International Journal of Multidisciplinary Research and Development
Online ISSN: 2349-4182, Print ISSN: 2349-5979, Impact Factor: RJIF 5.72
www.allsubjectjournal.com
Volume 4; Issue 4; April 2017; Page No. 82-86

Possibilities of creating zero CO_2 emissions industrial plants due to energy use in Crete, Greece

John Vourdoubas

Department of Natural Resources and Environmental Engineering, Technological Educational Institute of Crete, 3 Romanou str., Chania, Crete, Greece

Abstract

Although the reduction of CO_2 emissions due to energy use in industries is of paramount importance, there are not many successful examples of zero CO_2 emissions industries so far. The possibility of creating zero CO_2 emissions industries due to heat and electricity use in Crete, Greece has been investigated. Energy consumption and CO_2 emissions in five small-size industries have been estimated. It has been indicated that the use of locally available renewable energy sources like solar energy and solid biomass could cover all the heat and electricity needs in those five industries zeroing their CO_2 emissions. Solar-PV energy with the net-metering initiative could be used in order to offset annually the grid electricity use. Olive kernel wood is a low-cost renewable fuel which already is widely used in Crete for heat generation. Its use could replace the use of oil for industrial heating. The solar-PV investment in those plants is economically viable due to the current low cost of these energy systems. Therefore the use of renewable energy technologies in those industries could cover all their heating and power needs, zeroing their carbon emissions. The results indicate that the use of various locally available and cost-effective renewable energies could also zero carbon emissions in other industries without requiring public financial support.

Keywords: crete, CO_2 emissions, energy use, electricity, heat, industrial plants

1. Introduction

Reduction of energy consumption and CO_2 emissions in the manufacturing sector has been studied extensively. Energy conservation in small enterprises in Northern Greece has been reported [1]. The authors have implemented preliminary audits in twelve representative small business enterprises and they found that the energy intensity varies from 50 to just over 300 KWh/m^2 with some heavier industry buildings having values up to 1,300 KWh/m^2. They reported that the main energy consumption in business enterprises is related with processing. They also found that the majority of the enterprises failed to adopt energy conservation measures and that the companies did not use any renewable energy sources. A report on energy use and specific energy consumption in the meat industry in four European countries has been published [2]. The authors found that natural gas was the main fuel used in the Netherlands, Germany and United Kingdom, with electricity in France. They also found that there has been a trend in all countries towards higher electricity use due to higher demand for refrigeration and motor drive power. The authors did not report on the use of renewable energies in the meat industry in those countries. A report on the energy efficiency in the Dutch food industry has been presented [3]. The authors found that food and tobacco industries have increased their energy efficiency by about 1% per year. They also reported that the main fuels used in this industrial sector are electricity and fossil fuels including natural gas. The use of renewable energies has not been reported. The impacts of urban forests on offsetting carbon emissions from industrial energy use in Hangzhou, China have been reported [4]. The authors quantified carbon storage by urban forests, offsetting carbon emissions from energy consumption by several industrial sources in Hangzhou in China. Carbon storage per hectare has been estimated at 30.25 ton C. They reported that Carbon storage in urban forests is lower than carbon storage in natural forests in China. They concluded that urban forests should be conserved and promoted in order to offset carbon emissions from energy use. Industrial symbiosis contributing to more sustainable energy use in Finland has been reported [5]. The authors studied energy use and greenhouse gas emissions in an industrial park based on pulp and paper manufacturing, comparing it with a stand-alone system. They concluded that stand-alone systems had higher carbon emissions than the industrial park. The possibility of creating zero CO_2 emissions olive pomace plants due to energy use in Crete, Greece has been reported [6]. The author reported that 99.1% of the energy use in the plant is provided by olive kernel wood, a local biomass resource, and the rest from electricity. Grid electricity consumption could be offset by solar-PV electricity which could be generated on-site. A review on solar energy use in industries has been published [7]. The authors studied the use of solar energy for heat and power generation in various industries. They presented various applications of solar thermal energy and solar photovoltaic energy in many industrial sectors, stating that solar electricity is widely used in the telecommunications, agricultural, water desalination and building industry. Tracking of CO_2 emissions in various manufacturing industries has been reported [8]. According to them, 36% of global CO_2 emissions are attributable to manufacturing industries but there are substantial opportunities to improve energy efficiency and to reduce CO_2 emissions in those industries. They proposed that some current and well proven energy technologies allow the decrease in the use of fossil fuels. Among them are co-generation of heat and power, waste heat reuse and solid biomass use. Stabilization of climate through near zero CO_2 emissions using an earth system model has been reported [9]. The results indicated that world climate stabilization requires near zero future CO_2

emissions. This necessitates the creation of innovative energy policies in order to achieve this target. The reduction of CO_2 emissions in heavy industries has been presented [10]. The authors proposed four key actions in order to significantly reduce industrial CO_2 emissions, which are:

a) Maximization of energy efficiency by replacing older, inefficient processes with current best available technologies,
b) Switching to low carbon fuels including renewable energies,
c) Acceleration of research into industrial CO_2 capture, and
d) Alteration of product design to facilitate reuse and recycling.

The development of solar-PV technology in the oil industry has been presented [11]. The findings of the authors showed that oil and gas companies have not integrated solar energy in their supply chain. The competitive advantage of these companies, according to the authors, is outside of renewable energies. The paths to low-carbon economy with reference to the Masdar example has been reported [12]. The author stated that Masdar city, in the United Arab Emirates, with approx. 90,000 inhabitants and many enterprises operating in its territory, is planning to become carbon neutral. The required technologies for obtaining this goal, including renewable energies and carbon capture technologies, are going to be developed and used in the city, offering long-term economic and technological benefits. Long-term US industrial energy use and CO_2 emissions have been reported [13]. The authors stated that the specific technologies that produce the basic industrial energy services such as heat and machine drive are already highly efficient. Current efficiencies to produce heat or steam from burning natural gas exceed 80% and the efficiencies of electric motors exceed 90%. They indicated that reduction of CO_2 emissions could be achieved with the re-design of various processes, with higher electrification of them and with the increased use of renewable energies and low carbon technologies like CHP. Additionally in the pulp and paper industry, the wood industry and the food industry, it could be achieved with the increased use of waste biomass. Energy demand and energy-related CO_2 emissions in Greek manufacturing with an assessment of a carbon tax has been reported [14]. The authors investigated the demand of energy in various manufacturing sectors in Greece and the impact of a carbon tax on energy-related CO_2 emissions. They concluded that a carbon tax of 50$ per ton of carbon results is a considerable reduction in direct and indirect CO_2 emissions from their 1998 level. However such a carbon tax is environmentally effective although costly. Energy production from sugarcane bagasse in Brazil has been reported [15]. The authors stated that bagasse from sugarcane is traditionally used in the Brazilian sugar and ethanol industry to meet the energy needs of its own production processes and, more recently, to generate surplus electricity for sale on the national grid. The sugar industry, according to the authors, faces a dilemma: either to enhance electricity generation from bagasse or to use it in order to produce more ethanol through biochemical processes. A report on co-generation of heat and power in sugarcane factories has been published [16]. These factories utilize bagasse-fired co-generation systems in order to generate all the steam and electricity needed in the factory, leaving little surplus bagasse. Due to the fact that bagasse is a "free" fuel, there are no incentives in these factories to optimize the use of bagasse. The authors concluded that these plants should improve their energy efficiency with better utilization of bagasse. The PV market developments in Greece with net-metering have been reported [17]. The author presented the state of the PV market in Greece, stating that net-metering was firstly introduced at the end of 2014 and it was operational by May 2015. The reduction of industrial energy use and CO_2 emissions has been presented [18]. The authors focused on the development of new materials and new manufacturing processes which could decrease the energy use and the CO_2 emissions in manufacturing industries. The creation of zero CO_2 residential buildings in Crete, Greece has been presented [19]. The author indicated that various reliable and cost-effective renewable energies which are locally available could cover all the energy needs in residential buildings, resulting in zeroing their CO_2 emissions. The same author [20] has reported on the creation of zero CO_2 emissions hotels in Crete, Greece. An increase in the sustainability of the hospitality industry could be achieved, according to the author, with the use of various renewable energy sources including solar energy, solid biomass and low enthalpy geothermal energy.

The purpose of this study was:

a) To estimate the heat and electricity consumption and the CO_2 emissions as well as the fuels used in various small-size industries in the food and juice sectors located in Western Crete, Greece, and
b) To investigate the possibility of using locally available renewable energy sources including solar-PV energy and solid biomass for covering all the energy needs and zeroing the CO_2 emissions due to energy use.

In order to achieve that, the energy consumption and the CO_2 emissions in five small-size industries were estimated and the possibility of using solar-PV energy for power generation and locally produced olive kernel wood for heat generation were examined. The economic and environmental considerations in the case of replacing fossil fuels used with renewable energies in those plants have also been examined.

2. Energy consumption and CO_2 emissions in industrial plants in Crete, Greece.

Energy consumption and CO_2 emissions have been estimated during 2015 in five (5) small-size industries located in Western Crete. All of them produce food and drinks and include:

1. A cereal mill (Cretan Mills)
2. An olive pomace plant (ABEA)
3. An olive oil production and bottling plant (Terra Creta)
4. A natural water bottling plant (Etanap), and
5. An orange juice production and bottling plant (Viochym)

These manufacturing enterprises are using electricity and heat in various processes. They use grid electricity for the operation of various equipment and either oil or solid biomass (burning olive kernel wood) for heat generation. Four of them have replaced oil with olive kernel wood in the previous years due to cost reasons. Olive kernel wood is produced from olive pomace plants and it is a cheap renewable fuel with satisfactory heat content. Its heating value is approx. 4,500 Kcal/kg and its cost approx. 0.1 €/kg. Therefore it is considerably cheaper than fuel or heating oil. Heat and electricity consumption and CO_2 emissions in the five plants are presented in Table 1. The ratio of electricity to heat consumption in the five plants studied varies widely as well as their CO_2 emissions due to energy use. Two out of five plants studied were using more heating energy than electricity. Grid electricity is generated in Crete mainly from fuel and heating oil. Additionally both solar-PV and wind energy contribute approximately 20% in the annual electricity generation in Crete. This percentage could be higher if the grid in Crete was interconnected with the continental grid.

Table 1: Energy consumption and CO_2 emissions in five industrial plants in Western Crete

	Cretan Mills	**Etanap**	**Viochym**	**ABEA**	**Terra Creta**
Annual energy Consumption (MWh/year)	9,820	2,395	2,945	25,778	297
Electricity consumption (MWh/year)	7,500	2,350	625	232	241
Heat consumption (MWh/year)	2,320	45	2,320	25,546	56
Ratio of electricity to heat	3.23	52.22	0.27	0.01	4.3
Heating fuel	biomass	oil	biomass	biomass	biomass
Necessary quantity of solid biomass for covering all the heating needs (tn/year)	700	13.7	700	5,133	17
CO_2 emissions due to electricity consumption (tn/year) [1*]	5,625	1,762	469	174	181
CO_2 emissions due to heat consumption (tn/year) [2*]	0	113	0	0	0
Total CO_2 emissions (tn/year)	5,625	1,775	469	174	181
Total CO_2 emissions per unit energy consumed (Kg CO_2/KWh)	0.57	0.74	0.16	0.007	0.6

[1*] CO_2 emissions coefficient for electricity = 0.75 kgCO_2/KWh
[2*] CO_2 emissions coefficient for oil = 3.2 kgCO_2 per kg of oil

Total CO_2 emissions due to energy use vary between 0.007 Kg CO_2/KWh to 0.74 Kg CO_2/KWh depending on the ratio of electricity to heat consumed. Higher ratios of electricity to heat result in higher total CO_2 emissions.

Additional CO_2 emissions are produced in these plants due to vehicles used for transport and distribution of the good produced. These vehicles consume fossil fuels and their CO_2 emissions have not been estimated in the present calculations. Solid biomass use is considered to have zero CO_2 emissions since carbon capture by photosynthesis offsets the emissions produced during biomass burning. However energy is consumed and CO_2 emissions are produced during harvesting, processing and transporting the solid biomass to its utilization site. These biomass emissions have been neglected in the abovementioned analysis.

3. Requirements for zeroing CO_2 emissions in industrial plants due to electricity and heat used.

Industries could reduce or zero their CO_2 emissions due to energy use during their operation with various ways including:

a) Reduction of energy consumption using more efficient equipment and processes,
b) Replacing fossil fuels used with renewable energies which are cost-effective. Fossil fuels are used mainly for heat production in the factories and for transporting the goods produced in the market, and
c) Offsetting the grid electricity used with solar-PV electricity. This must be permitted from the existing legal framework.

The possibility of financing the necessary investments in renewable energy technologies either with own funds or bank loans or financial incentives by the state will facilitate the achievement of this goal.

In the case that there is high availability of renewable energies near the plant location, replacement of the fossil fuels used could result in the decrease or zeroing of the carbon footprint due to the operation of the plant. The availability of solar energy in Crete is high and solar-PV electricity is a reliable, mature and cost-effective technology. Therefore solar-PV electricity could offset the grid electricity consumed during the operation of the above-mentioned plants. Olive kernel wood is a by-product of the olive oil producing industry and its current production in Crete is approx. 110,000 ton/year. Its price is relatively low compared with fuel or heating oil and it is broadly used for heating purposes in buildings, greenhouses and industry. Therefore the combined use of solar-PV energy and solid biomass in the abovementioned small-size industries in Crete could result in zeroing their carbon footprint. The necessary technologies are currently mature, reliable and cost-effective. Since the end of 2014 it is allowed in Greece to use net-metering for offsetting on an annual base the grid electricity used with solar-PV electricity.

In order to zero CO_2 emissions due to electricity and heat used in the plants, the following two conditions must be fulfilled:

a) Fossil fuels must not be used in the plants and they must be replaced by renewable fuels, and
b) All the grid electricity consumed must be offset annually from solar-PV electricity.

In that case that the plant could zero its CO_2 emissions due to the electricity and heat used.

4. Design of the required renewable energy systems for offsetting the grid electricity used in the plants.

Zeroing of CO_2 emissions in the above-mentioned small-size industries in Crete could be obtained with a reduction of their energy consumption and the replacement of fossil fuels used with renewable energies, as has been described previously. Assuming that the industries are using the best available technologies to improve their energy efficiency, they must also utilize appropriate renewable energy technologies for covering all their energy needs. The necessary quantities of olive kernel wood to cover all their heating needs has been presented in Table 1. The nominal power of the solar-PV system for offsetting annually the grid electricity used in these small-size industries is presented in Table 2.

Table 2: Sizing of the solar-PV systems generating all the required electricity in the plants.

	Cretan Mills	Etanap	Viochym	ABEA	Terra Creta
Required electricity annually (MWh)	7,500	2,350	625	232	241
Nominal power of the PV plant (KWp) [1*]	5,000	1,567	417	155	161

[1*] Annual electricity generation from PVs in Crete = 1,500 KWh per KWp

The capital cost of the required solar-PV systems in order to offset all the grid electricity used in the small-size industries in Crete is presented in Table 3. The annual cost of olive kernel wood required to generate all the heat needed in the plants is also presented in the same table.

Table 3: Capital cost of the required solar-PV systems and annual cost of the required olive kernel wood for zeroing CO_2 emissions in small-size industries in Crete.

	Cretan Mills	Etanap	Viochym	ABEA	Terra Creta
Capital cost of the PV System (€) [1*]	6 mil.	1.88 mil.	0.5 mil.	0.186 mil.	0.193mil.
Cost of the required olive kernel wood (€/year) [2*]	70,000	1,370	70,000	513,300	1,700
Annual savings in electricity (€/year)	1.5 mil.	0.47 mil.	0.125 mil.	0.046 mil.	0.048mil.

[1*] Capital cost of PV systems = 1,200 € per KWp
[2*] Cost of olive kernel wood in Crete = 0.1 €/kg

The capital cost of the PV systems varies from 0.186 mil€ up to 6 mil€, depending on the plant. However the annual savings due to electricity bills are high and the investment in the solar-PV systems is attractive. The annual cost of the required olive kernel wood is relatively low and since it is a cheaper renewable fuel than fuel oil, the fuel shift is also attractive in those small-size industries. This is why Cretan mills, Terra Creta and Viochym have already replaced the previously used fuel oil with olive kernel wood by installing wood boilers. The required size of the PV systems is high as well as the required surface for installing them. Practically they should be installed off-site on appropriate land.

5. Conclusions

Electricity and heat consumption and CO_2 emissions in five small-size industries in the food sector located in Crete, Greece have been estimated. The plants are using grid electricity for the operation of various electric devices and oil or solid biomass for heat production. Four of them are using olive kernel wood as heating fuel since its price is low compared with oil. The use of solid biomass instead of fossil fuels for heat generation results in decreasing their CO_2 emissions. Few industries have been reported so far which are not using external energy sources for covering all their energy needs. The sugarcane industry is one of them, using bagasse for heat and power generation, covering all its energy needs and selling the surplus to the grid. Higher electrification in manufacturing industries combined with the use of either renewable energies or low carbon technologies have been indicated as appropriate measures for decreasing their carbon footprint. The use of solar-PV electricity for off-setting grid electricity consumption is currently allowed in Greece with the net-metering initiative. Therefore the above-mentioned industries could install PV systems, either on-site or off-site, generating the annually consumed grid electricity during their operation. The current cost of photovoltaic systems is low and the investment could be profitable. The combination of solar-PV energy use for electricity generation and solid biomass use for heat production could result in zeroing the CO_2 emissions due to energy use in the above-mentioned industries. Solar irradiance is high in Crete, Greece as well as the availability of olive kernel wood which already is used as fuel for heating purposes. Unfortunately there are not many solar-PV applications for power generation reported so far in food processing industries, probably due to the fact that only recently solar-PV technology became cost-effective. Current studies indicate that there are various renewable energy technologies which are mature, reliable and cost-effective and they could be used in small-size industries for zeroing their carbon footprint due to energy use. Since the required capital investments are financially attractive, they could be implemented without public financial incentives. Carbon emissions due to vehicle use in these industries should be estimated and the ways for reducing or eliminating those emissions should also be indicated. A detailed cost analysis is further needed in order to prove the profitability of the above-mentioned sustainable energy technologies in other industries apart from the food sector. Future research should also investigate the possibility of using surplus olive kernel wood in olive pomace plants for co-generation of heat and power in order to offset their grid electricity consumption.

6. References

1. Markis T, Paravantis JA. Energy conservation in small enterprises. Energy and Buildings. 2007; 39:404-415.
2. Ramirez CA, Patel M, Blok K. How much energy to process one pound of meat? A comparison of energy use and specific energy consumption in the meat industry of four European countries. Energy. 2006; 31:2047-2063.
3. Ramirez CA, Blok K, Neelis M, Patel M. Adding apples and oranges: The monitoring of energy efficiency in the Dutch food industry. Energy Policy. 2006; 34:1720-1735.
4. Zhao M, Kong, Zheng-Hong, Escobedo FJ, Gao J. Impacts of Urban forests on offsetting carbon emissions from industrial energy use in Hangzhou, China. Journal of Environmental Management. 2010; 91:807-813.
5. Sokka L, Pakarinen S, Melanen M. Industrial symbiosis contributing to more sustainable energy use - an example from the forest industry in Kymenlaakso, Finland. Journal of Cleaner Production. 2011; 19:285-293.
6. Vourdoubas J. Possibilities of creating zero CO_2 emissions olive pomace plants due to energy use in Crete, Greece. Open Journal of Energy Efficiency. 2016; 5:78-87. http://dx.doi.org/10.4236/ojee.2016.53008

7. Mekhilef S, Saidur R, Safari A. A Review on Solar Energy Use in Industries. Renewable and Sustainable Energy Reviews. 2011; 15:1777-1790. http://dx.doi.org/10.1016/j.rser.2010.12.018
8. International Energy Agency, Tracking Industrial Energy Efficiency and CO_2 Emissions. 2007. https://www.iea.org/publications/freepublications/publication/tracking_emissions.pdf
9. Matthews HD, Caldeira K. Stabilizing Climate Requires Near-Zero Emissions. Geophysical Research Letters. 2008; 35:L04705. http://dx.doi.org/10.1029/2007gl032388
10. Grantham Institute for Climate Change, Reducing CO_2 Emissions from Heavy Industry: A Review of Technologies and Considerations for Policy Makers. Briefing Paper No. 7, Imperial College, London, 2012. https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/Reducing-CO2-emissions-from-heavy-industry---Grantham-BP-7.pdf
11. Pinkse J, Van Den Buuse D. The development and commercialization of solar PV technology in the oil industry. Energy Policy. 2012; 40:11-20.
12. Nader S. Paths to a Low-Carbon Economy-The Masdar Example. Energy Procedia. 2009; 1:3951-3958. http://dx.doi.org/10.1016/j.egypro.2009.02.199
13. Wise MA, Smith SJ, Sinha P, Lurz ZP. Long Term US Industrial Energy Use and CO_2 Emissions. Report for the US Department of Energy. 2007. http://www.pnl.gov/main/publications/external/technical_reports/PNNL-17149.pdf
14. Floros N, Vlachou A. Energy Demand and Energy-Related CO_2 Emissions in Greek Manufacturing: Assessing the Impact of a Carbon Tax. Energy Economics. 2005; 27:387-413. http://dx.doi.org/10.1016/j.eneco.2004.12.006
15. Dantas GA, Legey LFL, Mazzone A. Energy from Sugarcane Bagasse in Brazil: An Assessment of the Productivity and Cost of Different Technological Routes. Renewable and Sustainable Energy Reviews. 2013; 21:356-364.
16. Ogden JM, Hochgreb S, Hylton M. Steam Economy and Co-generation in Cane Sugar Factories. International Sugar Journal. 1990; 92:131-140.
17. Tselepis St. The PV Market Developments in Greece, Net-Metering Study Cases, 2015. http://www.cres.gr/kape/publications/photovol/new/S%20%20Tselepis%20%20The%20PV%20Market%20Developments%20in%20Greece%20%20Net-Metering%20Study%20Cases%2031st%20EUPVSEC%202015%20Hamburg%20%207DV.4.26.pdf
18. Gielen D, Newman J, Patel MK. Reducing Industrial Energy Use and CO_2 Emissions: The Role of Materials Science. MRS Bulletin. 2008; 33:471-477. http://dx.doi.org/10.1557/mrs2008.92
19. Vourdoubas J. Creation of Zero CO_2 Emissions Residential Buildings Due to Energy Use. A Case Study in Crete-Greece. Journal of Civil Engineering and Architecture Research. 2016; 3:1251-1259.
20. Vourdoubas J. Creation of hotels with zero CO_2 emissions due to energy use: A case study in Crete-Greece. Journal of Energy and Power Sources. 2015; 2(8):301-307.