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Environmental and Economical Assessment for Net Zero Energy Data Centres

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Abstract

During the last years, the rapid increase of cloud computing, high-powered computing and the vast growth in internet use have aroused the interest in energy consumption and carbon footprint of data centres. The paper presents the results of an environmental and economic analysis to explore the path towards Net Zero Energy data centres. The economic and environmental assessment is presented for different data centre sizes (120 and 400 kW_{IT} of design IT power) and climate locations (Barcelona and Stockholm). It is the result of detailed TRNSYS simulations which have been developed in the framework of the European project RenewIT. Total cost of ownership and non-renewable primary energy consumption are used as main metrics to evaluate the performance of different energy concepts, energy efficiency strategies and the implementation of renewables, in particular PV and wind energy. Parametric analyses are presented to evaluate the influence of some of the main sizing variables for each concept.

Keywords: *Net Zero Energy Data Centres, renewable energy, energy efficiency, cost-benefit analysis*

1. Introduction

Data centres are unique buildings or dedicated spaces in other buildings which houses information technology (IT) rooms. The IT room is an environmentally controlled space that houses equipment and cabling directly related to computing and telecommunication systems which generate a considerable amount of heat in a small area. In the last years, the total energy demand of data centres has experienced a dramatic increase. This is why data centre industry and researchers are undertaking efforts to implement energy efficiency measures and to integrate renewable energy into its portfolio to overcome energy dependence and to reduce operational costs and CO_2 emissions (Salom, 2016). Oró et al. (2014) presented a comprehensive overview of the current data centre infrastructure and summarized a number of currently available energy efficiency strategies and renewable energy integration into the data centre industry together with the recent efforts for its characterization using numerical models. Shuja et al. (2016) presented a survey of case studies and enabling technologies to make cloud data centres more sustainable. In the framework of the European funded RenewIT project (Salom, 2016) holistic and dynamic energy models have been developed in TRNSYS (TRNSYS, 2012) to characterize the overall energy performance and the life-cycle economic impact of data centres after the implementation of energy efficiency strategies and renewables. This paper presents the economic and environmental results for different energy concepts as function of the data centre size (120 and 400 kW_{IT} of design IT power, being IT power the electrical power that must be supplied to the IT devices to work) and climate location in Europe (Barcelona and Stockholm).

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2. Methodology

Selected energy concepts which implement cooling and power supply of data centres with renewable energy systems are evaluated using detailed TRNSYS simulation. A set of TRNSYS projects to model the energy behaviour and compute the investment and running costs of different data centre concepts have been built in the framework of the RenewIT project. The different models are based on the combination of subsystems of a data centre facility using TRNSYS' macros capabilities and they have been run with a 15-min time step to derive the results presented in the current paper. Due to limited space, only a brief description of the modelled concepts (Shrestha et al., 2015; Rudolf et al., 2016) is presented in section 3 which have been validated with real life case studies (Salom et al., 2015; Oró et al, 2015) and lead to the development of the RenewIT tool (2016) (Garcia et al., 2016).

To evaluate the economic and the environmental impact of the use of advanced energy solutions in data centre portfolio different metrics have been evaluated. The total cost of ownership (TCO) is the main metric to evaluate the economic benefits of an applied solution. The TCO is the addition of the initial investment costs (CAPEX), the operational expenditures (OPEX) and the replacement cost minus the residual value of components, based on the methodology proposed by CEN (2008). The TCO is used to assess the true total costs of building, owning, and operating a data centre energy facility during a certain amount of years. In the present study, the assessment period is equal to the components life time span which is 15 years; therefore the cost of replacement of the components is neglected in the economics calculations and the residual value is zero. The OPEX is the net present value of the costs for running a data centre facility. It includes the energy costs ($OPEX_{EC}$), both electricity and/or other energy carrier costs as well as the costs derived from the data centre water consumption, the maintenance costs ($OPEX_{MC}$) and the environmental costs ($OPEX_{CO2}$), i.e. the cost of the CO_2 emissions. The energy costs are calculated for each energy carrier and prices are temporary dependent.

$$TCO = CAPEX + OPEX \qquad \text{(eq. 1)}$$

$$OPEX = OPEX_{EC} + OPEX_{MC} + OPEX_{CO2} \qquad \text{(eq. 2)}$$

The annual non-renewable primary energy consumption of the data centre (PE_{nren}) is used as main metric to evaluate the environmental performance although other metrics are widely used in the industry to evaluate the energy efficiency measures such as the well-known power usage effectiveness (PUE) or the data centre water consumption and CO_2 emissions. The non-renewable primary energy means energy from non-renewable sources which has not undergone any conversion or transformation process. The calculation of PE_{nren} is based on equations 3 and 4 (being equation 4 the evaluation of Pe_{nren} at each time step) and the energy fluxes through the data centre boundary depicted in Fig. 1, where both delivered and exported energy carriers are weighted using the non-renewable primary energy weighting factors.

$$PE_{nren} = \int_{year} Pe_{nren}(t) \cdot \mathrm{dt} \qquad \text{(eq. 3)}$$

$$Pe_{nren} = \left[\left(e_{del,el} \cdot w_{del,nren,el}\right) + \left(e_{del,fuel} \cdot w_{del,nren.fuel}\right) + \left(e_{del,Dheat} \cdot w_{del,nren,Dheat}\right) + \left(e_{del,DCool} \cdot w_{del,nren,DCool}\right)\right] - \left[\left(e_{exp,el} \cdot w_{exp,nren,el}\right) + \left(e_{exp,heat} \cdot w_{exp,nren,heat}\right)\right] \qquad \text{(eq. 4)}$$

where $e_{del,i}$ and $e_{exp,i}$ are the energy entering to and exported from the data centre boundary respectively for energy carrier i; $w_{del,nren,i}$ and $w_{exp,nren,i}$ are the non-renewable weighting (or conversion factor) for each energy carrier delivered or exported. About energy carriers, *el* means electricity; *fuel* can be natural gas, biogas or biomass; *Dheat* and *DCool* means thermal energy coming for a district heating and cooling infrastructure and *heat* means exported heat to a district heating or surrounding buildings. The renewable energy ratio (RER_{EP}), equation 5, is the metric that allows calculating the share of renewable energy use in a data centre. The renewable energy ratio is calculated relative to the total primary energy used in the data centre facility.

$$RER_{EP} = \frac{\sum_i e_{ren,i} + \sum_i[(w_{del,tot,i} - w_{del,nren,i}) \cdot e_{del,i}]}{\sum_i e_{ren,i} + \sum_i[(w_{del,tot,i} \cdot e_{del,i}) - \sum_i[(w_{exp,tot,i} \cdot e_{exp,i})} \qquad \text{(eq. 5)}$$

Notice that in order to compare the results between data centres of different size, both, PE_{nren} and TCO are normalized by the design IT power capacity of the facility [kW_{IT}]. Therefore, normalized PE_{nren} is expressed in [$kW \cdot h_{PE,nren}/kW_{IT} \cdot year$] while normalized TCO is expressed in [$€/kW_{IT}$]

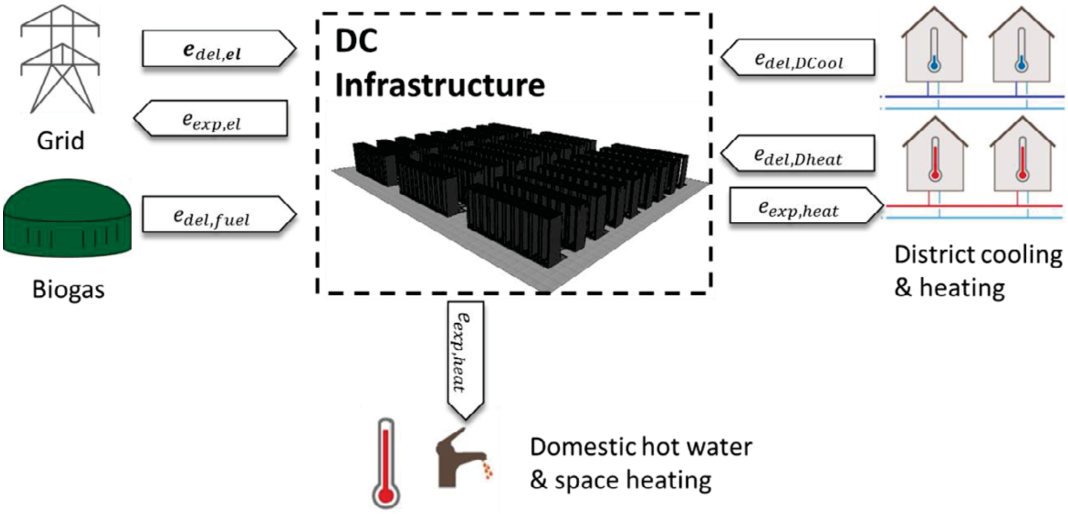

Fig. 1: Delivered and exported energy fluxes in a data centre facility

3. Concepts and scenarios

The present section describes briefly the different energy concepts, which have been simulated as well as the main characteristics of the four scenarios analysed: two sizes in two locations.

The concept 1, shown schematically in Fig. 2, is based on a conventional system where vapour-compression chillers along with dry coolers are used to produce cooling energy when it is required. Fig. 2 depicts the thermal and electric scheme of this concept. The electrical power required to drive the chiller and to run the IT hardware can be generated by a photovoltaic system and/or wind turbines installed in the building footprint; additional power is purchased from the grid. In winter, indirect air free cooling can be activated for efficient cooling supply to the data centre.

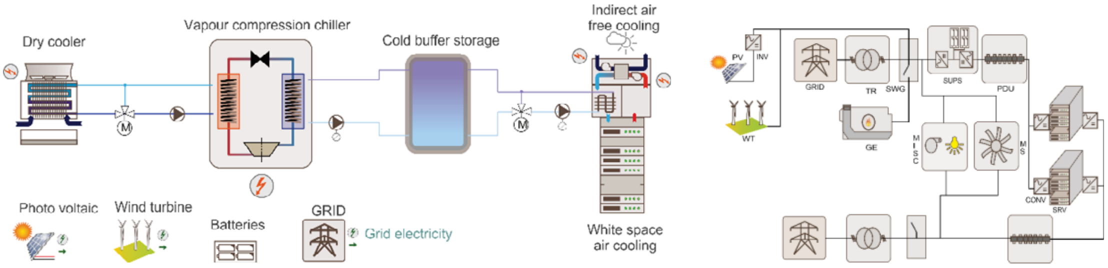

Fig. 2: Thermal scheme (left) and electric scheme (right) of concept 1 (conventional data centre concept with on-site PV and/or wind power systems)

Concept 2 is aimed for those data centres with liquid cooled servers. Depending on the technology used and implemented, part of the infrastructure will demand air cooling while other liquid cooling. Therefore, in this solution, chilled water for air-cooling is supplied by a district cooling system while heat from direct liquid cooling is reused for space heating and domestic hot water by means of a heat pump. A dry cooler could be used if there is no heat demand. Fig. 3 shows the thermal and electric scheme of this concept. Notice that during summer, chilled water from the district cooling system is used to cool the air flowing into the data centre but during winter, mostly indirect air free cooling can be conducted. With the objective to increase the use of renewables in the facility, this concept makes sense if the district heating and cooling system is fed by renewables at least to some extent. This is represented by the value used in the simulations of $w_{del,nren,DCool}$, which is 0.6, with the hypothesis of a district cooling system based on a biogas CHP system with absorption chillers.

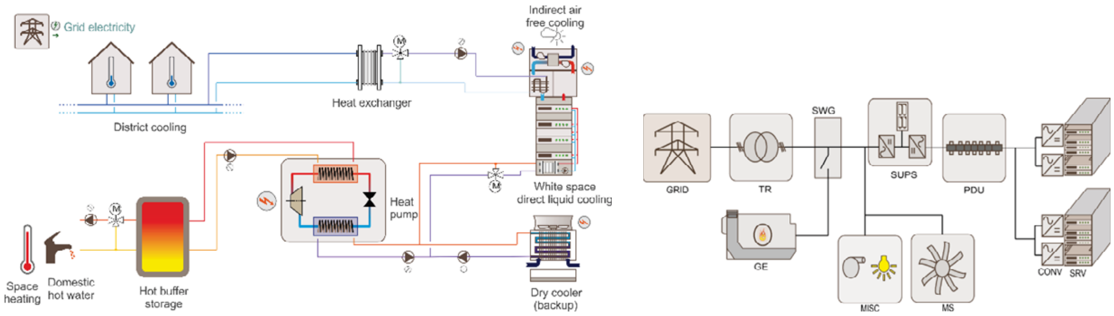

Fig.3: Thermal scheme (left) and electric scheme (right) of concept 2 (District cooling and heat reuse)

In concept 3, wet cooling towers (without the use of mechanical chillers) are used to produce cooling energy. Fig. 4 depicts the thermal and electric scheme of this concept. In winter, direct air free cooling is performed for efficient cooling supply to the data centre. When the evaporative free cooling is not possible, backup vapour-compression chillers along with the cooling towers are used. The electrical power required to drive the cooling towers and the backup chillers are purchased from the national grid.

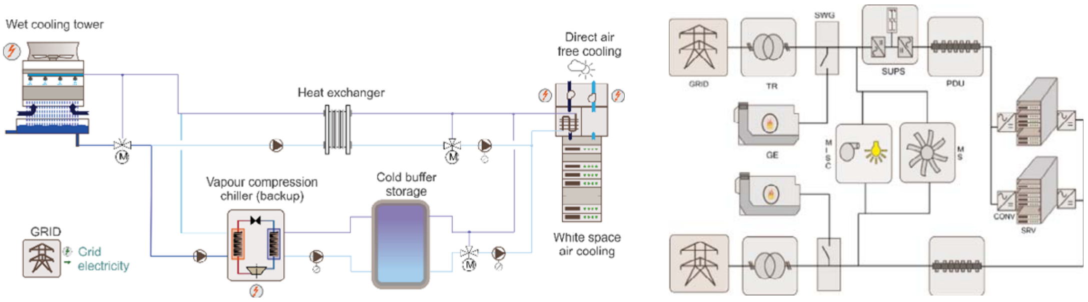

Fig. 4: Thermal scheme (left) and electric scheme (right) of concept 3 (Grid-fed wet cooling tower without chiller)

In concept 4, a biogas-fed fuel cell is applied for generating both power and heat, which is used for driving an absorption chiller during summer which produces cool (Fig. 5). In winter, indirect air free cooling avoids the operation of the chillers if it is activated. Then, the waste heat from the fuel cell can be recovered for space heating or might also be dissipated by a wet cooling tower. Because of the high temperature and pressure of the hot water, shell and tube heat exchanger are used for transferring the heat between the cooling tower and the fuel cell hot water circuit.

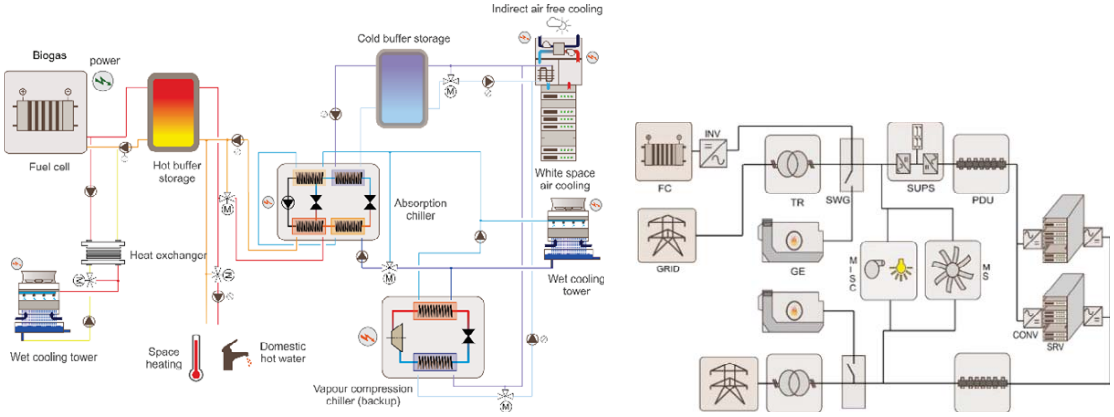

Fig. 5: Thermal scheme (left) and electric scheme (right) of concept 4 (Biogas fuel cell with absorption chiller)

The concept 5 shown schematically in Fig. 6 is based on biogas-fed tri-generation by means of a reciprocating engine combined heat and power (CHP) plant. The heat from this plant is used for driving a single-effect absorption chiller during summer and supplying space heating for offices or buildings close to the data centre during winter. Additionally, indirect air free cooling is implemented for efficient cooling supply to the data centre especially during winter. Then, the heat from the CHP plant is used for space heating and producing domestic hot water if required.

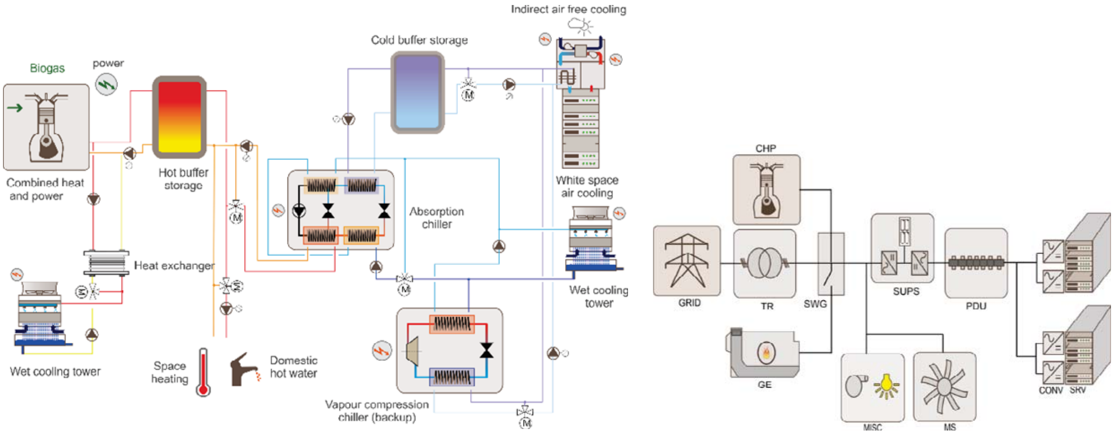

Fig. 6: Thermal scheme (left) and electric scheme (right) of concept 5 (Reciprocating engine CHP with absorption chiller)

Two different IT power capacities (120 kW and 400 kW) are analysed for each of the locations (Barcelona and Stockholm). In each of the scenarios, the main other parameters such as the rack density, the occupancy ratio (1.0 meaning fully occupied), the safety margin factor (1.0 meaning no safety margin), and the load profile are fixed as shown in Table 1. Safety margin factor indicates how much the data centre facility is oversized referred to the expected maximum IT Power, meaning 0.8 that the facility is 25% oversized. The white space area depends of the nominal IT Power capacity and the rack density and it was estimated using average ratios in the industry to determine the amount of floor occupied by a rack. In the present study the IT load profile used is a combination of the most standard/homogeneous IT workload profiles: Web, HPC and Data. In particular, the workload profile used is composed of 35% HPC, 30% Data and 35% Web based on Carbó et al. (2016). Table 2 shows some of the basic parameters used to define the sizing of the main elements in the different energy concepts. These parameters are used in the base cases scenarios for each of the concepts.

Table 1: Data Centre Scenarios

		Name of the scenarios			
Parameter	**Unit**	**BCN-120**	**BCN-400**	**STO-120**	**STO-400**
Location	[-]	Barcelona	Barcelona	Stockholm	Stockholm
IT power capacity	[kW]	120	400	120	400
Rack density	[kW/rack]	4	4	4	4
Occupancy ratio	[-]	1	1	1	1
Safety margin factor	[-]	0.8	0.8	0.8	0.8
White space area	[m^2]	90	300	90	300
IT Load profile	[-]	Mixed	Mixed	Mixed	Mixed
Average electricity price	[€/kW·h$_{\text{el}}$]	0.10	0.10	0.11	0.11
Biogas price	[€/kW·h$_{\text{biogas}}$]	0.08	0.08	0.08	0.08
District cooling price	[€/kW·h$_{\text{DCool}}$]	0.035	0.035	0.035	0.035
Exported heat price	[€/kW·h$_{\text{heat}}$]	0.025	0.025	0.025	0.025
CO$_2$ price	[€/tCO$_2$]	8.99	8.99	8.99	8.99
$w_{del,nren,el}$ (average)	[kW·h$_{\text{PE}}$/kW·h$_{\text{el}}$]	1.83	1.83	1.30	1.30
$w_{del,nren.biogas}$	[kW·h$_{\text{PE}}$/kW·h$_{\text{biogas}}$]	0.5	0.5	0.5	0.5
$w_{del,nren,DCool}$	[kW·h$_{\text{PE}}$/kW·h$_{\text{DCool}}$]	0.6	0.6	0.6	0.6
$w_{exp,nren,heat}$	[kW·h$_{\text{PE}}$/kW·h$_{\text{heat}}$]	0.7	0.7	0.7	0.7

Table 2: Specific assumptions for the investigated concepts. Base case scenarios

#	Description	Basic parameters
1	Vapour compression chillers with dry cooler. Additional on-site PV/Wind power system can be added	VCCH Nominal power • 180 kW (120 kW_{IT}) • 600 kW (400 kW_{IT})
2	District cooling and heat reuse	Heat reuse ratio = 1.0; Efficiency of liquid cooling = 0.65; Ratio of heat pump cooling power and max. liquid cooling demand = 0.50
3	Wet cooling tower	Wet cooling tower nominal power: • 225 kW (120 kW_{IT}) • 750 kW (400 kW_{IT})
4	Biogas fuel cell and absorption chiller	Heat reuse ratio = 1.0; Ratio of absorption chiller size related to the total cooling power of data centre = 0.3; Ratio of fuel cell size related to absorption chiller size = 1
5	Reciprocating engine CHP with biogas	Heat reuse ratio = 1.0; Ratio of absorption chiller size related to the total cooling power of data centre = 0.3; Ratio of biogas engine size related to absorption chiller size = 1

The simulation models developed allow the introduction of a set of energy efficiency measures individually or combined. The energy efficiency strategies are technical solutions that can be applied in almost all the data centres and combined with any system to supply cooling and power with or without renewable energy sources (RES). Therefore, first the strategies that allow to reduce the load demand as much as possible have been analysed before studying the use of the renewable resources available in the data centre's location. Further details about the energy efficiency measures can be found in Shrestha et al. (2015) which can be grouped in several categories:

- Advanced measures for building design. The building design may affect the cooling demand of the data centre.
- Advanced measures for electrical supply. Some well-known strategies are modular UPS and bypassed UPS which achieve a reduction of electrical losses in the power distribution lines. In the results presented in this paper, modular UPS have been applied when energy efficiency measures are mentioned.
- Advanced measures for cooling supply. These measures include the use of free cooling, hot/cold aisle containment for a better air management, variable air flow and the increase of allowable IT working temperatures. Using highly energy efficient components, in particular vapour compression chillers, can also lead to a significant reduction of the total energy demand.
- Advanced measures for IT management. Consolidation aims to concentrate IT workloads in a minimum number of servers to maintain the inactive servers in idle state. Then also those servers in idle state can be turned off. Finally, IT scheduling aims to move IT jobs according to the availability if RES when it is possible.

4. Results and discussion

4.1. Concepts comparison and impact of energy efficiency measures

Figure 6 presents the results of the different concepts proposed for the four scenarios analysed. In the same graph the results for each of the concepts applying the complete set of energy efficiency measures are presented and compared with the results of the base case where none of these energy efficiency measures are applied. Normalized TCO and normalized PE_{nren} are presented in Fig.6-left for Barcelona and in Fig. 6-right for Stockholm.

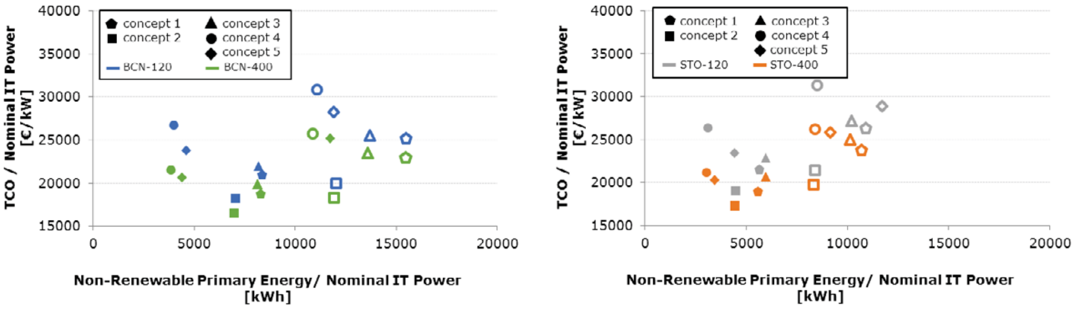

Fig. 6: Normalized TCO vs. normalized PE_{nren} for the location of Barcelona (left graph) and Stockholm (right graph). Results of no applying energy efficiency measures (unfilled shapes) and applying energy efficiency measures (filled shapes) are shown for all the concepts.

Analysing the influence of different sizes of the data centre for each of the concepts, the results show that the normalized PE_{nren} is similar for each concept independently of the size but there exists significant differences on the data centre cost. On average building and operating a data centre of 400 kW compared to one of 120 kW costs 13% less when energy efficiency measures are applied and 11% less for the base cases.

Talking about costs, one can observe that for the same concepts and the same sizes there are no significant differences between operating a data centre in Barcelona or in Stockholm under the hypothesis used in this study. TCO costs are mainly driven by the sizes of the main elements and labour costs of building a data centre to determine the CAPEX (which is not influenced by the location since average European prices have been used) and for the energy prices that influence the OPEX (which differences come from the differences in the electricity prices). The average difference of TCO between having a data centre in Stockholm or in Barcelona is 3%. However, the two locations present significant differences in the absolute values of PE_{nren} between the locations. As PE_{nren} considers the amount of non-renewable primary energy in the electricity network through the appropriate weighting factors there is a difference between the locations as well as in the influence of other climatic conditions: for example there are more hours of free cooling available in Stockholm than in Barcelona. Table 3 shows the results for concept 1 and concept 4, where differences between locations in normalized PE_{nren} are reduced because concept 4 is mainly based on biogas which has the same conversion factor for the two locations.

Table 3: Normalized PE_{nren} consumption [$kW{\cdot}h_{PE,nren}/kW_{IT}{\cdot}year$]

	BCN-400	**STO-400**
Concept 1- Conventional system: VCCH with dry coolers		
Without energy efficiency measures	15 314	10 711
With energy efficiency measures	8 194	5 541
Concept 4 - Biogas fuel cell with absorption chiller		
Without energy efficiency measures	10 884	8 415
With energy efficiency measures	3 846	3 033

For all the concepts and the locations, there is a significant benefit of applying as much energy efficiency measures as possible which will produce savings in the total costs and in the primary energy consumption. IT management strategies are the most beneficial ones, together with some measures which allow increasing the number of free-cooling hours or improving the efficiency in the electrical distribution. For the case studies presented here the impact of applying energy efficiency measures are 50% (in Barcelona) and 52% (in Stockholm) of reduction on PE_{nren} as well as 15% (Barcelona) and 17% (Stockholm) of TCO savings.

According to the results of the current study operating a conventional data centre (concept 1) without renewables can cost around 24450 €/kW_{IT} (± 7%) and consuming about 15383 $kW{\cdot}h_{PE,nren}/kW_{IT}{\cdot}year$ (± 0.5%) in Barcelona and 10750 $kW{\cdot}h_{PE,nren}/kW_{IT}$ (± 0.4%) in Stockholm. Although, it was commented that a significant reduction of TCO and PE_{nren} is possible applying different energy efficiency strategies, a reduction of primary energy resources is possible with different concepts to run a data centre. Among the ones presented in section 3, the concept 4 based on biogas fuel-cells gives the best results in terms of PE_{nren} reduction although it is an expensive concept compared with a conventional data centre. Having a CHP with a biogas engine, concept 5, gives also promising PE_{nren} savings but is less expensive than concept 4 although still having TCO higher than a conventional data centre. Both concepts 4 and 5 rely also on the availability of biogas as local and/or imported resource. The most cost effective concept, i.e. the one that combines more PE_{nren} and TCO savings, is concept 2 which connects the data centre to a district cooling system and heat from the data centre can be used for heating purposes. The reduction of TCO can reach up to 21% and the PE savings up to 22% when no energy efficiency measures are applied. Concepts 2, 4 and 5 rely on a 100% reuse of the heat produced by the facility. Finally, the implementation of concept 3 based on wet cooling towers show slightly higher economic figures than the conventional case and moderate PE savings compared to other concepts which also dependent on the location and if free-cooling strategies have been applied.

4.2. Analysis of concept 1 adding on-site renewable energy systems

Fig. 7 depics graphically the results of applying on-site renewable power systems to a conventional data centre: PV and wind turbines systems. On one hand, different sizes of on-site PV systems, which are characterized by their PV peak power, have been simulated. For the scenarios of 120 kW_{IT} and 400 kW_{IT}, PV systems are varied from 0 to 50 kW_p and from 0 to 100 kW_p, respectively (see Table 4). PV simulation which is integrated as part of the overall TRNSYS data centre models neglects the shadows effects of surrounding buildings and the own shadows of a large flat roof mounted PV field. The PV field is considered oriented south with an inclination slope of 32.2º for Barcelona and 44.6º for Stockholm. On the other hand, the use of small wind power systems has also been studied. For the 120 kW_{IT} data centre a unique 50 kW rated power wind turbine (Aeolos, 2015) is considered; while, for the 400 kW_{IT} data centre, the impact of having one and two identical wind turbines has been calculated.

Table 4: Specific assumptions of on-site PV and wind power systems for the investigated concept 1

Parameter	Unit	BCN-120 / STO-120	BCN-400 / STO-400
Total PV peak power	[kWp]	0, 10, 20, 30, 40, 50	50, 60, 70, 80, 90, 100
Total Wind rated power	[kW]	0, 50	0, 50, 100

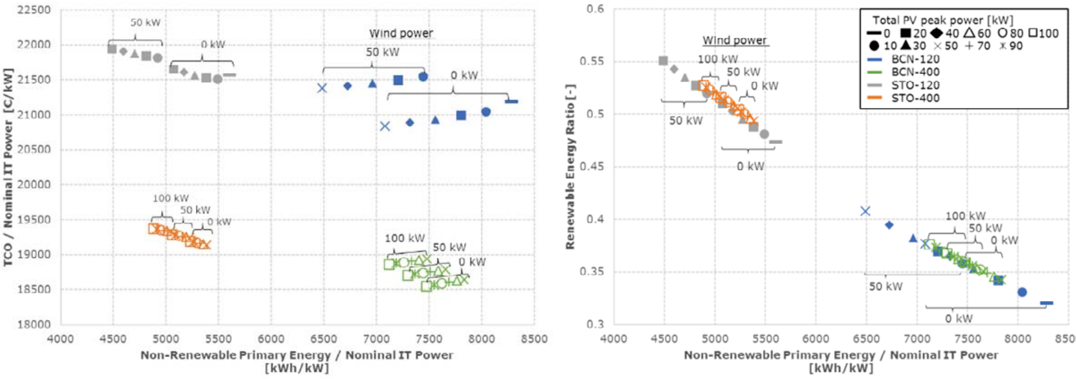

Fig. 7: Normalized TCO (left) and RER (right) vs. normalized PE_{nren} for different scenarios when adding on-site renewable power systems to concept 1

As expected, adding on-site PV and wind power systems implies an increase of the RER, as well as a decrease of the PE_{nren}. However, when analysing the economic and the energetic impact, it is shown that on-site PV systems are cost-effective when they are implemented in data centres located in Barcelona (south Europe) under the hypothesis of this study. PV systems in Stockholm are not cost-effective due to investment and the electricity prices considered and the low solar radiation over the year. Renewable electricity produced by on-site wind power systems in Barcelona and in Stockholm, which is based on wind availability in Meteonorm data files, is not enough to compensate the investment needed for such a systems. Using on-site wind power systems needs to be installed in locations where wind resource is available, which strongly depends on local conditions.

Table 5 shows the required roof space for a 50 kW_p and 100 kW_p PV field under the hypothesis that the PV field is mounted in a flat roof by tilted modules with a distance between rows based on rules which optimally minimize the occupancy of the roof and maximizes the PV production (RenewIT tool, 2016). The required roof space depends on the size of the PV system and on the location. Although different types of data centre buildings exists and whitespace rooms can be part of large corporate buildings, available roof space (A_{roof}) is estimated in relation with the whitespace area ($A_{DC,room}$) as shown in equation 6 and based on information available from the industry. The required roof space for the PV field exceeds the available space. Results of the load cover factor, which represents the ratio between the power produced by PV and the overall electrical data centre consumption, are also presented in Table 5. Load cover factor is very low (less or equal to 10% in most of the cases) even with PV systems that go beyond the available roof space in all the cases analysed. This means, that under grid parity conditions having an on-site PV system is a good solution to reduce the environmental impact of a data centre. Although this will be very dependent on the case, conventional roof mounted PV fields are limited by the available roof space covering a small portion of the electricity consumption of a data centre. Using PV to have larger load cover factors would require to use additional space available in the data centre footprint or explore BIPV (Building Integrated PV) solutions.

$$A_{roof} = f_{roof\text{-}ws} \cdot A_{DC,room} \qquad \text{where} \qquad f_{roof\text{-}ws} \cdot = 2.2\ m^2_{roof}/m^2_{DC,room} \qquad \text{(eq. 6)}$$

Table 5: Required roof space, available roof space and load cover factor for different scenarios with on-site PV power system for the investigated concept 1

		Name of the scenarios			
Parameter	**Unit**	**BCN-120**	**BCN-400**	**STO-120**	**STO-400**
Required roof space – 50 kWp	[m^2]	796		1570	
Required roof space– 100 kWp	[m^2]	1593		3140	
Available roof space	[m^2]	198	660	198	660
Load cover factor – 50 KWp	[%]	16	5	10	3
Load cover factor – 100 KWp	[%]	-	9	-	6

4.3. Analysis of concept 2 for different liquid cooling solutions and amount of heat reuse

Fig. 8 presents the results of the parametric analysis for concept 2 (data centre connected to a district cooling and heating system with reuse of heat from direct liquid cooled servers) for data centres of 400 kW_{IT} in both locations (BCN-400 and STO-400). Only results for 400 kW_{IT} are presented to contribute to readability of the graphs. Maintaining the hypothesis that 100% of the heat extracted from the data centre can be reused, the sensitivity analysis for two parameters has been performed. On one hand, there is the type of liquid cooling system which is characterized by its efficiency: 0.65 for on-chip liquid cooling and $1.0 \simeq 0.99$ for immersed liquid cooling system. This parameter means that for on-chip liquid cooling, 65% of the heat is extracted by water while the other 35% by air, while for immersed liquid cooling system, 100% of the heat is extracted by water. On the other hand, the size of the heat pump is varied which is characterized by the ratio between the heat pump cooling power and the maximum liquid cooling demand of the data centre. This ratio is varied from 0.1 to 0.5. The results shows that as the type of liquid cooling system allows extracting higher amount of heat from the servers, PEnren decreases as well as RER increases. As the ratio determining the size of the heat pump increases there is a reduction of the PE_{nren}, too. Having an immersed liquid cooling system with the capability to extract more heat is a bit more expensive, but with optimum sizes of the heat pump differences between different liquid cooling technologies are minimized both in terms of TCO and PE_{nren}. As it is shown in Fig. 8, the size of the heat pump has an important effect on the indicators having an optimal value between 0.4 and 0.5, while the differences between these two values of the parameter are negligible.

4.4. Analysis of concept 3 adding on-site PV power systems

Fig. 9 shows the results of applying on-site PV power sytems to concept 3 for the different scenarios. Results are in coherence with the findings of adding PV to concept 1 already explained in section 4.2. PE_{nren} decreases and RER increases as the size of the PV system increases, being cost-effective in Barcelona and not economically feasible for Stockholm in terms of TCO.

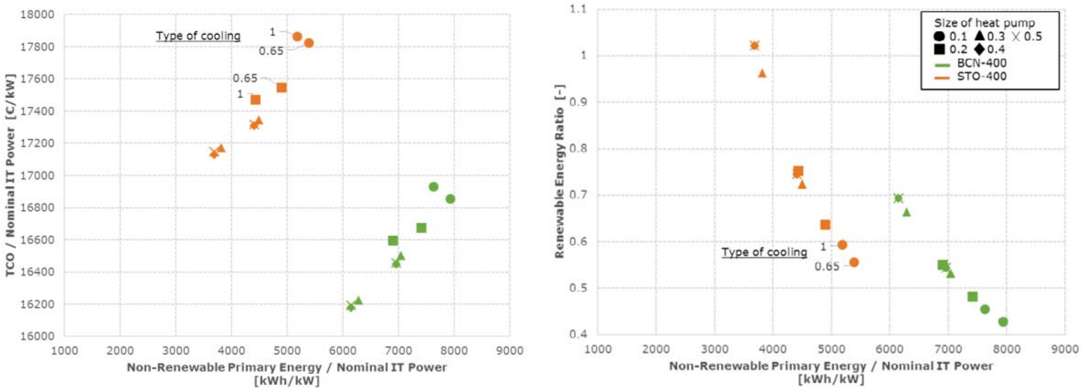

Fig. 8: Normalized TCO (left) and RER (right) vs. normalized PE_{nren} for different scenarios, types of cooling (On-chip/ Immersed) and sizes of the absorption chiller for concept 2

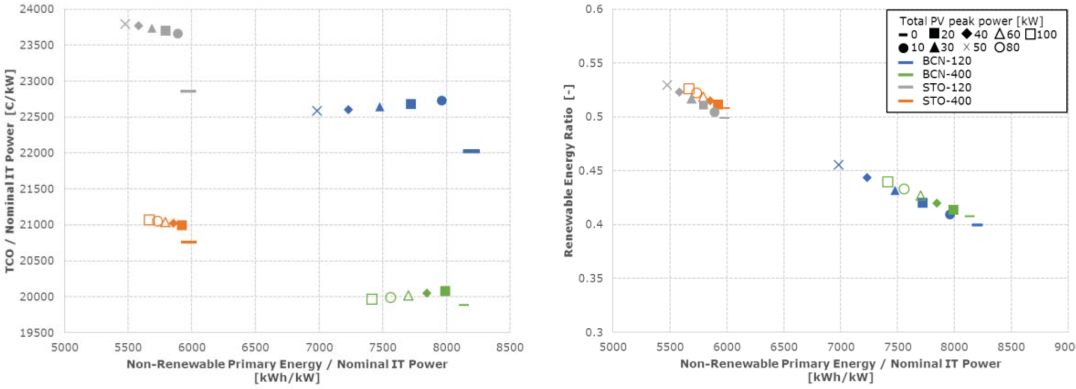

Fig. 9: Normalized TCO (left) and RER (right) vs. normalized PE_{nren} for different scenarios when adding on-site PV power systems to concept 3

4.5. Analysis of concept 4 with different sizes of absorption chiller and amount of heat reuse

Fig. 10 presents the results of a parametric analysis for concept 4 (data centre based on biogas fuel-cell driving an absorption chiller) for all the scenarios. Figure 10-right only shows results for 400 kW_{IT} data centre to improve the readability. The variation of two parameters has been analysed. One is the amount of heat produced by the facility which can be reused for other purposes outside the data centre: this is characterized by a ratio between 0.2 and 1.0, meaning 1.0 that 100% of the heat can be reused outside the data centre. The other parameters is the size of the absorption chiller which is characterized by a parameter from 0.2 to 0.5 which is the ratio between absorption cooling capacity and the total cooling power of the data centre. The results in Fig. 10 show that an increase of the absorption chiller size is not a cost-effective measure although it has an important effect on the reduction of the PE_{nren} and the increase of RER. For a ratio of the absorption chiller greater than 0.3, RER values are close to or great than 1.0 which indicates that the data centre facility is becoming a positive producer of primary energy even with low ratios of heat reuse. When the potential heat reuse is being reduced, the TCO increases as well as the PE_{nren} as consequence of the reduction of the exported heat.

4.5. Analysis of concept 5 with different sizes of absorption chiller and amount of heat reuse

Fig. 11 presents the results of a parametric analysis for concept 5 (data centre based on CHP – biogas engine driving an absorption chiller) for all the concepts. As in concept 4, the variation of two parameters has been analysed. One is the amount of heat produced by the facility which can be reused for other purposes outside the data centre; the other parameter is the size of the absorption chiller. The results in Fig. 11 show the same tendency than the ones for concept 4. An increase of the absorption chiller size is not a cost-effective measure although it has an important effect on the reduction of the PE_{nren} and the increase of RER. As well, as the amount of heat that can be reused is reduced (lower values of heat reuse ratio) the facility becomes more expensive to operate and PE_{nren} increases.

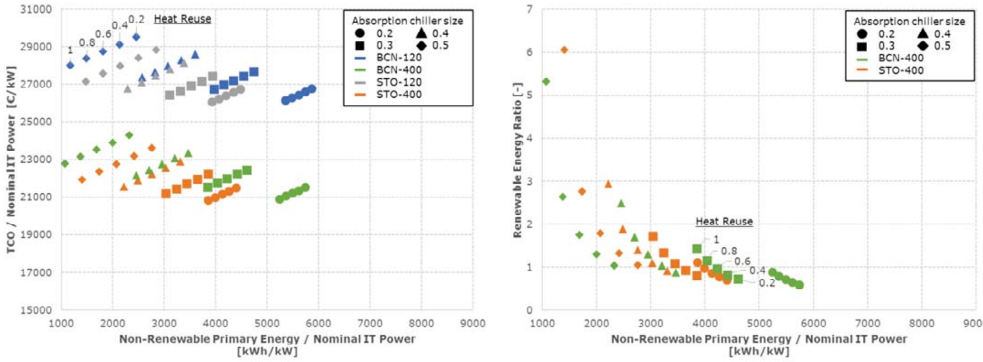

Fig. 10: Normalized TCO (left) and RER (right) vs. normalized PE_{nren} for different scenarios, relative absorption chiller sizes and amount of heat reuse ratio for concept 4

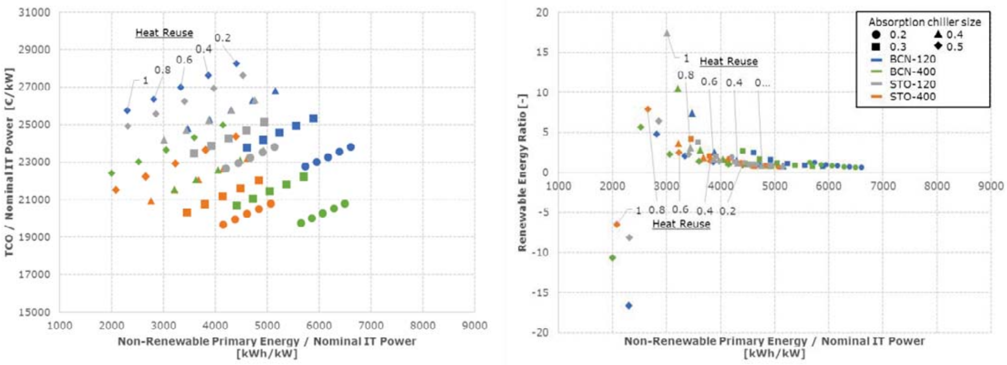

Fig. 11: Normalized TCO (left) and RER (right) vs. normalized PE_{nren} for different scenarios, absorption chiller sizes and amount of heat reuse ratio for concept 5

5. Conclusions

The extensive use of internet and cloud computing has increased the energy used for data centre industry. Thus, this paper studies the economic and environmental performance of different energy efficiency and renewable energy concepts in these unique facilities. Detailed TRNSYS simulation models developed in the European project RenewIT have been used to analyse the impact of those strategies in different data centre sizes and locations. In particular, the analysis has been performed for 120 and 400 kW_{IT} data centres in two climate locations: Barcelona and Stockholm. The aim of the different energy concepts analysed is to reduce the non-renewable primary energy consumption (PE_{nren}) as well as to explore how cost-effective each solution in terms of total cost of ownership (TCO) can be. Applying the most well-known energy efficiency measures such as free cooling, hot and cold aisle containment, the use of modular UPS, etc. lead to important reductions in PE_{nren} (about 50%) and in TCO (about 17%) and it should always be a must to explore energy efficiency measures alongside applying renewables. The concepts have also been compared to each other and the results show that the location has an influence on the absolute values of PE_{nren} due to climatic conditions and the differences between the shares of renewable in the national power grid, but there is not a lot of differences in TCO between the locations regarding the hypothesis about energy carrier prices considered in this study.

Data centres are very complex energy facilities and detailed optimization using the developed energy models is recommended together with information of local constraints, as energy prices or available space for renewables, to seek for a cost effective option. Together with the overview of the different energy concepts, basic parametric analysis have been performed in this paper varying some of the main parameters which characterizes the behaviour of each of the energy concepts. Concepts based on biogas CHP systems (with fuel cells or reciprocating engine) present promising numbers of PE_{nren} reduction but are not cost effective. These concepts rely on the availability of biogas as fuel resource as well as on reusing the heat which is not used by the absorption chiller outside the data centre whitespace. Small relative sizes of absorption chillers give better values of TCO but PE_{nren} increases. The connection of a data centre to a district cooling and heating grid and reusing the heat from liquid cooled servers is a very promising solution and cost effective. Parametric analysis have been presented considering different heat pump sizes and different liquid cooling technologies and the reduction of PE_{nren} can be up to 22% compared to a conventional data centre. Using on-site PV or wind power production can be an interesting option towards Net Zero Energy data centres, but is dependent on the location: the local availability of wind resource for wind production and the availability of free space to integrate PV panels. In locations with grid parity situation PV is a feasible solution and load cover factor is limited by the availability of space for the PV panels.

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