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Evaluating the Potential of Solar Heat Production for the Food and Beverage Industry in Cyprus From 2024 to 2035

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Abstract. The increasing heat demand in Cyprus' F&B industry presents an opportunity to leverage the abundant solar resources of the country as a sustainable alternative to fossil fuels for industrial processes. To project the final energy consumption (FEC) of the national F&B industry from 2024 to 2035, the GDP (PPP) is used as an exogenous variable. A regression model is obtained with an adjusted correlation coefficient (R^2) of 85.8%. For the projections, two economic growth scenarios are considered (positive, *PEG*, [+3%] and negative, *NEG*, [−1.5%]), combined with two scenarios for solar technology deployment (business-as-usual, *BAU*, [2%] and large, *LTD*, [20%]). Additionally, dynamic simulations in TRNSYS are conducted to estimate the annual yield of a model SHIP plant using Parabolic Trough Collectors. The modelled system, consisting of a total collector area of 660 m² and a thermal storage of 30 m³, yielded 4,320 MJ/m² of thermal energy. It was found that solar energy could uptake between 10% and 28% of the FEC for the NEG and PEG scenarios, respectively. Moreover, the solar heat potential ranged between 85 TJ and 444 TJ, which represents between 19,780 m² and 102,800 m² of solar collectors, respectively. Lastly, the projections also analyse the reduction of GHG emissions in 2035 compared with the baseline year (2023), where the NEG-LTD scenario achieved a reduction of 71%; meanwhile, the PEG-BAU scenario presented an increment of 25% in the GHG emissions.

Keywords: Solar Thermal, Solar Heat for Industrial Processes, Projection Scenarios

1. Introduction

Heat demand makes up approximately 50% of the global Final Energy Consumption (FEC) [1]. Solar technologies can play a key role in satisfying industrial heat demand, as IEA's forecasts, since projects with a weighted capacity of an additional 260 MW have been announced for 2024-2026 [2]. Nevertheless, there is a critical need to accurately quantify the potential of Solar Heat for Industrial Processes (SHIP) in countries through comprehensive studies, which would be essential to provide empirical evidence and insights into the feasibility and benefits of integrating SHIP technologies.

The study of the relationship between economic development and energy consumption has been widely mentioned in the literature, although the conclusions drawn are contradictory from study to study, as was shown by Mutumba et al. [3]. They performed a comprehensive review of 1,240 studies where they identified the different types of relationships between economic growth and energy consumption, considering the econometric and theoretical models implemented, the selected variables, and the temporal and geographical scope of the studies. Among these, a region-specific study was performed by László [4], who analysed the correlation between economic growth and energy consumption among members of the European Union from 2010 to 2019. His study showed that the EU countries are in significantly different positions regarding decoupling energy consumption from economic growth, where member states with large industrial bases have achieved a notable reduction in energy consumption while maintaining economic growth (negative correlation). In contrast, countries with a bigger service sector, such as Ireland, Greece, Malta and Cyprus, did not show a significant reduction in energy consumption and presented a positive correlation regarding economic growth.

On the other hand, many authors have showcased the potential of solar heat to satisfy the energy demand of industrial processes. To do so, they have modelled solar heat plants considering different technologies under different weather and operation conditions. For example, Ghabour and Korzensky [5] evaluated the performance of solar thermal systems in different Hungarian cities, focusing on low-to-medium heat generation industries. They simulated an Evacuated Tube Collector (ETC) plant to satisfy the thermal needs of a small food processing industry. They found that the modelled system would be able to produce between 745-850 kWh_t/m^2 of thermal energy yearly across the different cities and to cover between 48-55% of the industry's thermal needs, respectively. In another study, Lillo et al. [6] evaluated the potential of Parabolic Through Collectors (PTC) as an alternative to conventional sources of energy for different industrial processes such as sterilization, drying, distillation, etc. They found that the annual outputs of thermal energy, at a temperature level of 150 ºC, ranged between 468-750 kWh_t/m^2 at fourteen different locations in Argentina.

By conducting rigorous assessments and analyses, including data selection, statistical correlation, and modelling, it is possible to elucidate the opportunities and challenges associated with SHIP adoption in a particular region, providing insightful projections for its implementation. An example of this was achieved by Acosta-Pazmiño et al. [7], where the authors projected the demand of the F&B industry sector for Mexico from 2021 to 2030, considering different economic growth and technology deployment scenarios, and evaluated the potential of Low-Concentrating Photovoltaic and Thermal (LCPV/T) technologies. They concluded that it would be possible to satisfy up to 23.36% of the final energy demand of the F&B sector, mitigating up to 34.06% of the GHG emissions compared to 2018 and decoupling the GHG emission rate from the energy consumption under a *Large Technology Deployment* scenario.

Increasing heat demand for the F&B industry and the urgency to phase off fossil fuels for energy production are leading the sector to look for environment-friendly alternatives to satisfy their energy needs. These type of approaches aims to enable policymakers, industry stakeholders, and researchers to make informed decisions and implement targeted strategies to harness the full potential of solar energy for industrial heat applications. Therefore, this study seeks to contribute to the ongoing discourse by providing empirical evidence and insights into the SHIP potential in Cyprus to satisfy the projected energy demand of the F&B sector from 2024 to 2035 and to mitigate the consequential GHG emissions, laying the foundation for informed decision-making and sustainable energy development initiatives.

2. Methodology

The scope of this study focuses on the F&B industry in Cyprus because its location in the Mediterranean Sea provides it with abundant solar resources. Moreover, given the relatively small size of the country, it is reasonable to assume two things: firstly, that the weather on the whole island would be similar, justifying the use of weather data from the capital, Nicosia, as a reference; and secondly, that the F&B energy consumption of the country is also a reasonable representation of the specific, yet whole, geographical region. Furthermore, in Cyprus, the industrial sector is the second largest consumer of energy after transportation, with F&B and tobacco segments heading the consumption with 39.3% within the sectors [8]. According to the IEA [1], it is estimated that half of the Final Energy Consumption corresponds to heat consumption; hence, that proportion of the FEC is considered to compute the heat demand of the sector.

To find the regression equation that would describe the behaviour of the heat demand in the F&B industry in Cyprus for 2024-2035, the GDP is used as an exogenous variable to predict the future industrial energy demand, as several studies have done [9], [10], [11]. The GDP data, in 2024 USD using Purchasing Power Parity, is retrieved from The World Bank [12], and the F&B Final Energy Consumption (FEC), in TJ, comes from Eurostat [13]. The years used for the regression analysis are 1990 to 2019, as shown in Figure 1, excluding from 2020 to 2022 due to the abnormal behaviour associated with the COVID-19 pandemic and its effect on the global industry. After obtaining a regression model with a significantly relevant coefficient of determination (R^2), the model's validity is verified through different statistical tests.

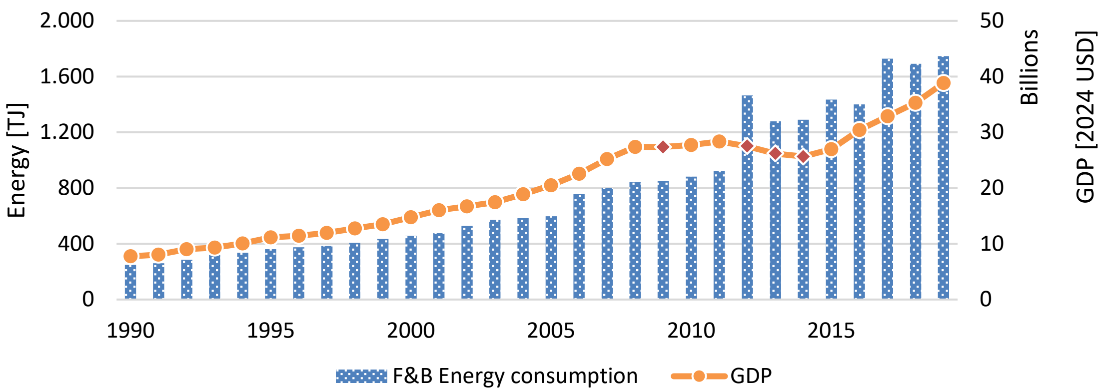

Figure 1. *Historical F&B energy demand and GDP from Cyprus from 1990 to 2019 (own elaboration with Eurostat [13] and The World Bank [12]). Red diamonds indicate a decrease in GDP compared to the previous year.*

2.1 Scenarios definition

Future energy demand scenarios are defined as a function of the expected economic growth of the country. For Cyprus, the expected growth rates for 2024 and 2025 are 2.8% and 3.0%, respectively [14]. Hence, two scenarios are envisioned for the study, where either a Negative Economic Growth (NEG) of −1.5% or a Positive Economic Growth (PEG) of 3.0% takes place for the following years. Additionally, the CO_2 emissions and the energy intensity mix for heat production are also estimated through two different levels of adoption of Concentrated Solar Heat (Business-as-usual [2% solar uptake] and Large [20% solar uptake] Technology Deployment [BAU and LTD, respectively]) to satisfy a fraction of the heat demand. Adjustments on the energy mix for Cyprus consider fuel consumption trends obtained through the geometric average of the consumption rates of the last ten years. The combination of economic growth and technology deployment scenarios results in a final matrix of 4 different scenarios.

2.2 TRNSYS setup

Parallel to forecasting the energy demand for the F&B industry, the average annual thermal yield in the region is computed using transient simulations of a defined SHIP plant in Cyprus. This enables the estimation of the number of PTC collectors required to be implemented by 2035 to meet the targets set in each scenario. The energy production model consisted of dynamic simulations developed using TRNSYS, a powerful component-based software package capable of simulating the behaviour of transient systems such as solar thermal collectors, geothermal heat pumps, wind turbines, and energy storage systems, among others. The hybrid collector was modelled using the Absolicon T160 PTC [15] as a reference. The thermal performance parameters of the PTC collector are used as input data to the transient energy production model to determine the annual energy yield of the SHIP plant, considering the weather parameters of Nicosia.

The potential solar field used for the dynamic simulations consists of 120 PTC collectors, arranged in 30 rows of 4 collectors each, for a total collector area of 660 m^2. It is based on the solar field at Birra Peroni Brewery in Bari, Italy, where the Absolicon T160 technology suits the thermal energy demand in the industrial plant and secures the energy independence of the pasteurizer processes. The system includes a thermal storage tank with a capacity of 30 m^3, equivalent to 45.5 litres per m^2 of collection area and is designed to meet a hot water demand at 142°C with an assumed constant daily profile throughout the year. This temperature level is suitable for various industrial processes within the F&B sector, where much of the demand for process heat occurs at temperatures of 300ºC or less [16]. The plant configuration represents a standardised version that can be effectively scaled to suit other specific installation sites or thermal energy requirements. Figure 2 shows a simplified layout of the SHIP plant utilised for the dynamic simulations in TRNSYS.

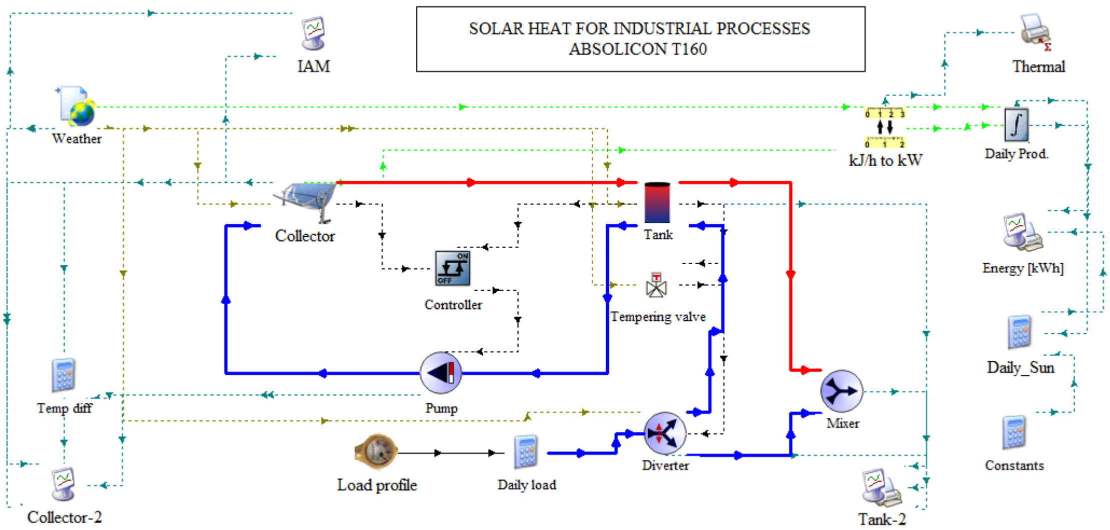

Figure 2. *Layout of the proposed SHIP plant in TRNSYS Simulation studio.*

3. Results and discussion

The regression model between the GDP and the FEC is presented in Equation 1, where the FEC is in TJ, and the GDP is in 2024 USD (PPP). This regression model obtained an adjusted R^2 coefficient of 85.8%. However, when analysing the behaviour of the residuals of the model versus the observation order, it is noticeable that there is a trend change in the FEC in 2012 when it rose drastically compared to the previous year, as presented in Figure 3. This could be occasioned by the establishment of new industries in the country or by an increase in energy consumption in the sector incentivised by the national or European governing bodies. This indicates that the regression model could be further improved, for example, by including another predicting variable to explain the disruptive behaviour or by analysing only the data after 2012 to obtain the regression equation. However, by doing so, the sample would become too small, hence reducing the accuracy of the model and the correlation coefficient. Therefore, this study continues to use Equation 1 as the regression model for the projected scenarios.

$$FEC = -240.5 + 50.57\ GDP \quad (1)$$

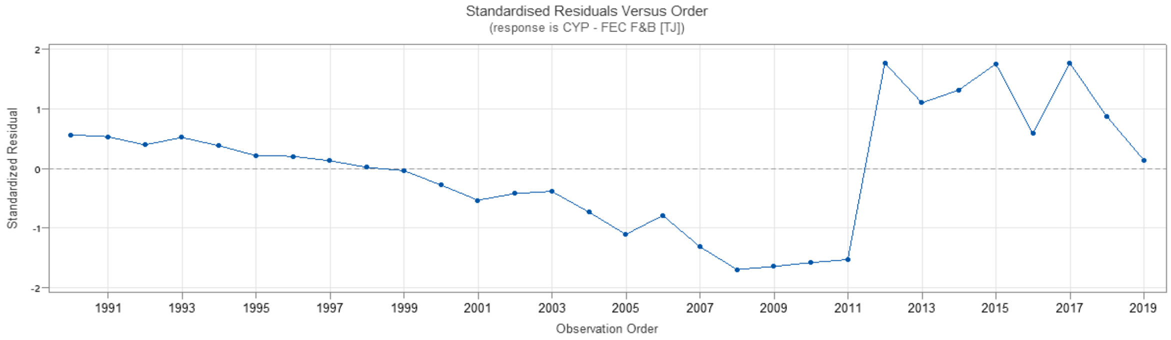

Figure 3. *Standardised FEC F&B [TJ] residuals versus observation order.*

Using this model, the FEC for the F&B industry and the energy mix were forecasted from 2024 to 2035 under different economic and technology deployment scenarios, as presented in Figure 4. Furthermore, the simulation showed that the solar field could produce up to 2.85 TJ (792,088 kWh_t) of heat per year, which is a specific yield of 4,320 MJ/m^2 (1,200 kWh_t/m^2). This value represents a deviation of 8.12% from the value reported by Absolicon at its Birra Peroni solar field [17]. Based on this yield, the Final Heat Consumption (FHC), considered as half of the FEC, was estimated. Table 1 shows how Cyprus could deploy between 19,780 and 102,800 m^2 of solar collectors to satisfy the solar heat demand in each forecasted scenario.

Table 1. *Forecasted FHC, solar heat potential and GHG emission abatement for the F&B industry in 2035 under different scenarios.*

GDP - Technology Deployment	*NEG - BAU*	*NEG - LTD*	*PEG - BAU*	*PEG - LTD*
Final Solar Uptake [TJ] (relative %)	171 (10%)	486 (28%)	309 (10%)	872 (28%)
Final Heat Consumption [TJ]	868	868	1,568	1,568
Solar heat potential [TJ]	85	243	154	444
Potential collection area (m^2)	19,780	56,240	35,750	102,800
GHG Emissions [kt CO_2 eq.] (% abatement)	66 (-31%)	27 (-71%)	119 (26%)	49 (-48%)

Additionally, as shown in Figure 5, the uptake of solar energy in the projected energy mix for the LTD scenarios represents a considerable reduction in GHG emissions in comparison with the baseline of 95 kt of CO_2 eq. from 2023, with an abatement of 71% and 48% for the NEG and PEG scenarios, respectively. Moreover, under the BAU scenarios, the total emission reduction was less significant for the NEG scenario (31%). In contrast, under the BAU-PEG scenario, emissions rose by +26% due to the increased economic activity while maintaining a low-renewable energy mix. This demonstrates how important it is to incentivise clean energy policies parallel to economic policies when looking for sustainable industrial growth.

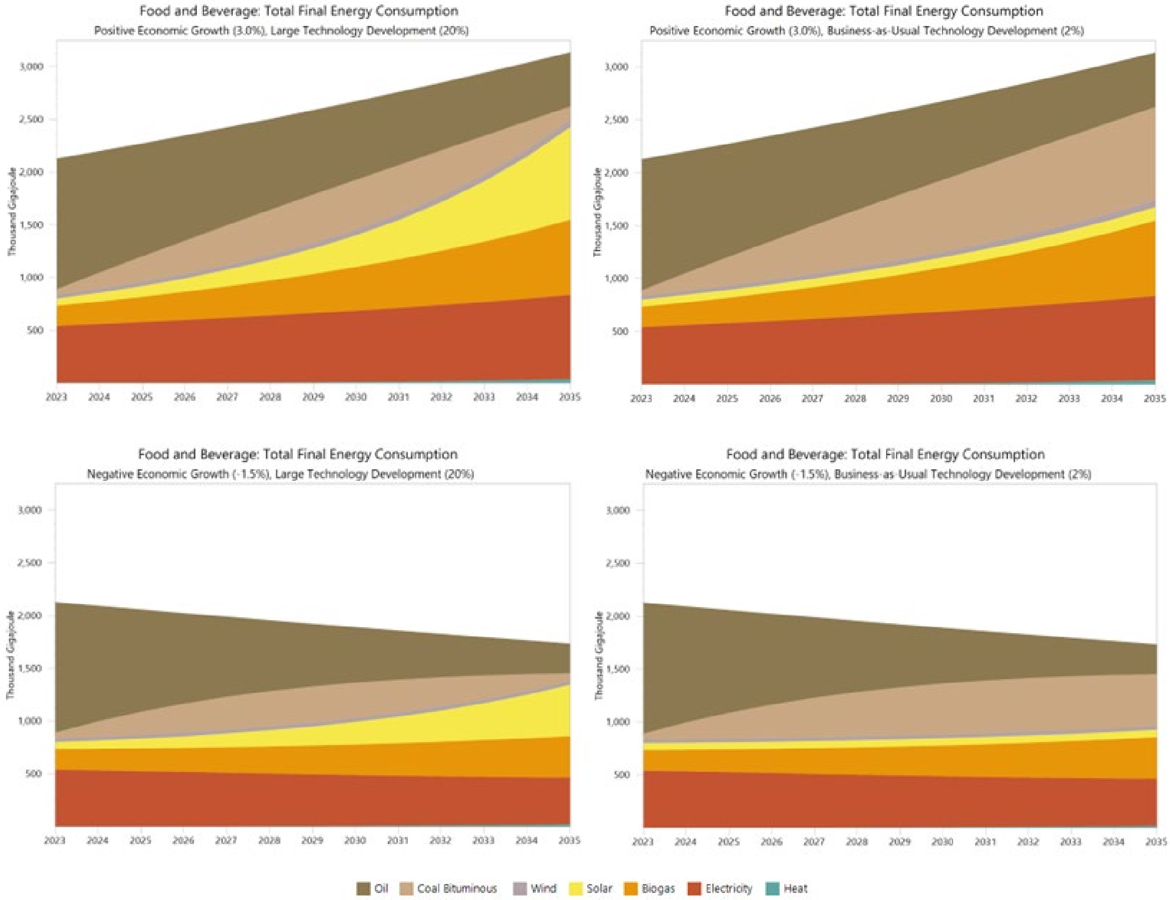

Figure 4. *Projection of the Final Energy Consumption in Cyprus for 2024-2035 under four different scenarios: PEG (top), NEG (bottom), LTD (left), and BAU (right).*

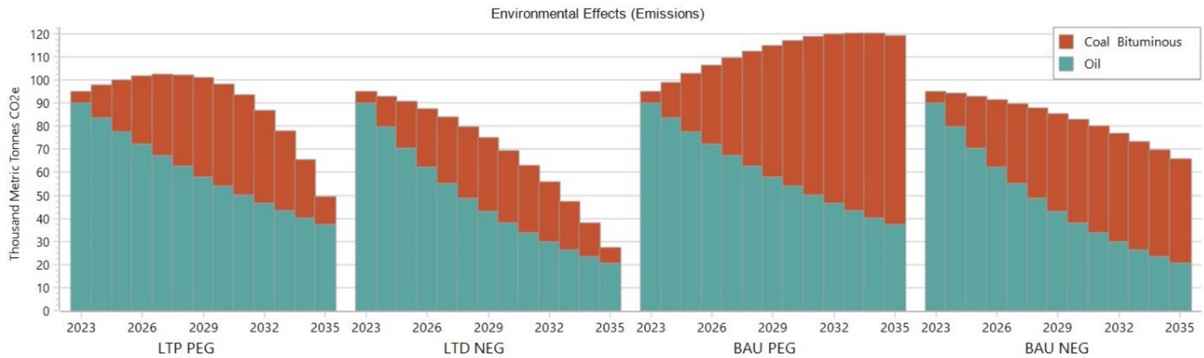

Figure 5. *Projection of the GHG emissions in Cyprus for 2024-2035.*
From left to right, LTD-PEG, LTD-NEG, BAU-PEG, BAU-NEG.

4. Conclusions and scope for future work

This study forecasts the heat energy consumption of the F&B industry in Cyprus, using its GDP as a predictor to estimate the yearly value. Four scenarios involving two different solar technology deployment levels and two economic growth rates for the country were considered to compare potential energy demand satisfaction and GHG abatement. The national solar potential of SHIP is estimated to be between 19,780 and 102,800 m^2 of solar collectors, depending on the evaluated scenario. The largest GHG reduction could be achieved under the LTD scenarios, with 71% and 48% for the NEG and PEG cases, respectively. In contrast, while the BAU-NEG scenario could achieve a GHG reduction of 31%, the BAU-POS case could reach an increment in GHG emissions of 26%, showing the impact of an unsustainable, solely economic-centred perspective.

Future work will encompass more technology-deployment- and GDP-related scenarios, with the respective detailed analysis of GHG emissions abatement for each. Moreover, the inclusion of explicit energy efficiency measures and additional exogenous factors could strengthen the projection of the total energy demand of the studied regions. It is important to notice that this analytical approach holds for countries where the GDP is strongly affected by industrial activity, as in other entities where it does not have such a significant effect on the economic outcome, the correlation could misrepresent the true behaviour of future years.

Lastly, this methodology can be extrapolated for other solar harvesting technologies, not only PTC, to evaluate different alternatives according to the resources available in the target region and industrial sector. On the same line, it is also intended to evaluate if this methodology is valid for other countries in the European Union, where it is critical to put particular care on the history-, market-, and policy-related specifics of the economic and industrial behaviour of the selected sector.

Data availability statement

The data used for this study are publicly available in [12] and [13].

Author contributions

Conceptualization: I.A.P.; Methodology: J.P.S., A.A.D., I.A.P.; Software: J.P.S., A.A.D.; Formal Analysis: J.P.S.; Investigation: J.P.S., A.A.D.; Resources: I.A.P., J.G.; Data Curation: J.P.S.; Writing – Original Draft: J.P.S., A.A.D.; Writing – Review & Editing: A.C.G., I.A.P.; Supervision: I.A.P.; Project Administration: I.A.P., J.G.; Funding Acquisition: J.G.

Competing interests

The authors declare that they have no competing interests.

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