Solar Energy Advances 4 (2024) 100068

Contents lists available at ScienceDirect

Solar Energy Advances

journal homepage: www.elsevier.com/locate/seja

Turning weakness into strength - A feasibility analysis and comparison of datacenter deployment in hot and cold climates

Michael Chrysostomou [a,c,*], Nicholas Christofides [b], Stelios Ioannou [c]

[a] MIEEK Larnaca, St. Anargyron 58, Larnaca, 6302, Cyprus
[b] Frederick University, Nicosia, Cyprus
[c] University of Central Lancashire, Pyla, Larnaca, Cyprus

ARTICLE INFO

Keywords:
Datacenter deployment
Hot and cold climates
Hybrid PV supply systems

ABSTRACT

Datacenters are major components of the Information and Communication Technologies (ICT) responsible for storing, processing and transmitting enormous amounts of data every second. The significance and importance of datacenters in the world economy can be identified from studies which report that in 2023, datacenter infrastructures consumed a total of 4 % of global electricity and contributed 3–5% of global carbon emissions, whereas between the years of 2017–2021, datacenters added $2.1 trillion to the U.S. Gross Domestic Product (GDP). A big portion of energy supplied in datacenters is consumed by the required cooling systems hence companies do not favor developments in hot climate countries. However, due to environmental and climate change concerns along with the steep increase of energy production costs in recent years made the industry look for alternatives. This work includes an in-depth feasibility and comparative study of datacenter construction and operation in hot and cold European countries and addresses the environmental impact of photovoltaics integration in the electrical supply system. The study considers cost parameters (land, operating expenses, photovoltaic system, etc.), the net present cost and levelized cost of energy which are different for each European country under investigation. Furthermore, for every country under consideration, the PV generation was simulated using the PVsyst software which includes multiple meteorological databases, whereas the feasibility analysis was simulated using the HOMER Pro software which integrates components, resources and economic calculations. An elaborate analysis of the results knocks down the common belief that datacenters have lower operational and running expenses in cold climates because of lower cooling requirements. On the contrary, this study shows that hot climates with high solar radiation levels may favor the operation of datacenters by providing 45 % higher green energy and 35 % lower CO_2 emissions, whereas the cooling cost is only 5 % higher. In addition, the break-even period for the photovoltaic system in Southern European countries with hot climates is 3–4 times faster.

1. Introduction

Digitalization has been the primary objective of global societies over the last decade. More specifically, “Europe’s Digital Decade” policy [1], aims at enabling the digital transformation of various industries by the year 2030, focusing on the following goals: (A) Improve the digital skills to >80 % of the population, (B) Provide 5 G coverage in Europe, (C) Availability of Gigabit connections to everyone, (D) Transform at least 10,000 micro-datacenters to climate neutral data-edge nodes, (E) Introduce computers with quantum acceleration, (F) Encourage at least 75 % of EU companies to use cloud, AI and Big data, (G) Stimulate 90 % of EUs SMEs to possess digital intensity, (H) Move entirely to 100 % online public services, (I) Ensure 100 % of medical records and (J) Motivate 80 % of EU citizens to acquire EU identity.

The goals set by the EU and other global entities including the World Economic forum [2] for digitalization by 2030, necessitate the use of datacenters to store and process the data required for the digitalization process. These set goals, positively affect the global datacenter (DC) market industry trends which clearly show, for the period 2021 to 2030, a compounded annual growth rate (CAGR) of 6.5 % which increases the total annual worth from 57 to 132 billion [3–5]. Media and entertainment maintain 35 % of datacenter usage whereas edge datacenters and cloud service provider datacenters have the highest CAGR of 23.2 % and 17.7 % respectively which projects an increase from $10.4 billion in 2023 to $29.6 billion in 2028 [6–9]. Furthermore, artificial intelligence

* Corresponding author.
E-mail address: netw.lar@mieek.ac.cy (M. Chrysostomou).

https://doi.org/10.1016/j.seja.2024.100068
Received 27 July 2024; Received in revised form 5 September 2024; Accepted 5 September 2024
Available online 10 September 2024

Nomenclature

Economics terms

NPC	net present costs, (Euro)
LCOE	levelized cost of energy, (Euro)
FiT	fit in tariff, (Euro)
OPEX	operational expenses, (Euro)
CAPEX	capital expenses, (Euro)

Engineering

CRAC	computer room air cooling
CRAH	computer room, air handling unit
DC	datacenter
PUE	power usage effectiveness
PV	photovoltaic
BSS	battery storage system
ICT	information and communications technology

Weather categories

Af	tropical rainforest climate
Am	tropical monsoon climate
Aw	tropical Wet and dry
As	tropical savanna climate
BWh	hot desert climate
BWk	cold desert climate
BSh	hot semi-arid climate
BSk	cold semi-arid climate
Cfa	humid subtropical climate
Cfb	temperate Oceanic climate
Cfc	subpolar Oceanic climate
Cwa	monsoon influenced humid subtropical climate
Cwb	subtropical highland climate
Cwc	cold subtropical highland climate
Csa	hot summer mediterranean climate
Csb	war summer Mediterranean climate
Csc	cold summer mediterranean climate
Dfa	hot summer humid continental climate
Dfb	warm summer humid continental climate
Dfc	subarctic climate
Dfd	extreme cold subarctic climate

(AI) occupies 20 % of global datacenter capacity and is expected to increase revenue by 58 % by 2028 which translates to approximately $76 billion [10–13]. The overall datacenter positive impact on society is identified with the significant contribution in the range of $2.1 trillion towards the U.S. Gross Domestic Product (GDP) including employment, labor income and tax contributions to federal state and local governments for the 5-year period of 2017–2021 [14].

Currently, the datacenter average size is 100,000 m^2 with the biggest one owned by China Telecom occupying a staggering 1 million square meters [3,4]. All this growth inevitably increases the demand for electrical power and energy. In 2023, datacenters consumed an average of 4 % of global electrical energy which is expected to increase significantly over the next few years [15–17]. Furthermore, the increase of peak power demand globally between 2022 and 2023 was in the range of 55 %, from 4.9 GW to 7.4 GW respectively [12]. Worth mentioning the case of Ireland, where in 2021 datacenters consumed 14 % of country's total energy and it is forecasted to increase to a staggering 25 % by 2030 [18].

Environmental concerns dictate the importance and monitoring of CO_2 emissions. The annual required energy for datacenters and other ICT nodes, micro-datacenters and ICT stations, is expected to exceed 38 PWh by the year 2030 with CO_2 emissions reaching 20 Giga tons which is equivalent to 5 % [16–20]. The EU has set some guidelines [21] including the European Green Deal [22] and the Climate Neutral Data Centre Pact [23] to minimize the environmental impact and CO_2 footprint. It encourages innovative practices aiming towards the reduction of energy consumption and the generation of carbon free green energy with the integration of renewable energy sources. This encouragement seems to be well accepted by industry and by the research community. There is ample scientific research on heat recovery techniques, power modeling and optimization [24–29]. New companies offering solutions, optimization and power management increased revenue by 77.9 % in 2021 [7,30,31]. Furthermore, the industry proudly presents nearly carbon free datacenters and recovering heat is now warming cities during cold winter periods [32–34].

Worldwide there are approximately 10,978 datacenters which 50 % are in the USA and 25 % in Europe [35–37]. Out of approximately 2745 European datacenters only 266 (9.7 %) are located in Mediterranean countries (Cyprus, Greece, Italy and Spain) that favor the use of PV systems [35–37] more than any other location. It should be noted that PV system power generation profile aligns with the consumption profile and demand trend of datacenters which peak around noon. Traditionally, however datacenters are built in northern countries which offer lower temperatures reducing the costs for cooling. Recommended operating temperatures are in the range of 20–22 °C and should not exceed 28 °C [38]. Cooling systems account approximately to 40 % of power consumption whereas the IT equipment and servers account for the remainder [39–41]. Server consumption is in the range of 200–1500 W and does not affect system efficiency. However, the fact that power supplies are oversized by 20 % to 50 % significantly affects the system efficiency decreasing it to approximately 80 % compared to 96 % offered by a fully loaded power supply [42]. Datacenter energy efficiency is determined by the Power Usage Effectiveness (PUE). PUE is the ratio of total power consumed over the power used to run the servers and other ICT equipment. Hence, minimizing the auxiliary power requirements, for example those for cooling and increasing power supply efficiency yields better PUE. Currently some state-of-the-art datacenters are promising PUE <1.2 [31,32].

This work aims to verify the "common belief" that datacenters are cheaper to run in cold (Northern) European countries because of lower cooling requirements compared to hot (Southern) European countries. In doing so, this study considers all parameters and concerns reported in the literature and aims to provide a more comprehensive techno-economic analysis by considering all costs associated with the deployment of a similar datacenter in different European countries with different climatic conditions.

The study considers various cost parameters and for every country under consideration the PV generation is simulated using PVsyst which includes multiple meteorological databases. The feasibility analysis was simulated using HOMER Pro software which integrates components, resources and economic calculations. No previous work compares techno-economically the deployment of datacenters with different power supply scenarios (including PV solar) in hot and cold climates in terms of Net Present Costs (NPC) and Levelized Cost of Energy (LCOE).

2. Methodology

The work initially investigated and identified the locations and number of datacenters globally deployed, the parameters affecting their capital and operational costs as well as the Net Present Cost (NPC). The capital costs are directly related to the cost of land, building construction cost, cost of PV systems and other initial investment costs. On the other hand, the Operational Expenses (OPEX) include the cost of energy, followed by labor costs. It is important to note that the biggest OPEX in a datacenter is the cost of energy which significantly affects NPC. Fortunately, for each European country there is ample official online data available which is required for the levelized cost of energy (LCOE) and NPC.

In addition, any income from excess RES fed to the grid if applicable was identified and included in the analysis. The specific parameters are rigorously presented and discussed. Furthermore, this work identified that climatic conditions in each European country are very important and significantly affect (a) the datacenter cooling power consumption which runs 24/7 throughout the year and (b) the energy generated by the proposed renewable energy system. As anticipated, most datacenters in Europe are found in Germany, England, the Netherlands, France, and Ireland. This study explored the reasons behind the concentration of datacenters in these specific countries with the primary factors being their industrial capacity and supposedly favorable climatic conditions. Consequently, Germany and the Netherlands were selected for this study as they are the leading countries in datacenter deployment. To examine the impact of climate on the energy consumption, three additional European countries; Spain, Greece, and Cyprus were chosen.

These countries, located in the southern parts of Europe, experience much warmer climates and they cover the entire length of the Mediterranean Sea. The attention was then addressed to the energy consumption of the cooling systems. For this task a common 100 kW datacenter ICT load was used as reference. To be able to simulate the energy consumption in the five different countries an online tool was used which uses weather data adopted from Weather Spark. Using this online simulation software, the total annual energy consumption per hour is calculated for each of the five countries. The simulation results were further used to calculate the datacenter Power Usage Effectiveness (PUE). To broaden the selection of climates, Egypt and Norway were also examined in addition to the five main countries. It is shown that even with more extreme weather conditions the consumption is not significantly different and covering a broader region would not alter the main results. This is because with new A3 and A4 technology ICT equipment the climate does not play a significant role in energy consumption as it may have done in the past.

Countries with higher temperature climatic conditions have also higher solar irradiation. The power profile of the solar PV systems was simulated using PVsyst for same system in each of the five countries. PVsyst includes multiple meteorological databases and offers high accuracy even on an hourly scale with horizontal resolution of the primary solar data source of a global 1° x 1° latitude/longitude while the meteorological data sources are ½° x $^5/_8$° latitude/longitude. The meteorological data subsequently exported for further analysis in Homer Pro.

The feasibility analysis is performed using Homer Pro which integrates components, resources and economic calculations such as LCOE and NPC. HOMER Pro is a software that is developed from National Renewable Energy Laboratory and its main target is the optimization of micro-grid designs and all types of hybrid energy supply systems with multiple energy resources and storage systems. The new optimization algorithms of HOMER Pro identify the least-cost options for distributed generation electrical power systems. The simulation model architecture and economics considers a discount rate of 6 % and a project lifetime of 15 years. The parameters shown in Table 2 and the CO_2 emissions in Kg per generated electrical kWh were used as inputs to the model. In addition, results with regards the energy consumption of datacenters were imported for each country. The average daily consumption of a datacenter specified was 3078 kWh for Germany, 3187 kWh for Cyprus, 3167 kWh for Greece, 3145 kWh for Spain and 3074 kWh for Netherlands. The calculated efficiency of the converter systems is 95 %.

The initial charging state of the BSS with Lithium batteries was assumed to be 100 % and the Depth of Discharge (DOD) was set to 80 %. The nominal voltage of the battery bank was set to 600 V, roundtrip efficiency at 90 %, maximum charge current at 167 A (for 100 kWh battery bank) and maximum discharge current at 500 A. The lifetime of the converter systems and batteries was set at 15 years as was for the whole project. The CO_2 emission values specified are 337 g of CO_2/ kWh for Greece, 174 for Spain, 381 for Germany, 534 for Cyprus and 268 g of CO_2 / kWh for Netherlands. All calculations are performed in Euros (€) as a base currency.

3. Results

3.1. Datacenter electrical energy consumption

To analyze the datacenter energy consumption, this study identified and analyzed the respective equipment and systems. Internet and Communications Technology (ICT) equipment are the most energy hungry followed by the cooling systems. With regards the consumption of the UPS systems efficiency improvement techniques such as PSU multiplexing or cascading converters are suggested by recent literature [43,44] with significant results especially on low loading conditions.

To minimize the energy consumption for cooling several researchers promote two stage cooling techniques [45,46], scheduling [47], or other technologies [48]. Considerations for energy efficiency improvements are not accounted for in this work because similar efficiency datacenter systems will be considered for all countries under consideration. The energy distribution in a typical datacenter can be seen in Fig. 1.

As can be deducted from the literature, the cooling requirements have a significant share to the PUE. As a result, warm weather countries have the worst PUE. The types of climates compared in this work are based on the Koeppen-Geiger classification [49] and these are: “Csa” for hot Mediterranean summer climate, “BSh” semi desert climate, “Bsk” Cold Semi-arid climate, “Cfa” for humid subtropical climate and “Cfb” for temperate oceanic climate or subtropical highland climate. In southern Europe with Csa and Bsh climatic classification there is obvious disadvantage in datacenter deployment. Previous studies showed that datacenters in hot climate countries had a very negative effect on datacenter energy consumption [50,51] compared to colder climates. Recent studies however reveal that this the difference is now very small and that the effect of external weather conditions have less effect on the energy consumption. This occurs because the new A3 and A4 technology ICT equipment operate at temperatures up to 40 °C and 45 °C respectively, permitting operating temperatures of 35 °C and minimizing in this way the cooling energy consumption [52–54]. It is worth mentioning that even in countries with Csa climates the average temperature is <35 °C for nine months of the year. Furthermore, as stated by Yingbo Zhang et al. [54], for A4 technology ICT equipment, free cooling units can be used in all climates globally provided that the ambient temperature is up to 40 °C. Their study is based on actual results from different datacenters in Beijing, Kunming and Hong Kong, proving that employing free cooling the savings between Dwa (Beijing), Cwb (Kunming) and Cwa (Hong Kong) climates are negligible.

To evaluate the energy effectiveness of a datacenter, the “Power Utilization Effectiveness” (PUE) metric is used. PUE is calculated by the total Datacenter power consumption over the total IT power stream consumption. PUE is the total IT load power consumed over the total datacenter load (including cooling and other systems consumption).

$$PUE = \frac{P_{total}}{P_{ICT}} \tag{1}$$

$$P_{total} = P_{ICT} + P_{PS} + P_{Dist} + P_{Cool} \tag{2}$$

where:

- P_{ICT} is the Consumption of Information and Communications Technology (ICT) Equipment (IT and networking devices)
- P_{Dist} is the Energy loss due to power distribution (i.e. cable losses, connection losses etc.)

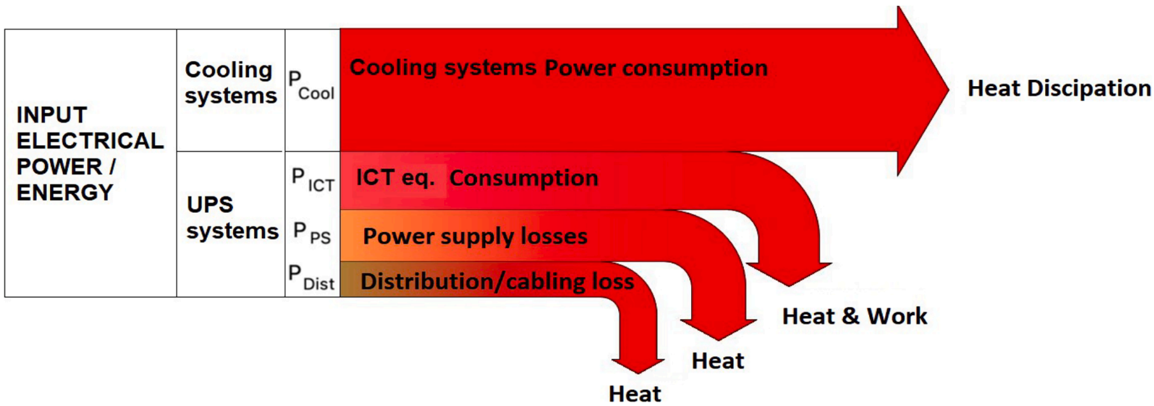

Fig. 1. Typical electrical energy distribution in datacenters.

- P_{Cool} is the cooling systems energy consumption

To calculate the load consumption of datacenters and their respective cooling systems in this work, a model consisting of 100 kW IT load has been used. The energy consumption of the cooling systems is simulated in different countries based on two scenarios:

- Computer Room Air Handling (CRAH - heat pump systems)
- Computer Room Air Conditioning units (CRAC).

The simulation is performed through the manufacturer supplied software (INTARCON). The simulation of cooling consumption is implemented based on temperature values of each of the five selected countries and each individual month extracted from [55]. The cooling consumption software calculates the energy consumption at any instance using specific parameters such as the requested temperature inside the datacenter, external weather conditions (temperature) and heat energy to be extracted. To be able to identify the energy consumption under different weather parameters, simulations for all different conditions are given, and then the formula that associates the parameters with the consumption is identified. The formula is then used to identify the consumption of the datacenter at any instance. The average energy consumption per hour using CRAC units can be seen in Fig. 2. The respective consumption of the same datacenter with CRAH units is shown in Fig. 3.

CRAC cooling systems were simulated using the Intracon MDW with compressor model 4MK-35X. CRAH cooling units were simulated using the Intracon MWW TT version. The results from the simulations can be validated from "cloudscene" datacenter market analysts [56], where it is shown that the average PUE in Spain is 1.33 and for Germany 1.29. The expected energy consumption of a datacenter in hot climates is higher but taking into consideration new ICT technologies that can operate in higher temperatures the energy difference is found to be between 0.2 to 4.7 % amongst the five European countries analyzed. Cyprus has the highest energy consumption among the five European countries and Germany (Hamburg) the lowest. A non-European mediterranean country is also included in the analysis to identify how weather conditions affect energy consumption even in extreme weather scenarios.

Two additional countries, Egypt and Norway, with more extreme climates compared to the selected five countries, were also included in the analytical study as shown in Table 1. The results show that even in extreme weather conditions such as those offered in Egypt and Norway, the energy consumption increase does not justify broadening the countries or regions under investigation. Netherlands and Germany present very similar energy consumption profiles with the difference being 0.2 %. The simulated average PUE per country using CRAH cooling units is shown in Table 1.

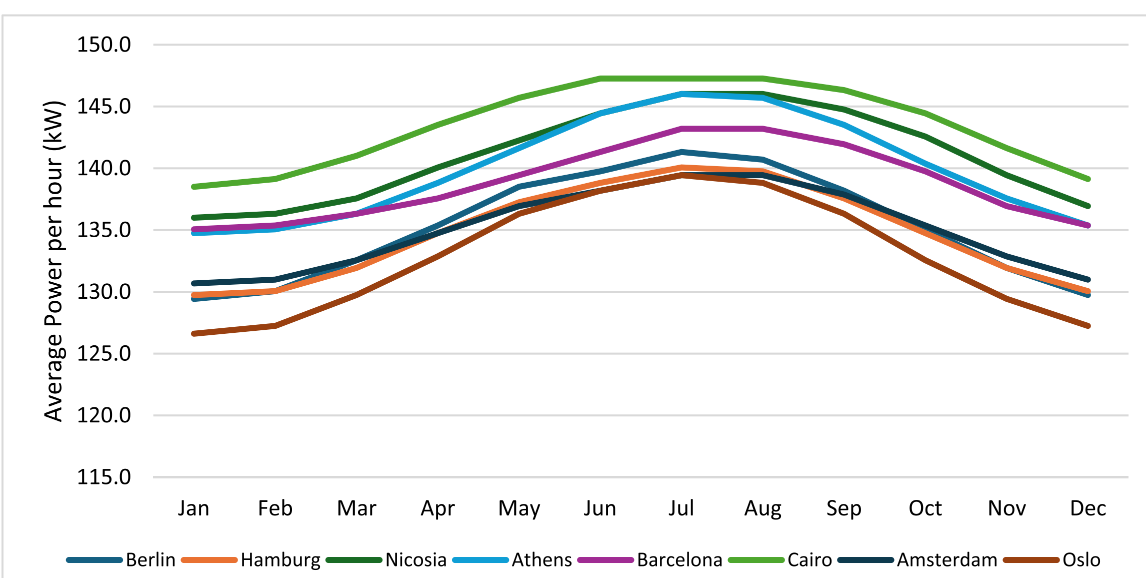

Fig. 2. Datacenter CRAC average hourly energy consumption with 100 kW IT load.

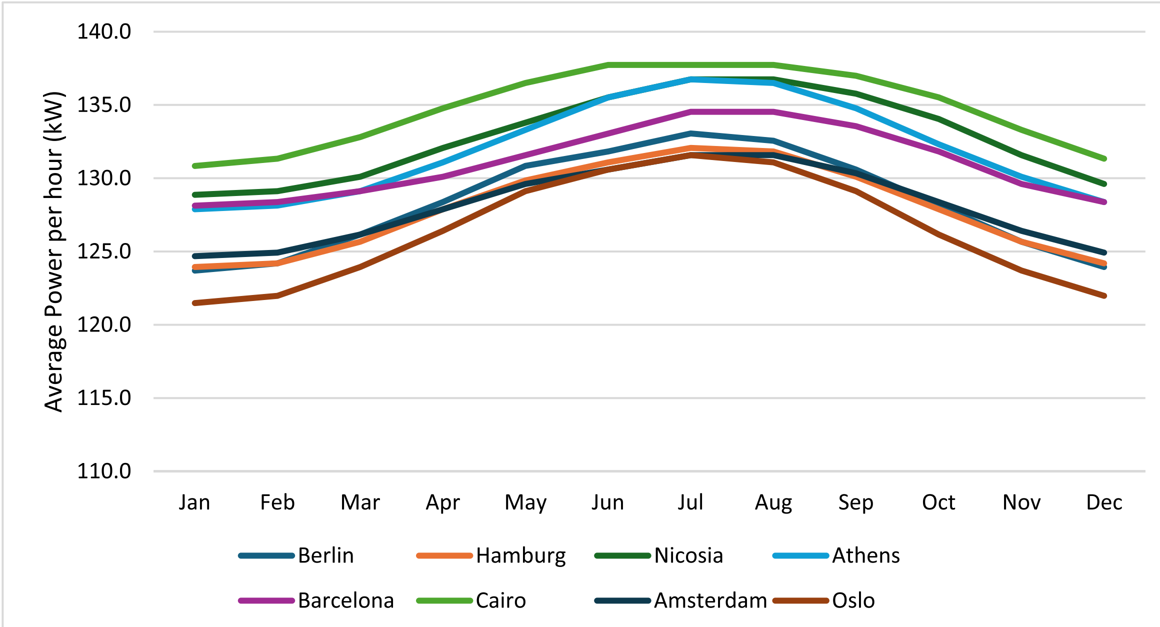

Fig. 3. Datacenter CRAH average hourly energy consumption with 100 kW IT load.

Table 1
Simulated average PUE for 100 kW IT load with CRAH cooling units.

Country	City	Calculated Average PUE based on simulations (CRAH)
Germany	Berlin	1.283
Cyprus	Nicosia	1.328
Greece	Athens	1.320
Spain	Barcelona	1.311
Egypt	Cairo	1.347
Netherlands	Amsterdam	1.281
Norway	Oslo	1.264

3.2. *Expected PV system output energy per country*

Despite the negative effects of Csa, climates significantly favor the use of PV systems for renewable energy generation. Using the software PVwatts (https://pvwatts.nrel.gov/), simulations suggest that 1 kWp PV system can generate annually 1615 kWh in Cyprus, 1566 kWh in Egypt, 1420 kWh in Greece, 980 kWh in Germany and 878 kWh in Netherlands. Furthermore, the yield per month of a 5 kWp system is presented in Fig. 4.

Performing similar simulations using PVsyst but with optimized parameters, the values were slightly higher. The higher yield is a result of the better power temperature coefficient of the modules used; −0.29% / °C Vs −0.39%/ °C of those in the initial simulation. Simulation results indicate that PV systems in Cyprus are expected to generate more than double the annual energy compared to the Netherlands. Therefore, the benefits of lower cooling energy consumption requirements of datacenters in cold weather countries correlate with lower PV generated energy. The output of PVsyst calculations was imported in HOMER Pro to evaluate also the total cost of ownership, levelized cost of energy and environmental impact of the energy generation systems in all five different European countries.

3.3. *Feasibility analysis of datacenters with solar PV systems*

Due to the need to minimize the carbon footprint of industries globally, the use of solar PV or other renewable energy sources is a necessity. Solar PVs today have very low prices compared to other renewable energy sources when used without energy storage as for example net metering or net billing schemes. When energy storage is incorporated into a solar PV system the cost is still a viable solution in most cases, depending on the size of the storage needed in each case. By default, datacenters incorporate battery storage systems (BSS) to remain operational in the event of grid failure. The batteries can support the whole datacenter load for a period from a few minutes up to half hour in most cases [57]. The BSS in conjunction with a predictable load would constitute the optimum scenario for solar PV integration. The techno-economic comparison with associated costs is presented in Table 2. All associated costs for each of the aforementioned parameters under consideration are tabulated in Table 2. Most of the tabulated values were either directly obtained or derived from Eurostat [62,67,68] which is a trustworthy source.

As seen in Table 2, Netherlands has the highest building cost, the highest labor cost, the highest cost of land per hectare and the highest cost of PV systems. This is due to the low solar irradiation and low utilization of solar PV in Netherlands in relation to other renewable energy sources such as biomass or wind energy. Cyprus has the highest cost of grid electricity and second highest cost of land per hectare. Cyprus however has the lowest building cost per square meter and second lowest labor cost. Spain and Greece have the lowest cost of land per hectare and the lowest grid electricity cost.

The costs acquired from the analysis shown in Table 2 are used to simulate the financial costs of a datacenter with 100 kW ICT load. The simulations identified the weather conditions and solar production in each location and compare the operation of the datacenter supplied with five (5) different scenarios namely:

- Datacenter supplied from grid and a 200 kWp Solar PV system (without sell back power option)
- Datacenter supplied from grid and a 200 kWp Solar PV system (without sell back power option) including 100 kWh Lithium-Ion Storage system
- Datacenter supplied from grid and a 300 kWp Solar PV system (without sell back power option)
- Datacenter supplied from grid and a 300 kWp Solar PV with option to sell-back the excess energy to the grid.
- Datacenter supplied from grid and a 500 kWp Solar PV with option to sell-back the excess energy to Grid.

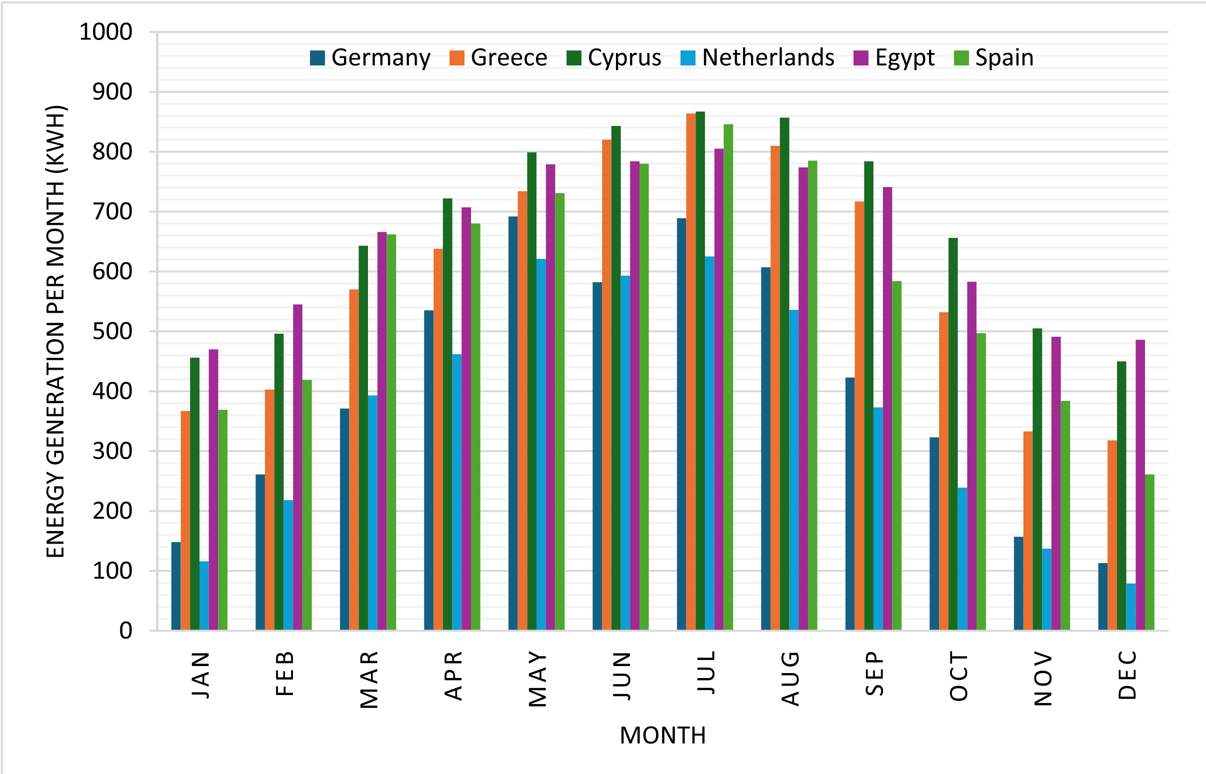

Fig. 4. Average monthly energy generation for a 5 kWp PV system.

Table 2
Technoeconomic analysis cost results.

	Cost of PV/ Wp (€)	Cost of Land/ hectare (€)	Labor cost/ hour (€)	Electricity Cost (€)	Buildings Cost per sqm (€)
Cyprus	€ 0.69 [58, 59,60]	€ 57,000.00 [61]	€ 20.10 [62]	€ 0.28 [63]	€ 2597.00 [64]
Germany	€ 0.90 [65]	€ 27,242.12 [66]	€ 41.30 [62]	€ 0.22 [63]	€ 5515.00 [64]
Greece	€ 0.52 [67]	€ 13,571.00 [68,69]	€ 15.70 [62]	€ 0.18 [63]	€ 4727.00 [64]
Netherlands	€ 0.95 [70]	€ 85,431.00 [69]	€ 43.30 [62]	€ 0.23 [63]	€ 7144.00 [64]
Spain	€ 0.90 [65]	€ 10,263.00 [69]	€ 24.60 [62]	€ 0.15 [63]	€ 6363.00 [64]

The comparison was carried out in five countries for a 100 kW ICT load and 200 kWp PV system. The simulations were carried out in HOMER Pro. The results of Net Present Cost (NPC), Levelized Cost of Energy (LCOE), Capital Expenses (CAPEX) and IRR for the same datacenter supplied from the grid and the 200 kWp solar PV system are shown in Table 3. The analysis was evaluated for a period of 15 years. The net present cost (or life-cycle cost) of the datacenter is the present value of all the costs of installing and operating the datacenter over the project lifetime minus the present value of all the revenues that it earns over the project lifetime.

The results suggest that despite the highest cost of grid electricity and land per hectare, Cyprus compares well in terms of NPC to Germany and better than Netherlands. Despite the aforementioned higher costs, still Cyprus offers lower Levelized cost of Energy at 0.233 €/kWh. On the other hand, Netherlands has the highest LCOE and Spain the lowest. The reason that the LCOE is comparatively considerably lower in Cyprus compared to Germany and Netherlands is due to the higher energy yield obtained from PVs because of the higher solar irradiation. This can be easily proven by the heat map LCOE of PV systems in the five countries as shown in Fig. 5. From Fig. 5, it can be deducted that the colder the climatic area for the datacenter installation the higher the LCOE of the solar PV system.

The Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) are given by the Eqs. (3) and (4):

$$NPC = -\left\{\sum_{i=1}^{n}\frac{R_i}{(1+r)^i} - Inv\right\} \quad (3)$$

where:

- R_i is the estimated net cash flow for i^{th} period

Table 3
Technoeconomic results for a datacenter of 100 kW ICT load and 200 kWp Solar PV system in different countries.

Category	Unit	Greece	Spain	Germany	Cyprus	Netherlands
Total NPC	(€)	2576,184	2482,646	3464,699	3466,288	3798,103
Levelized COE	(€)/kWh	0.1743	0.1692	0.2412	0.233	0.2662
Operating Cost	(€)	156,200	130,192	213,383	239,345	225,026
CAPEX (exc IT systems cost)	(€)	579,414	818,352	736,948	406,646	921,000
IRR for Solar system (200kWp)		50	24	19	61	15
Solar system payback (200kWp)	years	2	4.1	5.2	1.6	6.1

Fig. 5. Heat map of LCOE of 200 kWp PV systems deployment in Northern and Southern European Countries.

- *r* is the required rate of return per period
- *n* is the life of the project in years. For this project case was estimated 15 years.
- Inv is the initial investment.

$$LCOE = \frac{Inv + \sum_{i=1}^{n} \frac{A_i}{(1+IR)^i}}{\sum_{i=1}^{n} \frac{E_i}{(1+IR)^i}} \tag{4}$$

where:

- *Ai* is the annual cost per year
- *Ei* is the annual electrical Energy per year (kWh) per period
- *IR* is the interest rate
- n is the years of the project lifetime
- *i* is the current year

Examining the results for the Net Present Cost (NPC) it is noticed that Netherlands has the highest followed by Cyprus. It should be noted that the land was assumed to be purchased and not rented. The countries with the lowest NPC are Spain and Greece. Overall, for this scenario Cyprus presents the lowest payback time which is only 1.6 years. Netherlands presents the highest payback time with 6.1 years. As stated previously, datacenters incorporate batteries and diesel Generators for back-up power because of the critical loads. To verify the validity of the results this study also evaluated the same systems with the support of 100 kWh Lithium battery storage system and a 180 kVA Diesel. The results are shown in Table 4. In such a scenario, a datacenter deployed in Cyprus has the highest IRR in terms of PV system and lowest payback time. Deployment of such a datacenter Spain would have the lowest NPC from all five locations even though Spain has the second more expensive capital expense to deploy the datacenter.

To validate the initial hypothesis that datacenters in hot weather countries such as Cyprus, Greece and Spain have lower cost of ownership (lower NPC and LCOE), this study examined the use of larger PV systems. Using larger PV systems, it was necessary to examine what would happen with the excess energy. It was necessary therefore to evaluate feed in tariff scenarios. The feed in tariffs per country are depicted in

Table 5
Comparison of feed in tariffs for PV systems in different European countries.

Country	Feed in Tariff	Reference
Cyprus	€ 0.11	Electricity Authority of Cyprus [72]
Greece	€ 0.115	PV Magazine [73]
Spain	€ 0.06	Walburga Hemetsberger et al., "Global Market Outlook for Solar Power 23–27" [74]
Germany	€ 0.11	Federal Network Agency [75]
Netherlands € 0.09	Stimulering Duurzame Energieproductie (SDE+) [76]	

Table 4
Technoeconomic results for a datacenter of 100 kW ICT load and 200 kWp Solar PV system with 100 kWh lithium energy storage system in different countries.

Category	Unit	Greece	Spain	Germany	Cyprus	Netherlands
Total NPC	(€)	2677,744	2584,203	3570,000	3544,238	3898,862
Levelized COE	(€)/kWh	0.1812	0.1761	0.248	0.238	0.2733
Operating Cost	(€)	157,432	131,423	214,583	238,549	226,234
CAPEX (exc IT systems cost)	(€)	665,240	904,175	822,264	494,771	1010,000
IRR		27	15	11	39	9.5
Solar system payback	years	3.6	6.1	7.6	2.5	8.7

Table 5 with Greece presenting the highest feed-In-Tarif (FIT) from solar PV systems.

The results of the LCOE for the five different datacenter energy supply scenarios mentioned above are presented in Fig. 6, whereas the NPC results are shown in Fig. 7. As it can be seen, for all scenarios hot climate countries, Greece and Spain, have the lowest LCOE and NPC. Whereas, as expected due to the very high energy prices, Cyprus examined without solar and working purely on the grid has the highest LCOE and NPC. However, as the analysis continues and clearly shows on Figs. 6 and 7, solar irradiance is a game changer for Cyprus and gives it a competitive advantage.

Solar irradiance, as clearly shown on Figs. 6 and 7, gives Cyprus a competitive edge compared to Germany and Netherlands. Datacenters with solar PV systems in Cyprus have lower NPC than in Netherlands and Germany. The heat map in Fig. 8 indicates the NPC per country. It is possible to corelate between weather, location and cost of the datacenter. It can be easily seen that northern countries have higher NPC and LCOE when solar PV systems are used to supply the datacenters.

3.4. Environmental Impact

To evaluate the environmental impact of implementing the datacenter in the countries investigated in this study, an initial assessment is carried out based on the equivalent kg of CO_2 / kWh of grid supplied energy. Based on the Ember Energy institute report for 2024 [64], the energy generated in Greece emits 337 g of CO_2 / kWh, in Spain 174, in Germany 381, in Cyprus 534 and in Netherlands. This is based on the type of fuel or renewable energy mix used in the production of energy in each country. Cyprus has the highest emissions of CO_2 / kWh because of high percentage of energy generated from conventional sources using crude oil. To evaluate the emissions and compare different scenarios, the generated emissions from solar PV should be also considered. Based on [71], the emissions of CO_2 / kWh from PV solar systems are about 28 g/kWh. These emissions are based on the life cycle analysis of the production and dismantling of PV systems.

To compare the systems in different countries, this study evaluated three scenarios namely (a), supply of all energy from the grid, (b) supply of energy from the grid and 300 kWp solar PV system along with 100 kWh lithium-Ion Battery system, (c) supply from grid and 500 kWp PV and 400 kWh battery system. The results are shown in Fig. 9. It is shown that when the solar PV system is connected to battery energy storage, Southern European Countries (hot climates) have less environmental impact compared to Southern countries which have cold climatic conditions. The systems with the new scenarios with 500kWp Solar PV with 400 kWh battery are also analyzed in terms of NPC and LCOE as shown in Table 6.

4. Analysis of results and discussion

This work aims to verify the common belief that datacenters are cheaper to operate in (Northern) European countries due to the lower cooling energy requirements. As a result of this only 9.7 % of datacenters in Europe are deployed in countries with hot climatic conditions such as Cyprus, Greece, Italy and Spain. Datacenters in these countries have indeed higher cooling needs however, they favor the use of PV systems because of the higher solar irradiation which has shown to constitute a considerable advantage justifying the installation of datacenters in hot climates. A datacenter operating in a cold climate without solar PV system in the energy supply mix will have lower Net Present Cost compared to a hot climate. This predominantly depends on the cost of energy although deployment cost is also a factor. When solar PV systems are used in the electrical supply a DC in a hot climate may have lower Net Present Cost compared to one in a cold climate. This is due to the lower cost and higher energy output of RES in some hot climate countries that constitute them more favorable.

For every country under consideration, the PV generation was simulated using the PVsyst software which includes multiple meteorological databases specific for the countries studied, whereas the feasibility analysis was simulated using the Homer pro software which integrates components, resources and economic calculations.

In Section 3.1, the datacenter electrical energy consumption is analyzed for a 100 kW IT load using Computer Room Air Handling (CRAH - heat pump systems) and Computer Room Air Conditioning units (CRAC) cooling systems. As it can be seen from Figs. 2 and 3, CRAC systems require higher average power per hour compared to CRAH systems. In Netherlands for example during the summer period with CRAC cooling systems employed, approximately 140 kW is required whereas using the CRAH it drops to 132 kW. The same trends are observed with the other countries under consideration. Cyprus and Greece present similar numbers, 146 kW and 137 kW with the two types

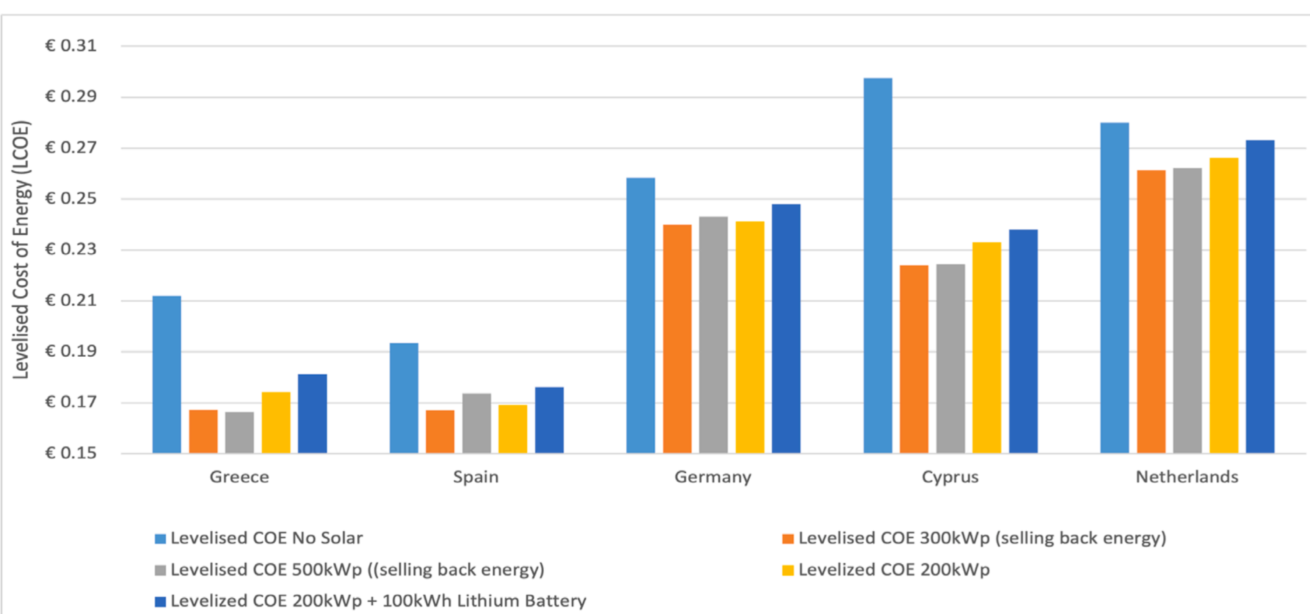

Fig. 6. Levelized Cost Of energy of different scenarios in different European countries.

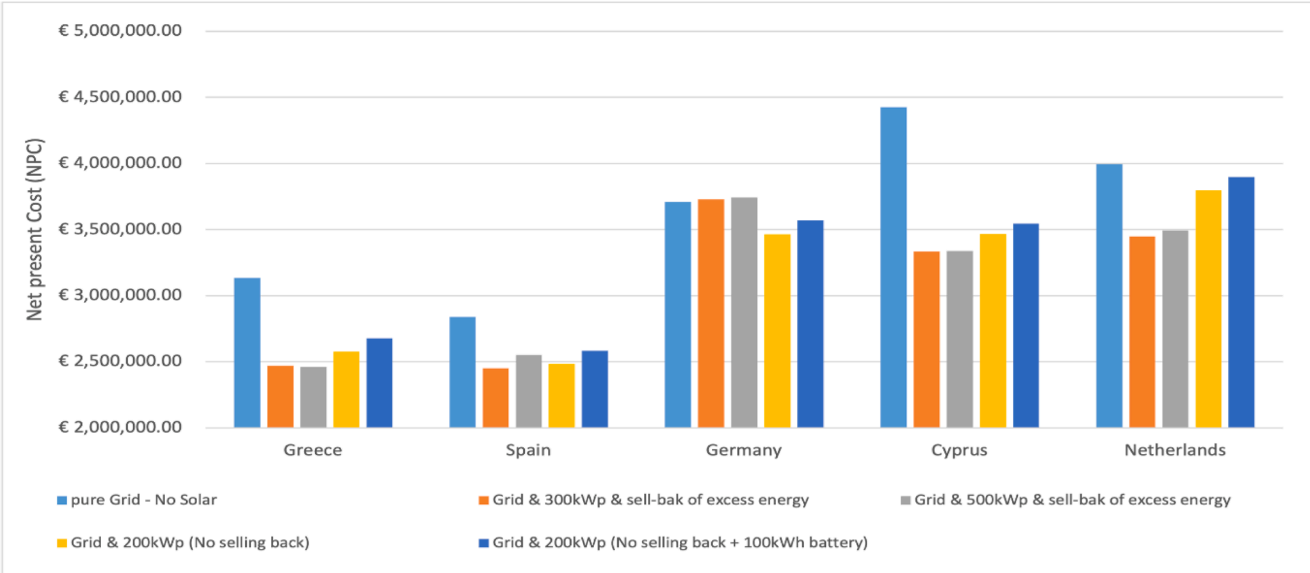

Fig. 7. Net present cost of deploying the same datacenter in different European countries (hot and cold climates).

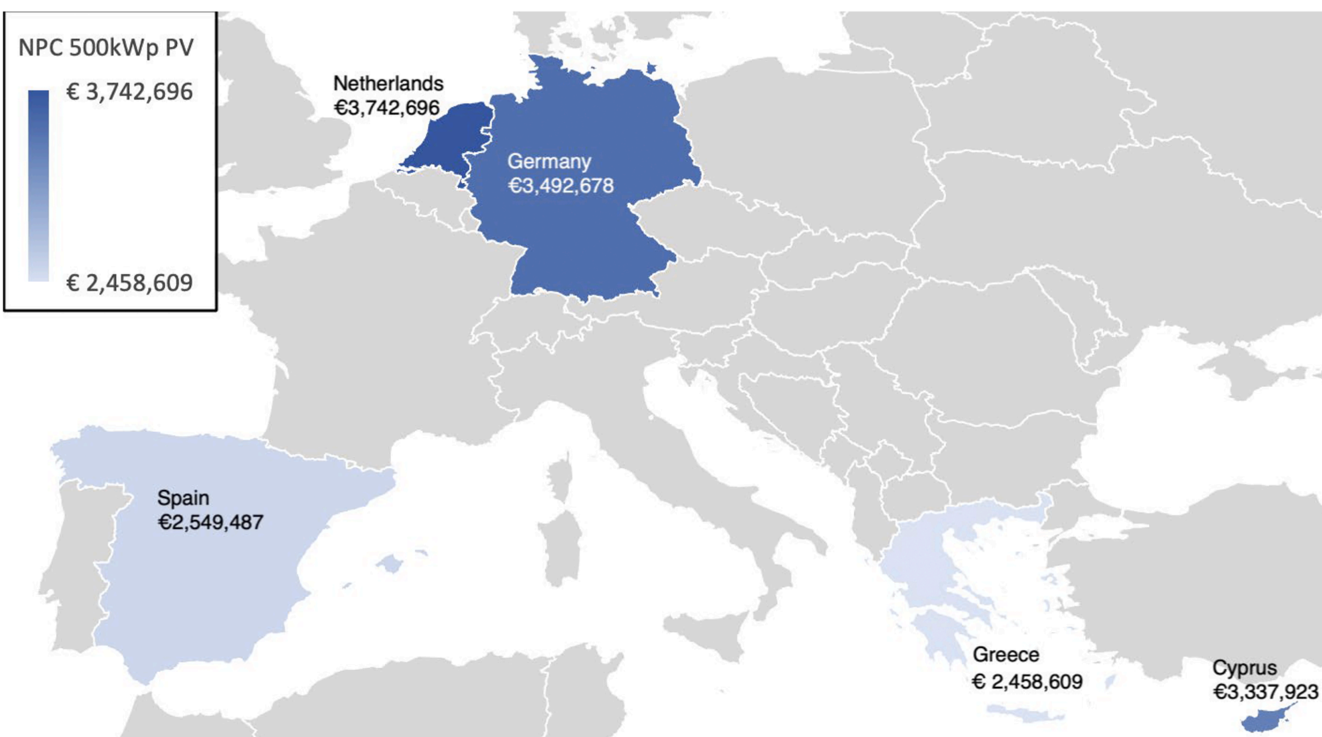

Fig. 8. Heatmap with the Net present Cost of deploying the same datacenter with 500 kWp Solar PV in different European countries (hot and cold climates).

of cooling systems respectively. The results of the calculated Power Usage Effectiveness (PUE) factor, Table 1, indicate Netherlands with the lowest PUE of 1.281 whereas Cyprus is one of the highest with 1.328. Hence, it can be said that Cyprus has the highest auxiliary costs such as cooling which yields higher PUE. However, the difference in consumption between hot (Csa, Bsh), medium cold weather (Bsk climates) and cold (Cfa, Cfb climates) is <5 %.

In Section 3.2, the study analyses and compares the PV energy that can be generated in the five different countries, using the same PV system. The results are visualized in Fig. 4, As it can be seen a PV system in Cyprus can generate more than double the energy per year compared to the Netherlands. Therefore, the benefits of lower cooling energy consumption requirements of datacenters in cold weather countries correlate with lower PV generated energy. The simulations are implemented using PVsyst software and validated with NREL and are imported in HOMER Pro software for the calculation of Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) for datacenter deployment in these 5 different countries.

In Section 3.3, the Net Present Cost for the construction of the same datacenter under five different scenarios is evaluated. The cost parameters considered were the cost of Land, cost of Labor, cost of PV systems, cost of Energy (kWh), building cost and cost of Feed in Tariff (FiT) for

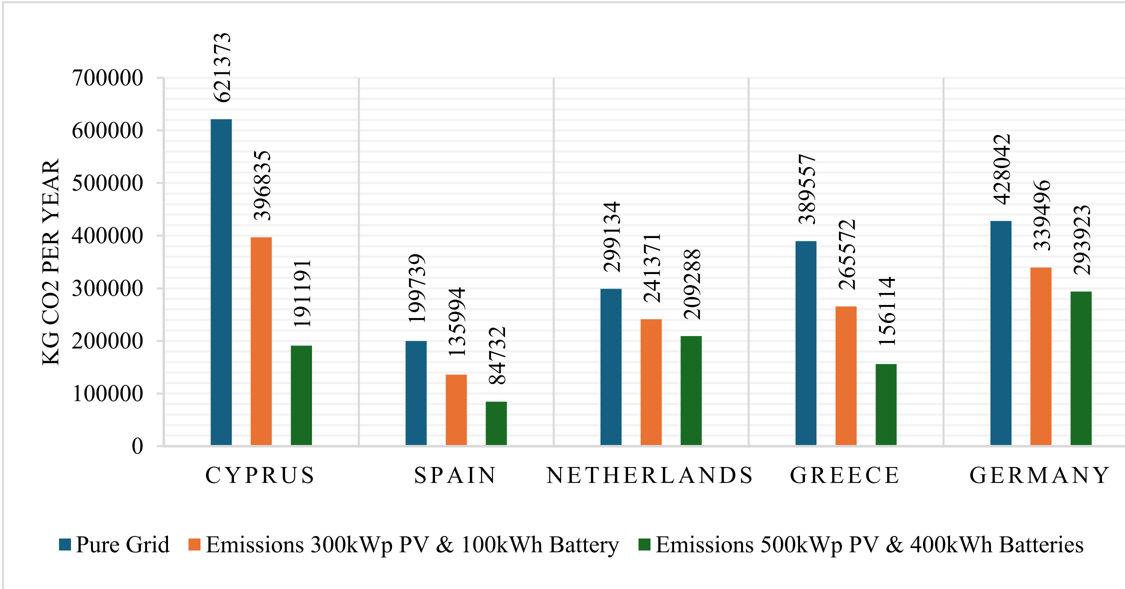

Fig. 9. Environmental impact of Pure Grid, 200kWp and 500kWp solar system integration comparison (net metering).

Table 6
Comparison of $C0_2$, NPC, LCOE and operating costs of 500kWp Solar PV and 400 kWh battery in different European countries.

500kWp PV & 400 kWh BSS	Unit	Cyprus	Germany	Greece	Netherlands	Spain
CO_2	kg/year	191,191	293,923	156,114	209,288	84,732
Total NPC	€	2,535,273	3,442,670	2,181,670	3,699,220	2,453,056
Levelized COE	€	0.1704	0.2397	0.1476	0.2593	0.1672
Operating cost	€	117,921	184,412	92,264	187,505	84,873
PV & BSS IRR		29	11	23	11	11
PV & BSS payback time		3.3	7	4.3	7.8	7.4

selling excess energy from PV to grid if it applies. Furthermore, CO_2 for the generated energy from grid in each individual country is taken into consideration and compared with different configuration scenarios. Netherlands has the highest cost of land per hectare, building cost per square meter, labor cost and cost of PV systems. Cyprus has the highest grid electricity cost. The lowest labor cost and cost PV systems is in Greece. The lowest building cost is in Cyprus and the lowest cost of land per hectare and grid electricity cost is that of Spain. Cyprus has relatively expensive land, second after Netherlands among the five countries of comparison.

The technoeconomic study has revealed that when no PV system is employed, Cyprus has the highest NPC to deploy and operate a datacenter for 15 years, higher by 10.7 % compared to Netherlands and higher by 19.2 % compared to Germany. When a 200 kWp solar system is used to supply the same datacenter however Cyprus has almost the same NPC with Germany and lower by 9.5 % compared to Netherlands. When the PV system utilizes a BSS that is already installed in the datacenter (100 kWh), Cyprus has 0.7 % lower NPC than Germany and 10 % lower than Netherlands. When the solar PV systems are increased to 300 kWp, Cyprus has 11.9 % lower NPC compared to Germany. In the case that the PV system is 500 kWp and the excess energy is fed back to grid, Cyprus has 12.1 % lowest NPC than Germany and 4.6 % lower NPC than Netherlands. The lowest NPC for the 200 kWp and 300 kWp solar system scenarios is in Spain and for the 500 kWp PV system with the excess energy fed to the grid, the lowest NPC is in Greece. The reason for this is the lowest cost of PV and slightly higher solar generation. It is proven that the Net Present Cost (NPC) and the levelized cost of energy (LCOE) is lower in hot weather countries under all scenarios with solar PV systems incorporated.

In Section 3.4, this work compares the environmental impact of deploying the datacenters in the five countries again with different supply scenarios. It is shown that when there is no solar PV in the datacenter supply mix, the datacenter deployed in Cyprus has the highest environmental impact. It is also noted that a datacenter deployed in Greece has similar environmental impact with Netherlands when no solar PV is used in the electrical supply. With solar PV systems and batteries used for the electrical supply of the DC the environmental impact is lower in Southern European countries. Deploying the datacenter in Spain presentments the least CO_2 emissions. It is worth to mention that deploying the datacenter in Spain, supplied from grid and a 500 kWp PV system with 400 kWh storage would generate 71 % less CO_2 compared to the same scenario in Germany. Similarly, when comparing Cyprus and Germany with the electrical supply only from the grid the DC in Cyprus presents 31 % higher CO_2 emissions. With a 500 kWp PV and 400 kWh storage however the DC in Cyprus would generate 34.9 % less CO_2. In that scenario, Cyprus has only 3 % higher NPC compared to Spain as depicted in Table 6.

Finally, it is worth noting that in all scenarios, the payback time when Photovoltaic system and batteries are installed is 2–3 times faster in Greece and Cyprus compared to Northern Countries. In particular, a 500 kWp PV system with a 400 kWh Battery storage, would have a payback time of 3.3 years in Cyprus and 7.8 years in Netherlands. It is interesting mention that the same hybrid system would have less payback time in Germany compared to Spain as show in Tables 3 and 4. This is due to the high cost of BSS and the low cost of grid electricity in Spain.

5. Conclusion

As a result of the digital transformation policies datacenters have in the last decade become the key components for the Information and Communication Technologies (ICT) industry. The significance of datacenters is evident from their enormous growth during the last decade and by the increase in their energy that has reached a 4 % of global electricity in 2023. Several studies have been conducted to minimize the energy consumption of datacenters. In the last few years, the research has been concentrated on green energy datacenters though no studies are conducted to techno-economically compare the deployments of such datacenters in different climatic conditions as was the aim of this work. To be able to proceed with the technoeconomic study the load profile of a datacenter in different climatic conditions was initially identified. Simulations were conducted with data provided by the manufacturers of cooling systems and using historical temperature values per country. Different size PV systems were simulated using PVsyst software and the data was imported in HOMER Pro. The feasibility analysis took into consideration the cost of land, grid electricity cost, cost of labor, cost of PV systems, building cost and feed in tariffs. The study considered also different scenarios with various PV system sizes and several configurations of power supply.

The obvious perception is to associate datacenters in hot environments with higher costs of energy and more severe environmental impact. Because of this only 9.7 % of datacenters in Europe are deployed in the Mediterranean countries (Cyprus, Greece, Italy and Spain). Cyprus has the highest cost of electricity among the five countries and second highest cost of land. On the other hand, Cyprus has the highest solar irradiation and due to the low cost of PV systems today, Cyprus has lower levelized cost of energy compared to northern European countries when datacenters employ PV systems. Under the specified conditions in this study, the country with the lowest NPC to deploy a datacenter and the lowest cost of energy is Greece. The second-best country to deploy a datacenter with small difference is Spain.

It is noteworthy to mention that a datacenter in Greece of 100 kW ICT load supplied from grid and 500 kWp PV system may have up to 52 % lower NPC (for 15 years) compared to a respective datacenter deployed in Germany, 42 % lower NPC compared to Netherlands, 35.7 % lower compared to Cyprus and 3.5 % lower compared to Spain.

Through this study it has been shown that although datacenters in Europe are mostly deployed in northern countries, they present higher NPC when solar PV are used in the energy supply. Furthermore, it has been shown that datacenters in hot environments such as in Cyprus, Greece or Spain have lower levelized cost of energy and less environmental impact under certain conditions compared to datacenters implemented in cold climatic conditions such as Germany or Netherlands. A future study can extend the technoeconomic analysis by including more countries globally, involving extreme weather conditions/scenarios such as very hot and very cold climatic conditions and investigating waste heat recovery.

CRediT authorship contribution statement

Michael Chrysostomou: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Nicholas Christofides:** Writing – review & editing, Formal analysis, Data curation. **Stelios Ioannou:** Writing – review & editing, Validation, Software, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] EU, Eu's Digital Policy, 2024. https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade.
[2] WEF. World economic forum agenda 2022. https://www.weforum.org/agenda/2022/05/a-digital-silver-bullet-for-the-world/.
[3] R. Vardhman and TechTrends G. Defensor. 15 Crucial data center statistics to know in 2024. OnlinePosting:https://techjury.net/blog/data-center-statistics/. 2024.
[4] Globe Newswire L. Wood. The data center colocation market - global outlook forecast 2022-2027 re- port. OnlineAvailable:https://www.globenewswire.com/news-release/2023/02/02/2600212/0/en/Global-Data-Center-Colocation-Market-Report-2023[AccessedJune17,2024], 2022.
[5] Minnix. Brightlio technology illuminated – datacenter stats – april 22, 2024. OnlineAvailable:https://brightlio.com/data-center-stats[AccessedJune17,2024], 2024.
[6] Markets and Markets. Edge datacenter market forecast. OnlineAvailable:https://www.marketsandmarkets.com/Market-Reports/edge-data-center-market-142018469.html[AccessedJune17,2024], Aug 2023.
[7] Yahoo Finance. Data center infrastructure management market size, share trends analysis report by component, by data center type, by deployment, by application, by enterprise, by industry vertical, by region and segment forecasts, 2022 –2030. OnlineAvailable:https://finance.yahoo.com/news/data-center-infrastructure-management-market-135100441.html[AccessedJune17,2024], Jan 2023.
[8] Reportlinker. European data center trends in 2024. OnlineAvailable:https://www.reportlinker.com/clp/global/6112[AccessedJune17,2024]., 2024.
[9] Future Market Insights S. Saha. Data center market outlook from 2024 to 2034. OnlineAvailable:https://www.futuremarketinsights.com/reports/data-center-market[AccessedJune17,2024]., 2024.
[10] A. Loten, Ai-ready data centers are poised for fast growth, Wall Street J. (2023).
[11] J. McGregor. 2024 global data center market comparison, 2024.
[12] J. McGregor. Forbes, May 2023. Generative AI breaks the data center: data center infrastructure and operating costs projected to increase to over $76 billion by 2028.
[13] G. Dolven P. Lynch and J. Ruttner. Intelligent investment - north america data center trends h2 2023 - technological innovation is driving record demand despite power constraints, 6 Mar 2024.
[14] S. Buckley. Data centers contribute 2.*1ttotheu.s.economy* , 6 Mar 2024.
[15] F. Wang, C. Lv, J. Xu, Carbon awareness oriented data center location and configuration: an integrated optimization method, Energy 278 (2023) 127744.
[16] J. Howarth. 34 amazing cloud computing stats (2024). OnlineAvailable:https://explodingtopics.com/blog/cloud-computing-stats[AccessedJune17,2024]., 19 Feb 2024.
[17] Engie. Decarbonization - replace your electricity consumption with 24/7 carbon-free energy generation, generating revenue and achieving high resiliency for your data center. OnlineAvailable:https://www.engie.com/en/campaign/green-data-centers [AccessedJune17,2024].
[18] S. Malik. 21 New data centres planned outside of dublin. OnlineAvailable:https://www.capacitymedia.com/article/2b1ar1gqvxfc735o5lnnk/news/21-new-data-centres-planned-outside-of-dublin-report-says, [Accessedon20/Dec/2022].
[19] M. Manganelli, A. Soldati, L. Martirano, S. Ramakrishna, Strategies for improving the sustainability of data centers via energy mix, energy conservation, and circular energy, Sustainability 13 (11) (2021) 6114.
[20] E. Selvaraji C. Dale and C. Yang. Singapore - push to green datacenters as they guzzle more power amid growing digital demands. OnlineAvailable:https://www.channelnewsasia.com/singapore/push-green-data-centres-they-gu 2024]., Dec 2023.
[21] European Commission. Directorate general for communications networks, content and technology, 2020.
[22] EU Green Deal. The European green deal. *Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels*, 2020.
[23] Climate newtral datacenters. The green deal needs green infrastructure. OnlineAvailable:https://www.climateneutraldatacenter.net/[AccessedJune17,2024].
[24] Z.M. Marshall, J. Duquette, A techno-economic evaluation of low global warming potential heat pump assisted organic rankine cycle systems for data center waste heat recovery, Energy 242 (2022) 122528.
[25] Q. Zhang, Z. Meng, X. Hong, Y. Zhan, J. Liu, J. Dong, T. Bai, J. Niu, M. Jamal Deen, A survey on data center cooling systems: technology, power consumption modeling and control strategy optimization, J. Syst. Archit. 119 (2021) 102253.
[26] J. Cho, J. Yang, C. Lee, J. Lee, Development of an energy evaluation and design tool for dedicated cooling systems of data centers: sensing data center cooling energy efficiency, Energy Build. 96 (2015) 357–372.
[27] L. Amiri, E. Madadian, N. Bahrani, S.A. Ghoreishi-Madiseh, Techno-economic analysis of waste heat utilization in data centers: application of absorption chiller systems, Energies 14 (9) (2021) 2433.
[28] A.Z. Ahwazi, C. Bordin, S. Mishra, A. Horsch, P.H. Ha, Sustainable and decarbonized data-center facilities: a socio-techno-economic discussion. 2021 IEEE PES Innovative Smart Grid Technologies-Asia (ISGT Asia), IEEE, 2021, pp. 1–5.
[29] L. Gibbons, B. Coyne, D. Kennedy, S. Alimohammadi, A techno-economic analysis of current cooling techniques in irish data centres. 2019 25th International Workshop On Thermal Investigations of ICs and Systems (THERMINIC), IEEE, 2019, pp. 1–6.
[30] Krishna. Energy-efficient data centers: innovations in cooling and power management. OnlineAvailable:https://medium.com/@codebykrishna/energy-efficient-data-centers-innovations-in-cooling-and-power-managem 2024].
[31] A. Jones. Digital goes green: more data centers migrating to renewable energy. OnlineAvailable:https://www.ispartnersllc.com/blog/data-centers-renewable-energy/[AccessedJune17,2024].

[32] T. Swallow. Top 10: green energy data centres. OnlineAvailable:https://energydigital.com/top10/top-10-green-energy-data-centres[AccessedJune17,2024].
[33] E. Biba. The city where the internet warms people's homes. OnlineAvailable:https://www.bbc.com/future/article/20171013-where-data-centres-store-info-and-heat-homes[AccessedJune17,2024].
[34] All things Distributed. District heating: using data centers to heat communities. OnlineAvailable:https://www.allthingsdistributed.com/2024/03/district-heating-using-data-centers-to-heat-communities.html[AccessedJune17,2024]., 13 Mar 2024.
[35] Statistica team. Leading countries by number of data centers as of march 2024. OnlineAvailable:https://www.statista.com/statistics/1228433/data-centers-worldwide-by-country/[AccessedJune17,2024]., Mar 2024.
[36] Cloudscene team. Where you connect with providers. OnlineAvailable: https://www.statista.com/statistics/1228433/data-centers-worldwide-by-country/[AccessedJune17,2024].
[37] Datacenter map team. Western europe datacenters. OnlineAvailable: https://www.datacentermap.com/western-europe/[AccessedJune17,2024].
[38] Secure IT Environments team. Avoid data centre heatstroke this summer. OnlineAvailable:https://siteltd.co.uk/blog/recommended-data-center-temperature-and-humidity[AccessedJune17,2024].
[39] Industrial Efficiency Decarbonization Office. Energy-efficient cooling control systems for data centers. OnlineAvailable: https://www.energy.gov/eere/iedo/energy-efficient-cooling-control-systems-data-centers[AccessedJ 2024].
[40] Boyd Corp. Energy consumption in data centers: air versus liquid cooling, Jan 2024. Dataspan. How much energy do data centers use?, Mar 2023.
[41] R. Bunger and W. Torell. Efficiency analysis of consolidated vs. conventional server power architectures. OnlineAvailable: https://www.apc.com/us/en/support/resources-tools/white-papers/efficiency-analysis-of-consolidatjsp [AccessedJune17,2024].
[42] M. Chrysostomou, N. Christofides, S. Ioannou, A. Polycarpou, Multicell power supplies for improved energy efficiency in the information and communications technology infrastructures, Energies 14 (21) (2021) 7038.
[43] M. Chrysostomou, N. Christofides, D. Chrysostomou, A novel machine learning-based load- adaptive power supply system for improved energy efficiency in datacenters, IEEE Access 9 (2021) 161898–161908.
[44] Y. Gong, F. Zhou, G. Ma, S. Liu, Advancements on mechanically driven two-phase cooling loop systems for data center free cooling, Int. J. Refriger. 138 (2022) 84–96.
[45] M. Borkowski, A.K. Piłat, Customized data center cooling system operating at significant outdoor temperature fluctuations, Appl. Energy 306 (2022) 117975.
[46] Q. Zhang, C. Tang, T. Bai, Z. Meng, Y. Zhan, J. Niu, M. Jamal Deen, A two-layer optimal scheduling framework for energy savings in a data center for cyber–physical–social systems, J. Syst. Archit. 116 (2021) 102050.
[47] G. Ye, F. Gao, J. Fang, A mission-driven two-step virtual machine commitment for energy saving of modern data centers through ups and server coordinated optimizations, Appl. Energy 322 (2022) 119467.
[48] Koppen-Geiger. Wolrd climate classification koppen-geiger. OnlineAvailable: https://koeppen-geiger.vu-wien.ac.at/present.htm.[Accessed:17/7/2024].
[49] E. Dzurko. The "why" of choosing data center location. OnlineAvailable:https://www.expedient.com/blog/the-where-and-why-of-choosing-data-center-location/2015[Accessed:17/7/2024], 2015.
[50] W. Torell, K. Brown, V. Avelar, The unexpected impact of raising data center temperatures, Write Paper 221 (2015).
[51] A.J. Díaz, R. Cáceres, R. Torres, J.M. Cardemil, L. Silva-Llanca, Effect of climate conditions on the thermodynamic performance of a data center cooling system under water-side economization, Energy Build. 208 (2020) 109634.
[52] Y. Zhang, K. Shan, X. Li, H. Li, S. Wang, Research and technologies for next-generation high-temperature data centers–state-of-the-arts and future perspectives, Renew. Sustain. Energy Rev. 171 (2023) 112991.
[53] Y. Zhang, H. Li, S. Wang, The global energy impact of raising the space temperature for high-temperature data centers, Cell Rep. Phys. Sci. 4 (10) (2023).
[54] Weather Spark. World temperatures. OnlineAvailable:https://weatherspark.com/compare/y/75981~68301~97684~ Comparison-of-the-Average-Weather-in-Berlin-Hamburg-Nicosia-Athens-Cairo-and-Amsterdam[Accessed: 01/05/2024].
[55] Cloudscene. Cloudscene datacenter market analysis. OnlineAvailable: https://www.cloudscene.com/market/,[Accessed:01/05/2024].
[56] J. Borgini. Data center power backup options to deal with downtime. OnlineAvailable:https://www.techtarget.com/searchdatacenter/tip/Data-center-backup-power-systems-standards-to-address-downti [Accessed:01/05/2024], May 2024.
[57] In Business News. Pv park 8mw in agia varvara, nicosia.OnlineAvailable:https://inbusinessnews.reporter.com.cy/article/2022/7/1/361371/photoboltaiko-parko-eur45-ekat-sta-skhedia-tes-aek/[Accessed:01/05/2024], 2022.
[58] ALA Planning Consultants. Environmental impact assessment study for the construction and operation of a 2,646 mw photovoltaic park in the community of agios theodoros in larnaca, May 2024.
[59] ALA Planning Consultants. Environmental impact assessment study for the construction and operation of a 3,769 mw photovoltaic park in dali municipality, May 2024.
[60] Altamira Real Estate. agricultural lands offered from altamira real estate in cyprus. OnlineAvailable.
[61] www.altamirarealestate.com.cy/.[Accessed:20/05/2024]. Eurostat. EU hourly labour costs, 2023.
[62] Eurostat. Eu report on electricity price statistics, 2024.
[63] Energy Institute Ember. Statistical review of world energy (2024)",. OnlineAvailable:https://ourworldindata.org/grapher/carbon-intensity-electricity [Accessed:20/05/2024], 2024.
[64] K. Talar. Solar farm cost investment unveiled: the true cost of building a profitable solar farm. OnlineAvailable: https://howtostoreelectricity.com/solar-farm-cost/[Accessed:01/07/2024], 2022.
[65] Savills Research Spotlight. Global farmland index report, September 2023.
[66] MP-Energy. Online quotations for pv park suppliers and installers in greece. OnlineAvailable:https://www.mp-energy.gr/.[Accessed:20/05/2024].
[67] Eurostat. Agricultural land prices and rent statistics, 2022.
[68] Eurostat. Eu agricultural land prices and rents: huge contrasts, 2024.
[69] Power-technology.com. Report analysis on leeuwarden solar pv park, netherlands. OnlineAvailable.
[70] www.power-technology.com/marketdata/leeuwarden-solar-pv-park-netherlands/[Accessed:20/05/2024].
[71] M. Tawalbeh, A. Al-Othman, F. Kafiah, E. Abdelsalam, F. Almomani, and M. Alkasrawi. Environmental impacts.
[72] Electricity authority of Cyprus, www.eac.org.cy.
[73] PV Magazine. Feed-in tariffs Europe. Available online: https://www.pv-magazine.com/features/archive/solar-incentives-and-fits/feed-in-tariffs-in-europe/#greece.
[74] W. Hemetsberger et al., "Global market outlook for solar power 23-27, Available online: https://www.solarpowereurope.org/insights/market-outlooks/global-market-outlook-for-solar-power-2023-2027-1 German Federal Network Agency Stimulering Duurzame Energieproductie, Available online: https://www.rvo.nl/subsidies-financiering/sd.