliminating their carbon footprint and fostering environmental sustainability. Schools are energy consumers due to their need for heating, cooling, lighting, and powering educational equipment. By upgrading these systems and adopting cleaner energy sources, schools can significantly reduce, or even eliminate, their carbon emissions. A primary focus of energy renovation in schools is improving building efficiency. This begins with enhancing insulation, windows, and doors to prevent energy loss. Proper insulation reduces the need for excessive heating and cooling, which are significant contributors to carbon emissions. Additionally, upgrading HVAC systems to more energy-efficient models ensures that schools use less energy to maintain comfortable indoor climates. Installing energy-efficient lighting, such as LED bulbs, can further decrease electricity use, as lighting is a major source of energy consumption in schools.

The integration of renewable energy is another essential component of energy renovation. Schools can install solar photovoltaic panels, wind turbines, or geothermal heat pumps systems to generate their own clean energy. This not only eliminates reliance on fossil fuels but also provides long-term savings on energy costs. Many schools can also turn to energy storage solutions, such as battery systems, to store excess energy generated with solar photovoltaics during off-peak hours and use it when demand is high. Energy renovations not only help eliminate the carbon footprint of schools but also offer economic benefits. Schools that produce their own renewable energy can reduce operational costs and redirect funds to educational resources. Additionally, energy-efficient buildings are more comfortable and healthier for students and staff, as better ventilation and lighting contribute to improved learning environments.

Greek schools can take several steps to reduce their carbon emissions. Switching to renewable energy sources, such as solar energy or biomass, is an effective way to cut down on emissions from electricity and heating energy use. Use of high efficiency heat pumps powered by solar electricity is another option. Improving insulation, upgrading HVAC systems, and using energy-efficient lighting are additional strategies. Encouraging sustainable transportation options, like walking, biking, or carpooling, can reduce emissions from commuting. Additionally, waste reduction programs, such as recycling and composting, help to lower a school's overall carbon footprint. Although energy renovation can be costly upfront, many schools can access government grants, incentives, and partnerships to help fund these projects. Engaging the community and involving students in sustainability initiatives can also foster a culture of environmental responsibility.

Assuming the average covered surface in each school in Greece is at 2,310 m^2 [26] the total covered surface of 7,756 primary and secondary Greek schools is estimated at 17,916,360 m^2. Assuming that the average annual energy consumption in school buildings in Greece is at 93 kWh/m^2 [15] the total energy consumption in primary and secondary schools in Greece is estimated at 1,666,221 MWh/year or 1.67 TWh/year. The abovementioned energy consumption corresponds at 0.55 % of the primary energy consumption in Greece in 2023 which was estimated at 305 TWh [27].

The elimination of the net-carbon emissions in school buildings in the next 25 years during 2025-2050, requires the energy renovation of 7,756/25 = 310 schools per year. The covered surface of the schools which must be renovated annually is estimated at 310 schools X 2,310 m^2/school = 716,100 m^2/year. Assuming the energy renovation cost at 500 €/m^2 the annual renovation cost of 310 schools is 358.50 mil. €/year. The energy renovation cost per school is at 2,310 m^2/school X 500 €/m^2 = 1,155,000 €/school. Taking into account that the total number of students in primary and secondary schools in Greece is 1,095,714 students [28] the total annual cost of energy renovation in school buildings eliminating their carbon emissions is evaluated at 358,500,000 (€/year)/1,095,714 students = 327.2 €/student- year. The results of energy retrofitting of school buildings in Greece for achieving net-zero carbon emissions by 2050 is presented in table 7.

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Table 7. Energy retrofitting of school buildings in Greece for achieving net-zero carbon emissions by 2050

Parameter	Value
Number of primary and secondary schools in Greece [6]	7,756
Number of students in primary and secondary schools in Greece [28]	1,095,714
Average covered surface of schools in Greece [26]	2,310 m^2/school
Average annual energy consumption in schools in Greece [11]	93 kWh/m^2
Annual energy consumption per school	214,830 kWh/school
Total covered surface of 7,756 schools in Greece	17,916,360 m^2
Total annual energy consumption in schools in Greece	1,67 TWh/year
Number of schools which should be retrofitted annually during 2025- 2050	310 schools/year
Average cost for net-zero emissions retrofitting	500 €/m^2
Cost for energy renovation per school	1,155,000 €/school
Cost for retrofitting 310 schools annually	358.50 mil. €/year
Total cost of retrofitting of 7,756 schools in Greece until 2050	8.96 billion €
Cost for net-zero emissions retrofitting per student	327.2 €/student-year

Source: [18], [15], [26], [28]

6. SUSTAINABLE ENERGY TECHNOLOGIES THAT CAN BE USED IN SCHOOLS IN GREECE

Several sustainable energy technologies can be used in primary and secondary schools in Greece for the reduction of their carbon emissions. These technologies are currently mature, reliable, well-proven and cost effective. These technologies can be categorized as:

a) Energy saving technologies,
b) Electricity generation technologies,
c) Electricity storage technologies,
d) Heat and cooling generation technologies,
e) Technologies co-generating heat and electricity, and
f) Technologies producing hot water

Depending on the size and the needs of schools one or more of these benign energy technologies can be used replacing the use of fossil fuels and decreasing their carbon emissions. The sustainable energy technologies which can be used for decreasing the carbon emissions in Greek primary and secondary schools are presented in table 8.

Table 8. Sustainable energy technologies which can be used for decreasing the carbon emissions in primary and secondary schools in Greece

Technology	Energy saving/generation/storage
Thermal insulation of the building envelope, roof, facades, windows and doors	Energy saving
Energy efficient lighting	Energy saving
Green roofs	Energy saving
Solar photovoltaic panels	Electricity generation
Power storage	Electricity storage
Heat pumps	Heat and cooling production
Co-generation systems	Heat and electricity generation
Fuel cells	Heat and electricity generation
District heating and cooling	Heat and cooling production
Biomass burning	Heat production
Solar thermal panels	Hot water production
Wind turbines	Electricity generation

Source: own estimations

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7. ELIMINATION OF THE CARBON FOOTPRINT DUE TO ENERGY USE IN A SCHOOL BUILDING IN GREECE

For the evaluation of the size of the necessary sustainable energy systems to eliminate the net carbon emissions due to energy use in the building of a Greek school the following assumptions are made:

a) The covered surface of the school is 2,100 m^2,
b) The initial specific annual energy consumption is 93 kWh/m^2 (table 3),
c) The share of energy consumption per sector is: for heat, cooling and ventilation 66%, for lighting 14%, for hot water 7% and for other electric uses 13% (table 1),
d) The initial annual energy consumption at 93 kWh/m^2 will be reduced by 20% with energy saving measures at 74.4 kWh/m^2,
e) The annual electricity generation of solar-PV panels in Greece is 1,400 kWh/kW_p,
f) The annual heat production from solar thermal systems is 300 kWh_{th}/m^2,
g) The COP of the heat pump system which will be used is 5,
h) The heat pump operates 1,200 hours per year, and
i) The required electricity will be generated with a solar photovoltaic system installed on the rooftop of the school. The air-conditioning will be provided by a high efficiency heat pump. The hot water will be produced by a solar thermal system installed on the rooftop of the school. Electricity storage, if necessary, will be provided by electric batteries.

The annual energy consumption in the school, after the energy saving measures, will be at 156,240 kWh. The energy consumption in heat, cooling and ventilation will be 103,118 kWh, for lighting 21,874 kWh, for hot water production 10,937 kWh and for other electric uses 20,311 kWh.

The annual electricity consumption of the heat pump with COP equal to 5 will be 103,118/5=20,624 kWh. The total annual electricity consumption in the school will be 21,874 kWh + 20,624 kWh + 20,311 kWh = 62,809 kWh.

The nominal power of a solar-PV system generating the required electricity will be 62,809 (kWh/year)/1,400 (kWh/year)/kW_p = 44.9 kW_p.

The electric power of the heat pump will be 20,624 (kWh/year)/1,200 (hours/year) = 17.2 KW.

The solar collectors' area of the solar thermal system producing 10,937 kWh_{th}/year will be 10,937 (kWh/year)/ 300 (kWh_{th}/m^2 year) = 36.46 m^2.

8. DISCUSSION

The use of sustainable energy technologies in elementary and secondary schools in Greece has been studied. Application of these technologies can reduce or completely eliminate their net-carbon footprint related with energy consumption in their buildings. De-carbonization of school buildings in Greece is facilitated for several reasons comprising: a) the high solar irradiance in Greece, b) the large surfaces on rooftops for installing solar panels, c) the fact that in the period of peak demand for heat – winter and colling - summer the schools are closed, d) the fact that schools do not need electricity at night when solar energy is not available. This reduces the need for power storage. Energy consumption and carbon emissions in school buildings is relatively low compared to other types of private of public buildings. Solar photovoltaic energy, solar thermal energy and high efficiency heat pumps can cover all the energy demand in school buildings in Greece eliminating their carbon emissions due to energy use. These technologies are mature, reliable and cost-effective while they are broadly used in many sectors. Due to high number of school buildings in Greece a large number of them should be renovated annually in order to achieve the target of net-zero carbon emissions by 2050. Our study indicates the total cost of energy renovation in school buildings in Greece eliminating their net-carbon emissions in the next 25 years.

The accuracy of the estimated refurbishment cost of school buildings in Greece depends on the assumptions made regarding the size and the energy consumption per sector in school buildings as well as the energy renovation cost per m^2 in them.

Future research should be focused: a) on experimental evaluation of the energy consumption per sector in typical school buildings in Greece, and b) in a more detailed study regarding the cost of energy refurbishment in a typical school building in Greece eliminating all its net-carbon emissions.

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9. CONCLUSIONS

The possibility of eliminating the carbon emissions from primary and secondary school buildings in Greece using sustainable energy sources has been studied. Our findings indicate that:

a) The specific energy consumption in school buildings in Greece is below 100 kWh/m^2 year,
b) There are 7,756 primary and secondary school buildings in Greece while their total energy consumption was evaluated at 1.67 TWh/year,
c) For achieving the target of net-zero carbon emissions by 2050, 310 Greek schools should be energy refurbished annually eliminating their carbon footprint in the next 25 years,
d) The use of solar thermal energy, solar photovoltaic energy and high efficiency heat pumps using solar electricity can cover all the energy demand in school buildings in Greece, and
e) The total cost of energy renovation and the elimination of carbon emissions is estimated at 1,156,000 €/school or 8.96 billion € for 7,756 schools in the country.

Reducing energy consumption and carbon emissions in schools is not only a financial necessity but also an environmental responsibility. By investing in energy-efficient and low-carbon technologies and promoting sustainable practices, schools can lower their energy costs and contribute to a healthier planet.

Our results could be useful to policy makers who are willing to develop appropriate polices achieving the target of net-zero carbon emissions by 2050 in Greece.

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