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Offset of Carbon Emissions Due to Energy Use in Hospitals via Reforestation in Abandoned Mines. A Case Study in Chania, Crete, Greece

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Abstract

Climate change mitigation requires the reduction of fossil fuels used in energy generation and their replacement with carbon-free energy sources. Carbon offsetting is a carbon removal option that can be achieved with several schemes including carbon sequestration by tree plantations. The possibility of offsetting part of carbon emissions due to energy use in the public hospital of Chania is investigated in the current research. The annual energy consumption in the hospital has been estimated at 12,840 MWh/year while its annual carbon emissions, due to energy use at 7,904 $tnCO_2$/year. Several benign energy systems using renewable energies and low carbon energy technologies can be used to reduce its annual footprint. Reforestation of degraded land is an accepted method for offsetting carbon emissions via carbon sequestration. Reforestation of abandoned mines in an area at 100 ha in Prefecture of Chania can remove 1,000 $tnCO_2$ annually corresponding at 12.65% of its total annual carbon emissions. The total cost of reforestation was evaluated at $ 250,000 while various external environmental and social co-benefits will be generated. It is indicated that nature-based solutions like reforestation of degraded land can be successfully used with affordable cost for offsetting part of carbon emissions in the public hospital of Chania.

Keywords: carbon emissions; Crete-Greece; energy; hospitals; abandoned mines; reforestation.

1. Introduction

Hospital buildings are characterized by high specific energy consumption compared to other public or private buildings. Most of them use conventional fuels and grid electricity while the use of renewable energies in their premises is limited so far. The necessity to mitigated climate change requires the reduction of energy consumption and carbon emissions in hospitals minimizing or zeroing their carbon footprint due to energy use.

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Hospitals, should reduce their carbon emissions using modern benign energy technologies while they can offset any remaining emissions using the existing regulated or voluntary offsetting schemes. Among several offsetting methods a low cost and environmentally friendly method of carbon removal is either with protecting existing forests from degradation or with new reforestation. Current research investigates the possibility of creating new tree plantations in abandoned mines located in Prefecture of Chania, Crete, Greece for offsetting part of carbon emissions of the public hospital of Chania through carbon sequestration. Reforestation of abandoned mines results in many economic, social and environmental benefits concerning the hospital, the local society as well as the local and global environment. Present research is important since it indicates that reduction of the carbon footprint due to energy use in the public hospital of Chania, via carbon removal with land reforestation, is technically and economically feasible generating also several local environmental benefits.

1. Literature survey

The literature survey is separated in three sections concerning, a) the energy consumption and the carbon emissions in hospitals, b) the offset of carbon emissions, and c) the land reforestation and the resulted carbon sequestration.

1.1 Energy consumption and carbon emissions in hospitals

The energy consumption in health care facilities in USA has been evaluated [1]. The authors stated that the annual energy intensity of the U.S. hospitals is in the range of 640.7 KWh/m^2 to 781.1 KWh/m^2 with an average value at 738.5 KWh/m^2. They also mentioned that the average annual consumption in European hospitals is significantly lower at 333.4 KWh/m^2. The energy consumption in hospital buildings in China has been estimated [2]. The authors stated that the average annual consumption in Chinese hospitals varies in the range of 338.42 KWh/m^2 to 382.65 KWh/m^2 depending on their capacity. They also mentioned that electricity had a share at 64% in their overall energy consumption. The energy consumption in Polish hospitals has been studied [3]. The author stated that during 2003-2008 the annual energy consumption in large Polish hospitals, with more than 600 beds, varied between 250 KWh/m^2 to 333 KWh/m^2. The energy consumption in Hellenic hospitals has been studied [4]. The authors stated that their annual energy consumption varied from 407 KWh/m^2 in hospitals to 275 KWh/m^2 in clinics. The energy consumption in Brazilian hospitals has been evaluated [5]. The authors stated that their annual energy consumption varied between 230 KWh/m^2 to 460 KWh/m^2 while more electricity that heating fuel was used in them. Evaluation of energy consumption in German hospitals has been implemented [6]. The authors stated that during 2005-2015 the average annual energy consumption in 23 public hospitals in Germany was estimated at 270 KWh/m^2. Assessment of energy consumption in Spanish hospitals has been made [7]. The authors evaluated their average annual energy consumption at 270 KWh/m^2. The energy consumption and the carbon emissions in Venizelio public hospital located in Crete, Greece have been evaluated [8]. The author stated that its annual energy consumption was at 280.4 KWh/m^2 and its annual carbon emissions due to energy use at 168 $KgCO_2/m^2$. He also mentioned that the share of electricity in the total energy mix was almost double than the share of heating oil. The energy consumption in a large-scale educational hospital in tropical climate in Malaysia has been evaluated [9]. The authors stated that the annual energy consumption was at 245 KWh/m^2 while electricity had a share at around 75% in the total energy mix. The CO_2 emissions due to energy use in Spanish hospitals have been calculated [10]. The author estimated their annual CO_2 emissions at around 100 $KgCO_2/m^2$. The energy consumption and the carbon emissions in a large Metropolitan hospital in Australia have been evaluated [11]. The annual energy consumption was evaluated at 255 KWh/m^2 while its annual carbon emissions due to energy use at 224 $kgCO_2/m^2$. The energy performance in British hospital buildings has been evaluated [12]. The authors mentioned that their average annual consumption was in the range of 318 KWh/m^2 to 429 KWh/m^2 while their annual carbon emissions due to energy use were in the range of 99 $kgCO_2/m^2$ to 123 $kgCO_2/m^2$. The energy consumption and the carbon emissions in several hospitals in various countries are presented in table 2.1.

Table 1: Energy consumption and carbon emissions in several hospitals in various countries.

Country	Author, year	Annual energy consumption (KWh/m^2)	Annual carbon emissions due to energy use ($kgCO_2/m^2$)
USA	Bawaneh and his colleagues 2019	738.5	
China	Ji and his colleagues 2019	338.42-382.65	
Europe	Ji and his colleagues 2019	333.4	
Spain	Garcia-Sanz-Calcedo and his colleagues 2018	270	
Greece	Vourdoubas, 2018	280.4	168
Malaysia	Moghimi and his colleagues 2011	245	
Poland	Bujak, 2010	255-333	
Greece	Santamouris and his colleagues 1994	275-407	
Germany	Gonzalez Gonzalez and his colleagues 2018	270	
Brazil	Szklo and his colleagues 2004	230-460	
England	Jain and his colleagues 2021	318-429	99-123
Spain	Garcia-Sanz-Calcedo, 2019		100
Australia	Department of Health, 2010	255	224

Source: various authors, Energy consumption includes air-conditioning, hot water and steam production, lighting and operation of several devices and equipment.

1.2 Offsetting carbon emissions

The options of carbon offsets and renewable energy certificates for achieving carbon neutrality by 2050 have been studied [13]. The authors stated the similarities and differences between these two approaches and the criteria for choosing the best option. A report concerning carbon offsetting with nature-based solutions has been published by [14]. The report stated that nature-based solutions for carbon offsetting includes projects related with forests, wetlands, oceans and agricultural land. A guidance to *carbon* markets and offsets has been published [15]. The report defined carbon offset as the reduction or the removal of CO_2 that is used to counterbalance or compensate for emissions from other activities. It is also mentioned that typical carbon offsetting projects include projects related with energy efficiency, fuel switching, renewable energies, biological and geological sequestration as well as methane gas destruction. A guide for using carbon offsets has been published [16]. The authors stated that carbon offset projects may involve: a) development of renewable energies, b) capture of GHGs, and c) maintaining existing forests and promoting reforestation as well. They also mentioned that the characteristics of high-quality carbon offsetting projects are: a) additionality, b) permanence, c) exclusive claim of carbon credits, d) accurate estimation of carbon removal, and e) avoidance of social and environmental harm. The ethics of carbon offsetting have been studied [17]. The authors stated that offsets can be obtained either with regulated offsets or with voluntary offsets. They also mentioned that ethical questions should be answered like: a) can the offsetting project deliver the carbon emissions claimed? and b) Would the carbon emissions reduction have happened without the proposed scheme? The carbon offsetting worldwide has been assessed [18]. The authors recommended several carbon removal rules that should be followed including: a) Try to reduce first your own carbon emissions, b) Buy offsets only from reliable organizations that provide details for their projects, c) Choose offsetting organizations that help to estimate your own emissions, d) Choose offsetting projects that are independently accredited by a recognized organization, and e) get documentation regarding your offsets purchased. The future demand, supply and the prices for voluntary carbon credits has been published [19]. The report stated that the current price of carbon credits at 3-5 $/tnCO_2$ is very low and a future price at 20-50 $/tnCO_2$ is foreseen by 2030. It is also mentioned that by 2030 the voluntary carbon market could be supplied entirely by nature-based solutions including forest's protection and reforestation of degraded land. These are the cheapest available options generating also additional social and environmental benefits. The carbon tax, trading and offsets have been studied [20]. The authors mentioned the two existing markets in carbon offsetting including the large compliance market and the small voluntary market. They also stated that carbon offsets reduce the risks associated with future increase in CO_2 emissions policy. The prices of voluntary carbon offsets have been analyzed [21]. They stated that the prices of voluntary carbon offset vary broadly. Providers located in Europe sell offsets at prices 30% higher than providers located in North America and Australia while prices are 20% higher when the projects are implemented in developing or least-developed countries. They also mentioned that legislation in some countries allows to companies to offset up to 30-63% of their total carbon emissions. The principles for net zero carbon offsetting have been reported [22]. It is mentioned that several best practices regarding carbon offsetting should be followed for achieving the optimum results including maintaining transparency, focus on long live carbon storage, use of long-term agreements, ensuring environmental integrity, preference to restoration and protection of natural and semi-natural ecosystems.

1.3 Land reforestation and carbon sequestration

The carbon sequestration in Indonesian forests has been studied [23]. The authors estimated the total carbon stock of *Acacia Mangium* trees at 690.73 tnC/ha while the annual CO_2 sequestration rate was up to 362.14 $tnCO_2$/ha. The carbon sequestration capacity of forests in USA has been studied [24]. The authors mentioned that forests in USA can uptake annually the equivalent 14% of human made CO_2 in the country. They also stated that planting all the available land in USA with trees will increase the annual CO_2 uptake by 20%. A report regarding carbon sequestration through reforestation has been published [25]. The report described the opportunities of utilizing abandoned mines for planting trees obtaining carbon credits. It is also mentioned that reforestation in abandoned mines results in economic, social and environmental benefits. A study regarding the impacts of reforestation on the global climate has been published [26]. The authors stated that natural forests store more carbon than tree plantations while it is better to plant trees in former forests and in high productivity sites. They also mentioned that the harvested residues of the plants can replace fossil fuels in energy generation. The principles of carbon sequestration by tree plantations have been studied [27]. The authors stated that the maximum growth rate of trees occurs in the early life of a new tree plantation while mature forests continue to store significant amounts of carbon. Several aspects of carbon sequestration in forests have been investigated [28]. The authors stated that forestry appears to offer a relative low-cost approach to carbon sequestration while the required technology is well-known and effective. They also mentioned that in most studies the cost of carbon sequestration has been estimated in the range of 1-50 $/tnC while other studies evaluate the cost in the range of 10-82 $/tnC. A global analysis regarding the cost-efficiency in carbon sequestration in forests in several countries has been made [29]. The authors stated that, taking into account the co-benefits due to timber harvesting, the cost in the 50 most cost-effective countries is in the range of 4-9 $/tn$CO_2$ for forest conservation projects while the cost in reforestation projects is at around 16-25 $/tn$CO_2$. They also mentioned that taking into account the external ecological and social benefits the total cost of carbon sequestration could be negative. Ten golden rules for optimizing the carbon sequestration in reforestation projects have been presented [30]. The ten rules are:1. Protect existing forests first, 2. Involve all stakeholders in reforestation, 3. Maximize biodiversity recovery, 4. Select appropriate areas for restoration, 5. Use natural regeneration wherever possible, 6. Select species to maximize biodiversity, 7. Use resilient plant material, 8. Plan ahead for infrastructure, capacity and seed supply, 9. Learn by doing, and 10. Ensure the economic viability of the project. Several abandoned and not operating mine areas in the Prefecture of Chania, Crete have been recorded [31]. It is mentioned that various gravel and sand production mines have been abandoned and interrupted their operation in the Prefecture of Chania. These mine areas could be used for reforestation in the future.

Aims of the current work are:

a) *The estimation of energy consumption and carbon emissions due to energy use in hospitals worldwide from the published literature,*

b) *The estimation of energy consumption and carbon emissions, due to energy use, in the public hospital of Chania using data from the existing literature,*

c) *The presentation of several reliable and cost-efficient measures and technologies for reducing the carbon emissions due to energy use in the hospital of Chania, and*

d) *The investigation of offsetting part of hospital's carbon emissions with reforestation of abandoned mines located in the area of Chania, Crete.*

After the literature review the characteristics of the public hospital in Chania are mentioned with estimates concerning its annual energy consumption and the carbon emissions due to energy use. After that the methods and technologies that could reduce hospital's carbon emissions are stated while the annual carbon sequestration via reforestation of several abandoned mines in the Prefecture of Chania has been evaluated. In the next sections the economic, social and environmental benefits of the proposed offsetting scheme are stated followed by discussion of the findings and the conclusions drawn.

2. The public hospital in Chania, Crete

The public hospital of Chania with capacity 460 beds is located 4 Km south of the city. It was built in 2000 and its covered area is at 49,400 m^2. The hospital is using grid electricity and diesel for covering its energy requirements in electricity, heat, cooling, steam and domestic hot water production. An energy renovation project is currently under implementation improving its energy performance with the use of several energy saving technologies and the use of solar energy for heat and electricity generation. In order to comply with the EU goals for climate change mitigation the public hospital of Chania should try to zero its net carbon emissions due to energy use in the near future. Taking into account that the specific annual energy consumption in several hospitals worldwide is in the range of 230 KWh/m^2 to 738.5 KWh/m^2 and the annual carbon emissions are in the range 100 $kgCO_2/m^2$ to 224 $kgCO_2/m^2$, according to published research mentioned in the previous section, it is considered that the annual energy consumption in the public hospital in Chania is at 260 KWh/m^2 while its annual carbon emissions, due to energy use, are at 160 $kgCO_2/m^2$. The overall annual energy consumption in the hospital is calculated at 12,840 MWh/year while its annual carbon emissions, due to energy consumption, at 7,904 $tnCO_2$/year.

3. Methods and technologies for reducing the carbon emissions due to energy use in the public hospital of Chania

Energy is used in Chania’s hospital for heating, cooling, hot water and steam production, lighting and operation of various medical devices and several equipment. It is also used for transportation of the staff, the patients, the visitors as well as for emergency medical care. The main fuels and energy sources used are grid electricity, heating oil and diesel fuel in vehicle’s transportation. Use of renewable energies or low carbon emission fuels is limited in the hospital so far. Future reduction in carbon emissions due to energy use in the public hospital of Chania can be achieved with:

A) Reduction of energy consumption in hospital’s buildings mainly with better thermal insulation,
B) Replacement of the old and less efficient lights, devices and machinery with modern and more efficient,
C) Replacing fossil fuels used in heat production with renewable energies like solar thermal energy and biomass that are locally available,
D) Replacing the old conventional ambulances with new equipped with electric batteries that are going to be recharged with solar electricity,
E) Covering part of the annual electricity consumption with solar-PV electricity generated in-situ,
F) Use of high efficiency heat and cooling equipment like heat pumps,
G) Use of a heat and power co-generation system in the hospital, and
H) Offsetting part of its carbon emissions with the available offsetting schemes.

The energy systems as well as other methods and technologies that could be used in the public hospital of Chania decreasing its carbon emissions are presented in table 4.

Table 2: Energy systems, methods and technologies that could be used for reduction of carbon emissions in the public hospital of Chania, Crete.

Activity	Technology/method	Energy or fuel required	Type of intervention	Result
Energy saving	Use better thermal insulation in hospital's buildings	No	Improve building's thermal insulation	Reduction of current CO_2 emissions
Energy saving	Low energy lighting, use of energy efficient equipment	Electricity	Improve the old lighting system, replace old equipment	Reduction of current CO_2 emissions
Heat production	Solar thermal systems for DHW production	Solar energy	Install solar thermal heating systems	Zero CO_2 emissions due to DHW production
Heat production	Solid biomass burning	Solid biomass	Replace the old conventional heating systems based on fossil fuels	Zero CO_2 emissions due to heat production in various sectors including in space heating
Heat and cooling production	Heat pumps	Ambient heat and electricity	Install new energy efficient heat pumps	Reduction of current CO_2 emissions
Electricity generation	Solar-PV systems	Solar energy	Install solar-PV systems	Decrease of CO_2 emissions due to electricity use
Co-generation of heat and power	CHP system	LPG	Install a CHP system	Reduction of current CO_2 emissions
Emergency medical care	Electric ambulances with electric batteries	Solar-PV electricity for re-charging the batteries	Replace the conventional ambulances with new electric ambulances	Zero CO_2 emissions due to fuel consumption in ambulances
Carbon offsetting	Reforestation	No	Create tree plantations	Offsets any carbon emissions that cannot be removed with other methods/technologies

Source: own estimations

4. Reduction of carbon emissions in the hospital with carbon offsetting schemes

Carbon offsetting is the reduction or the removal of CO_2 that is used to counterbalance or compensate for emissions from other activities. United Nations, with the adoption of Kyoto protocol in 1997, have created a major global mechanism for carbon offsets, the Clean Development Mechanism. Carbon offsetting schemes can be either regulated or voluntary. These schemes combined with technological measures related with reduction of own emissions facilitate the decarbonization in several organizations. Usually, an organization after reducing its own carbon emissions with the use of existing technologies may choose to offset any remaining emissions with an offsetting scheme that is often cheaper compared to other options. Fair pricing of carbon offsets is important for the transition to a decarbonized economy. The current price of carbon is very low at 3-5 $ per $tnCO_2$.

However, the price is foreseen to grow up to 20-50 \$/tnCO_2 by 2030 while prices are expected to continue increasing until 2050. Usually, the price of carbon offset is corelated with the quality of the offsetting project. Among several options for carbon offsetting the most environmentally friendly are related with nature-based solutions. These include forest protection and restoration as well as reforestation of degraded land. These nature-based options are the cheapest among others while they generate external social and environmental benefits that can not be ignored. It is foreseen that by 2030 voluntary carbon offsets will be supplied almost entirely by nature-based solutions [19].

5. Offsetting part of hospital's carbon emissions with reforestation of abandoned mines in the Prefecture of Chania, Crete

Several abandoned mines, that used to produce sand and gravel in the past, exist in Prefecture of Chania while others have interrupted their operation due to difficulties to comply with the legal requirements concerning environmental protection. The total land area of these mines that can be used for reforestation is estimated at around 100 ha while planting trees in the abandoned sites is going to have positive environmental impacts locally and globally. The main factors influencing land's reforestation include:

A) Quality of the soil. Acidic and rocky soils in steep sites have difficulties in reforestation. Poor quality soils can be enriched with organic matter like compost, containing biosolids rich in nutrients, that support tree's growth. It should be noted that there are large quantities of compost rich in biosolids available in the existing landfill in Chania that can be used for soil's enrichment in the reforested mines,

B) Selection of tree species. Local or endemic tree species that can grow easily at the site are preferred,

C) The ownership of the reforested land,

D) The cost of reforestation. It depends on site's specific characteristics and it usually varies at around 1,500-2,500 \$/ha, and

E) Regional variations since there are not universal approaches for reforestation of abandoned mines.

For estimating several parameters related with reforestation of abandoned mines in the Prefecture of Chania, Crete it has been assumed that the annual carbon sequestration, from mature trees in the reforested mines, is at 10 tnCO_2/ha [25] while the reforestation cost is at 2,500 \$/ha. The annual carbon sequestration, in the mine's area at 100 ha, is at 1,000 tnCO_2 while the initial cost of reforestation is at 250,000 \$. Taken into account that the overall annual carbon emissions due to energy use in the public hospital of Chania is at 7,904 tnCO_2 the carbon sequestration due to reforestation of the abovementioned abandoned mine's land corresponds at 12.65 % of the total annual carbon emissions in the hospital. The economic benefits from the carbon offsetting project are related with the value of the harvested timber, if any, and the resulted carbon credits.

6. Economic, social and environmental benefits

Reforestation of abandoned mines results in several benefits for the organization, the local society as well as the local and global environment including [25]:

a) Improvement of air-quality beyond CO_2 sequestration. The leaves of the trees can remove air pollutants like nitrogen oxides and sulfur dioxide,

b) Reforestation may create a wild life habitat in abandoned mines. The habitat can be useful to endangered and threatened species,

c) Creation of recreational opportunities like hunting and bird watching,

d) Stabilization of the soil with tree roots that reduce solid erosion and improve the water quality,

e) Phytoremediation removing any soil pollutants that might be present in the abandoned mines,

f) Timber harvesting related economic benefits due to the value of timber collected,

g) Non-timber harvesting related economic benefits due to collection of edible plants and tree's residues used for energy generation,

h) Obtaining governmental support for reforestation projects including capital subsidies and tax reliefs,

i) Carbon credits due to the fact that carbon offsetting might be cheaper than reducing their own carbon emissions, and

j) Solid and liquid waste recycling. Ash produced in coal and biomass combustion systems as well as processed liquid wastes from nearby located treatment plants can be recycled in the tree plantation.

7. Discussion

Organizations willing to reduce their carbon footprint have the option to offset part of their carbon emissions with various mechanisms. The conventional methods for the reduction of carbon footprint include measures related with energy saving and replacement of carbon emitting fuels with renewable energies. Carbon emissions reduction can be also achieved with various carbon offsetting schemes including reforestation of degraded lands that offers many environmental and social benefits. Our results indicate that the public hospital in Chania can offset part of its annual carbon emissions due to energy use with reforesting the land in abandoned mines in Prefecture of Chania. The findings are important since they indicate that zeroing the net carbon emissions due to energy use in the local hospital can be partly obtained with reforestation of local mine's land that has broader positive impacts. The area of the degraded land in the local abandoned mines that can be reforested has not been precisely evaluated neither the desired trees that can be planted and grow. The detailed cost of reforestation has not been also evaluated. The results could be useful in the local public hospital administration for future creation of a clean energy transition plan zeroing its net carbon emissions due to energy use in compliance with the global efforts for climate change mitigation.

8. Conclusions

The possibility of offsetting part of the annual carbon emissions due to energy use in the public hospital in Chania, Crete has been investigated. The specific annual energy consumption in hospitals worldwide vary in the range of 230 KWh/m^2 to 738.5 KWh/m^2 while their annual carbon emissions, due to energy use, vary in the range of 100 $kgCO_2/m^2$ to 224 $kgCO_2/m^2$. The annual energy consumption in the public hospital of Chania was estimated at 12,840 MWh/year while its annual carbon emissions, due to energy use, at 7,904 $tnCO_2$/year. Several sustainable energy technologies can be used to reduce the carbon emissions in the hospital. These include various the use of energy saving technologies, solar energy for heat and electricity generation, biomass for heat generation, ambient heat with heat pumps for air-conditioning, CHP systems for heat and electricity generation etc. Reforestation of degraded land in local abandoned mines in an area at 100 ha can sequestrate 1,000 tnCO_2/year that correspond at 12.65% of the total annual carbon emissions due to energy use in the hospital. Reforestation is a nature-friendly and attractive option for offsetting part of the carbon emissions in the hospital while it generates external environmental and social benefits. The results indicate that carbon emissions in the hospital of Chania can be partly offset with nature-based solutions generating local co-benefits. Further research should be focused on the precise evaluation of the local degraded land that can be used for reforestation, the total reforestation cost, the quantity of the harvested timber, the biomass productivity as well as the annual amount of the sequestrated carbon.

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