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Creation of Zero CO_2 Emission Plants Due to Energy Use: A Case Study in Crete, Greece

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Abstract

Creation of zero CO_2 emission enterprises due to energy use in Crete, Greece has been examined with reference to an orange juice producing plant (Viochym). Energy intensity at Viochym has been estimated at 1.66 KWh per € of annual sales. Oil used for heat generation has been replaced with solid biomass produced locally in Crete and resulting in zero CO_2 emissions due to the use of heat. Offsetting CO_2 emissions due to grid electricity use has been proposed with two options. The first includes the installation of a solar photovoltaic system with nominal power of 417 KWp, according to net metering regulations, generating annually 625 MWh equal to annual grid electricity consumption in the plant. Its capital cost has been estimated at 0.5 mil € which corresponds to 1.07 € per kg of CO_2 saved annually.The second option includes the creation of a tree plantation in an area of 107 hectare resulting in carbon sequestration equal to carbon emissions in the plant due to electricity use. Both options for offsetting CO_2 emissions in Viochym have various advantages and drawbacks and they are considered realistic and feasible, resulting in the elimination of its carbon emissions due to energy use. Improvement of the energy intensity of various processes in Viochym could result in lower CO_2 emissions and smaller sizing of the required renewable energy systems for eliminating them.

Keywords: CO_2 emissions, Crete, energy, forest, industry, solar electricity

1. Introduction

Climate change is one of the most important global environmental problems and its mitigation requires the decrease or elimination of anthropogenic carbon emissions in the atmosphere. Global energy mix must change soon, promoting the use of non-carbon fuels and reducing the share of fossil fuels in it. Industries consume large amounts of energy and contribute significantly in total anthropogenic CO_2 emissions. European Union (E.U.) regulations currently promote the creation of new buildings or the refurbishment of old ones in order to have nearly zero energy consumption and low carbon emissions. However the promotion of nearly zero energy consumption and/or nearly zero CO_2 emissions enterprises is not included in the current legislative framework and regulations in many EU countries.

1.1 Energy Use and CO_2 Emissions in Industry

Industrial energy use and CO_2 emissions in the United States (US) have been reported (Wise et al, 2007). The authors used appropriate models to predict fuel choices and energy technology use on a long term under policy constraints. Their results indicated that electrification is an important response to climate policy. Additionally the switch to low carbon fuels is important as well as the use of co-generation systems fed with biomass. Energy use and CO_2 emissions in Indonesian small- and medium-size enterprises have been reported (Priambodo and Kumar, 2001). The authors have analyzed many factories in various sectors estimating their energy intensity and their CO_2 emissions due to energy use. They found that the sectors of chemical industries, and food and beverages have the highest energy intensity compared with other sectors. Measuring industrial energy intensity (energy input/industrial output) has been proposed (Freeman et al, 1997). The authors have found discrepancies between value and volume indicators of energy intensity. They indicated that the large number of goods produced in the manufacturing industries make the use of volume-measured energy intensity almost impossible. Energy demand and energy-related CO_2 emissions in Greek manufacturing have been reported (Floros and Vlachos, 2005). The authors found that in the food and beverages sector, electricity consumption corresponds at 55.19 % of the total energy use and at 47.50 % of total CO_2 emissions due to energy use. A review of technologies for CO_2 emissions reduction from heavy industries has been presented (Brown et al, 2012). The authors proposed four key actions: a) Replacement of old inefficient processes with current best available technologies,

b) Replacement of fossil fuels with low carbon energy sources, c) Acceleration of research into industrial CO_2 capture, and d) Facilitation and promotion of reuse and replacement of matter and energy in order to close their loops. An investigation on energy conservation in small enterprises located in the region of Epirus, Greece has been implemented (Markis and Paravantis, 2007). Analyzing the results from energy audits in 12 SMEs, the authors found that the annual energy intensity varied from 50 KWh/m^2 up to 1500 KWh/m^2. Research regarding changes in energy efficiency in the Dutch industry has been implemented (Ramirez et al, 2006). The authors stated that data analysis indicated improvements in their energy efficiency by 1 % annually. This increase is coherent with the implementation of energy conservation projects. A report on reducing industrial energy use and CO_2 emissions has been published (Gielen et al, 2008). The authors stated that nearly one third of the world's energy consumption and 36 % of CO_2 emissions are attributable to manufacturing industries. They also stated that energy efficiency could be improved by 18-26 % if the best available technologies were used. Further improvements could be obtained with better use of materials and less energy-intensive processes. A report on specific energy consumption in the meat industry in four European countries (Ramirez et al, 2006) showed that during the last decade there has been a large increase in energy consumption per ton of meat produced. A large share of the increase is attributed to higher energy consumption due to strong hygiene regulations. A report on industrial symbiosis contributing to more sustainable energy use with reference to the forest industry in Finland has been published (Sokka et al, 2011). The authors stated that industrial symbiosis with recycling of matter and energy results in more sustainable fuel consumption and reduced greenhouse gas emissions. A report on tracking industrial energy efficiency and CO_2 emissions has been published (International Energy Agency, 2007**)**. According to this study the overall industrial energy use has been growing strongly. The largest share of the growth has been observed in emerging economies while energy efficiency has improved substantially in all the energy-intensive manufacturing industries.

1.2 Nearly Zero CO_2 Emission Plants

A report on the requirements for climate stabilization has been presented (Matthews and Caldeira, 2008). The authors stated that climate stabilization requires not only the decrease of current CO_2 emissions but their entire elimination. Therefore the policies for climate stabilization should be focused on zeroing CO_2 emissions rather than partially reducing them. A report on energy generation from sugarcane bagasse in Brazil has been presented (Dantas et al, 2013). The authors investigated two different alternative uses of bagasse produced from sugarcane in Brazil. The first concerned its use for electricity generation and the second its biochemical processing for increasing bio-ethanol production. According to their estimations, electricity generation from bagasse provides more benefits from the perspective of an investor. A report on co-generation in cane sugar factories has been published (Odgen et al, 1990). The authors stated that most cane sugar factories have been designed to be energy self-sufficient using a bagasse-fired co-generation system providing all the required heat and electricity in the plant, leaving little surplus bagasse. A report on the possibility of creating zero CO_2 emission olive pomace plants due to energy use in Crete, Greece has been presented (Vourdoubas, 2016). The author stated that heat requirements in those plants have a share of more than 95 % in the total energy needs. Heat is provided with the consumption of olive kernel wood produced in the factory. Grid electricity consumption could be offset with solar photovoltaic (solar-PV) electricity according to the existing net-metering regulations. The path to a low carbon economy in Masdar city, United Arab Emirates has been investigated (Nader, 2009). The author stated that the Masdar initiative is trying to promote and scale up renewable energy and other sustainable energy technologies. Masdar city is planned to become a carbon-neutral city and will probably be a leader in the future regarding sustainability and low-carbon economy. A study for the creation of zero CO_2 enterprises in Crete due to energy use has been presented (Vourdoubas, 2017). Analyzing data concerning heat and electricity consumption in five SMEs in Crete, Greece, the author proposed the replacement of fossil fuels with locally available renewable energies for covering all their energy requirements. The author indicated that with the use of locally produced olive kernel wood and solar electricity, all energy needs could be covered, thereby eliminating the use of fossil fuels and the emission of greenhouse gases.

1.3 Use of Solar Electricity in Industry

An investigation on the development and commercialization of solar-PV technology in the oil industry has been implemented (Pinkse and Van Den Buuse, 2012). Analyzing data from the three largest oil and gas firms in Europe the authors concluded that there is a trend for leaving solar energy, probably due to the fact that they may not be profitable. A report on the feasibility of adopting solar-PV technology in a poultry firm in the US has been published (Bazen and Brown, 2009). The authors stated that solar-PV investments in poultry firms could be profitable, at current PV prices, given that all state incentives would be obtained. A review on solar energy use in industries has been published (Mekhilef et al, 2011). The authors stated that solar electricity is applied in telecommunications, agriculture, water desalination and the building industry to operate lights, pumps, engines, fans, refrigerators and water heaters. A report on the development of the solar-PV market in Greece with the support of net metering regulations has been presented (Tselepis, 2015). The author stated that the installation of a commercial solar-PV plant of 20 KWp could be profitable with current prices from an investor's perspective.

1.4 Offsetting Industrial CO_2 Emissions With the Growth of Tree Plantations

An investigation on the impacts of urban forests for offsetting carbon emissions from industrial energy use in China has been implemented (Zhao et al, 2010). The authors estimated that carbon storage in Hangzhou, China was 30.25 tones carbon (tC) per hectare (ha)and annual carbon sequestration was 1.66 tC per ha. A report on carbon storage and sequestration by urban trees in the US has been published (Nowak and Crane, 2002). The authors stated that the national average urban forest carbon storage density was 25.1 tC per ha compared with 53.5 tC per ha in typical forests. It was also estimated that the annual carbon sequestration was 0.8 tC per ha. A report on carbon storage and accumulation in US forest ecosystems has been presented (Birdsey, 1992). The author estimated that the average forest in the US contains 17.7 kg/m^2 of organic carbon above and below the ground.

Current European policies target in the creation of nearly zero energy buildings which have very low carbon emissions. However industries, apart from buildings, consume large amounts of energy and contribute significantly in the overall carbon emissions. Creation of low energy or nearly zero carbon emission enterprises will result in the mitigation of climate change and will increase the overall sustainability. The objectives of the current work are: a) Estimation of energy consumption and energy intensity in an orange juice producing and bottling plant in Crete, Greece; b) Investigation for offsetting its grid electricity consumption with solar-PV electricity according to the net metering principle; c) Investigation for offsetting its CO_2 emissions due to electricity use with the creation of tree plantations which result in carbon sequestration; and d) Assessing the technical and economic feasibility of both options in order to achieve a zero CO_2emissions plant due to energy use.

The methodology used included the following steps :

- *Estimation of the annual electricity and fuel consumption in Viochym*
- *Estimation of the CO_2 emissions in the plant*
- *Estimation of the required power of a solar-PV system located in Crete which could annually generate the same amount of electricity that is consumed in the plant*
- *Estimation of the required area of a tree plantation in Crete which could sequestrate the same amount of CO_2 that is emitted in the plant. Data from existing literature were used for that.*

2. Energy Consumption and Energy Intensity in a Small Orange Juice Producing and Bottling Company in Crete, Greece

Viochym societe anonymous (S.A). is a small orange juice producing and bottling company located in Crete, Greece. Its annual heat consumption is 2320 MWh, its electricity consumption is 625 MWh while its total energy consumption is 2945 MWh. The ratio of electricity to heat was 0.27. Viochym has recently changed its heating fuel, using solid biomass instead of heating oil. With the installation of a heat boiler utilizing olive kernel wood, a locally produced renewable fuel, it covers all its heating needs with a benign fuel. The replacement of the boiler was profitable due to the current prices of heating oil and olive kernel wood in Crete. Assuming that the use of biomass does not contribute to greenhouse gas emissions, CO_2 emissions due to electricity use in the plant have been estimated at 496 tons per year. The value of total sales of the plant during 2014 were 1 775 307 € [balance sheet of Viochym, year 2014]. The total energy intensity per value of annual sales has been estimated at 1.66 KWh/€. Electricity intensity was 0.35 KWh/€ and its heat intensity was 1.31 KWh/€. CO_2 emissions due to energy use per value were 0.28 $kgCO_2$/€. Energy consumption, CO_2 emissions and energy intensity in Viochym are presented in Table 1.

Table 1. Energy consumption, CO_2 emissions and energy intensity in Viochym

Total energy consumption	2945 MWh/year
Electricity consumption	625 MWh/year
Heat consumption	2320 MWh/year
Share of electricity to total energy	21.22 %
CO_2 emissions due to electricity consumption	469 ton/year
CO_2 emissions due to heat consumption (fuel used was solid biomass)	0 ton/year
Total CO_2 emissions	469 ton/year
Annual sales (in 2014)	1 775 307 €
Total energy intensity per value	1.66 KWh/€
Electricity intensity per value	0.35 KWh/€
Heat intensity per value	1.31 KWh/€
Total CO_2 emissions per value	0.28 kg CO_2/€

3. Requirements for Zero CO_2 Emissions Due to Energy Use in Viochym

Viochym utilizes energy in the form of heat and electricity in various processes. It also uses energy for the transport of raw materials and final products. In order to zero its CO_2 emissions due to heat and electricity use, the following two requirements must be fulfilled:

a) Fossil fuels used for heating must be replaced with renewable energies, and

b) CO_2 emissions due to grid electricity use must be offset either with solar-PV electricity generated on or off the plant and fed into the grid, or with the creation of tree plantations which absorb atmospheric CO_2 through photosynthesis. Annual CO_2 sequestration in the tree plantation must be equal to annual CO_2 emissions due to grid electricity use in the plant.

Both options are allowed since the installation of solar-PV modules is permitted in order to offset the grid electricity consumption annually (according to the national net-metering regulations). Creation of tree plantations is also allowed and afforestation could take place in a remote area, not necessarily near the plant. Offset of CO_2 emissions due to fossil fuels use for transport in Viochym is not considered in the current analysis. It is also assumed that all the grid electricity in Crete, Greece is generated with fossil fuels. However the island of Crete has an isolated electric grid which is not interconnected with the continental grid; currently 14-18 % of the electricity is annually generated from renewable energies, mainly solar and wind energy. The possibilities of zeroing CO_2 emissions due to energy use in Viochym are presented in Table 2.

Table 2. Possibilities of zeroing CO_2 emissions due to energy use in Viochym

CO_2 emissions due to heat consumption	Replacement of heating oil with olive kernel wood
CO_2 emissions due to grid electricity consumption	Installation of a solar-PV system generating the same amount of grid electricity consumed annually in the plant OR Creation of a tree plantation. Annual CO_2 sequestration must be equal to annual CO_2 emissions due to grid electricity use in the plant

4. Grid Electricity Offset With Generation of Solar-PV Electricity in the Plant

Grid electricity consumption in the plant could be offset annually with the equal generation and injection of solar electricity into the grid. The solar-PV system could be installed either on-site or off-site to the plant, according to the current net-metering regulations in Greece. The high solar irradiance in the island increases the economic attractiveness, additionally to the environmental benefits, of the system. Offsetting grid electricity consumption, generated by fossil fuels with green solar electricity, eliminates the net CO_2 emissions due to electricity consumption in Viochym. The sizing and the cost of the required photovoltaic system is presented in Table 3.

Table 3. Sizing of the solar-PV system generating the required electricity in Viochym

Electricity generation	625 MWh/year
Nominal power of the PV system [1]	417 KWp
Capital cost of the PV system [2]	0.5 mil €
Ratio of capital cost of the PV system to the annual sales of the plant in 2014	28.16 %
CO_2 emission savings due to green electricity generation [3]	469 ton/year
PV Investment cost per CO_2 savings	1.07 € per kg CO_2 saved annually

[1] Annual electricity generation from PVs in Crete, Greece = 1500 KWh per KWp

[2] Capital cost of the solar-PV system in Crete = 1200 € per KWp

[3] CO_2 emissions coefficient for electricity generation in Crete = 0.75 kgCO_2/KWh

5. Grid Electricity Offset With the Creation of Tree Plantations

Apart from using renewable energy sources for offsetting carbon emissions due to grid electricity consumption in Viochym, the creation of tree plantations could also contribute to atmospheric carbon sequestration since biomass growth absorbs CO_2 through photosynthesis. Various trees could be planted in an area nearby the factory due to limited space in it. Fast-growing tree species with high biomass productivity should be selected, resulting in high carbon sequestration. Taking into account the annual carbon emissions due to electricity use in Viochym and the annual carbon sequestration per unit area of the tree plantation, the required area for offsetting carbon emissions can be calculated. For the following estimations, the average value reported in the literature cited (Zhao et al, 2010; Nowak and Crane, 2002) has been used, which was 1.2 tC per hectare (4.4 t CO_2 per hectare). Tree species which are indigenous in the local ecosystems in Crete should be preferred. The creation of the tree plantation would result, apart from carbon sequestration, in many environmental benefits including increase of soil fertility, improvement of local ecosystems, mitigation of land desertification, and better rainwater drainage. It should be noted that land desertification is an important environmental problem in Crete and the creation of the tree plantation will contribute in its mitigation. Additional economic benefits could also be achieved in the case where tree products will be collected and commercialized. The required area of the tree plantation is presented in Table 4.

Table 4. Required area of a tree plantation which could offset carbon emissions due to electricity use in Viochym

Annual CO_2 emissions due to grid electricity use in Viochym	469 ton CO_2
Annual CO_2 sequestration due to tree plantation[1]	4.4 ton CO_2 per ha
Required area of the tree plantation for offsetting carbon emissions	107 ha
[1]Zhao et al, 2010; (Nowak and Crane, 2002).	

6. Assessment of Alternative Options for Zeroing CO_2 Emissions Due to Electricity Use in Viochym

Two alternative options for zeroing CO_2 emissions due to electricity use in Viochym have been described. The first one includes annual generation of green solar electricity equal to grid electricity consumed in the plant. The second includes the creation of a tree plantation which contributes to annual sequestration of the same amount of CO_2 which is emitted from the plant. Both options are feasible in Crete, Greece without presenting difficulties in their implementation. A multi-criteria comparison of them is presented in Table 5, assessing various technical, economic, environmental and social factors.

Table 5. Comparison of two options for zeroing CO_2 emissions due to electricity use in Viochym

	Solar-PV system	Tree plantation
Technical feasibility	Easy	Easy
Social acceptance	Yes	Yes
Required land area	Small	Large
Additional environmental Benefits ?	No	Yes
Investment cost	Relatively high	Relatively high
Are there state subsidies for the required investments?	Yes, through EU Structural funds	Yes, through EU Structural funds
Maintenance cost	Low	Low
Does the legal framework allows the implementation?	Yes	Yes
Any difficulties foreseen ?	No	Yes, finding the required land

7. Discussion

Industries consume large amounts of energy and contribute significantly in anthropogenic carbon emissions. Although the creation of nearly zero energy buildings has been legally promoted in E.U., creation of low energy or nearly zero carbon emission industries has not been promoted so far with appropriate directives. Creation of nearly zero carbon emission industries can be achieved with the combination of the following measures:

a) Reduction of energy consumption using energy efficient technologies,

b) Replacing fossil fuels use with renewable energies,

c) Offsetting grid electricity use with electricity generated by renewable energies, and

d) Offsetting CO_2 emissions with carbon sequestration activities including creation of tree plantations

In the current work the possibility of reduction of energy consumption in the plant has not been taken into account. However the replacement of old inefficient processes with new more efficient could reduce the size of renewable energy systems required to achieve zero carbon emissions in the plant. Zero CO_2 emission plants have been reported in Brazil concerning sugar cane plants and in Crete concerning proposals for olive pomace plants. Both of them utilize mainly solid biomass for covering their energy needs. Improvement of energy efficiency in Viochym could reduce the size of the solar-PV system as well as the area of the tree plantation required for offsetting its carbon emissions. Increasing the energy efficiency in the plant and offsetting its carbon emissions, with both options, could be subsidized by current EU structural funds. In the abovementioned estimations it has been assumed that all the grid electricity in Crete is generated by fossil fuels which is not true since part of it is generated by renewable energies. Subsequently the required size of the solar-PV system and the area of the tree plantation are overdesigned.

8. Conclusions

Zeroing CO_2 emissions due to energy use in the Viochym plant in Crete, Greece is technically and economically feasible. Heating oil used in previous years for heat generation has been replaced with olive kernel wood, resulting in significant CO_2 emissions and cost savings. Since the share of heat in the total energy consumption is high, significant elimination of total CO_2 emissions is already obtained with the use of solid biomass, instead of fossil fuels, for heat generation. Two options have been examined in order to zero carbon emissions due to grid electricity use including the use of solar-PV energy and the growth of tree plantations. Both of them could be used as they have various advantages. They are socially accepted but perhaps finding the required land for the creation of a tree plantation might be difficult. The abundance of solar irradiance in Crete increases the attractiveness of the solar-PV system and the existing legal framework allows its implementation. It is estimated that the pay-back period of the investment is 8-10 years. Current land desertification in Crete increases the attractiveness of the creation of tree plantations which, apart from offsetting carbon emissions, will result in many additional environmental benefits. The ratio of electricity to heat consumption in Viochym is 21.22 %, lower than the average value reported in Greece which is 55.19 % for food and beverage industries. Current work indicates that the creation of zero CO_2 emission enterprises due to energy use could be a realistic and feasible option in many cases. It contributes towards the global effort for minimizing or eliminating anthropogenic CO_2 emissions in industry. Therefore it should be promoted with appropriate regulations and directives in E.U. like nearly zero energy buildings which are currently promoted. Further work should be focused on reducing energy consumption in Viochym, increasing the energy efficiency of various processes and reducing the overall energy use. Additional investigation of zeroing CO_2 emissions due to transport of raw materials to the plant and the final products to the consumers is also required.

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