Achieving net zero carbon performance in a commercial building by aligning technical and policy alternatives – An UK case study

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Abstract:
Quantifying a detailed inventory of carbon emissions attributed to a retail building is of vital importance to minimize (or offset) their environmental impact. However, quantifying the environmental impact of a commercial building's operation has attracted great controversy regarding both the carbon fields considered within the building's operational boundaries and the different responsibility levels among participants. This paper details a robust framework on how businesses operating under UK policy can measure the operational carbon performance attributed to their buildings. Furthermore, the paper investigates how the quantified emissions can be offset in order to reach net zero carbon operational performance.
The analysis is structured in three levels and its applicability is showcased through an industry-sourced example of a supermarket building. The first level aims to classify building emissions according to their sources namely electricity consumption, on-site fuel burning, water supply, transport operations and waste management & disposal. The developed carbon fields' analysis technique treats a commercial building as an on-going energy consuming system where different operations (e.g. transport activities) contribute to the building's commercial use as well as to its operational carbon footprint. In the second level, the study compares a food store's carbon footprint across different supply and operation scenarios in order to analyse how each sector can influence emissions. In the third stage, the research details the carbon off-setting achieved by installing a bioenergy combined heat and power (CHP) unit in its premises and thus achieving net zero carbon performance.
Results illustrate the environmental benefits for different CHP capacity solutions. These results show how urban cogeneration plants can de-carbonise UK buildings. However, the UK carbon accounting framework is still evolving and therefore is constantly subject to regulatory changes. Consequently, business stakeholders need to be periodically updated with carbon regulation if they wish to design, manage and sustain zero carbon buildings.

Keywords:
Bioenergy, Cogeneration, Commercial buildings, Greenhouse gas (GHG) protocol, Net zero carbon operation.

1. Introduction

The buildings sector is considered one of the most dominant sources of emissions globally and is responsible for 45% of the total consumed energy and its associated emissions [1]. The European Union policy framework with its Directive on Energy Performance of Buildings (EPBD) proposes that all buildings associated with the public sector should achieve "nearly zero" energy operation by 2018 and the same applies for all new constructions by 2020 [2]. Moreover, the UK Government, through its policy, requires operationally zero carbon residential buildings by 2016; while commercial buildings have to follow the same directive by 2019 [3,4]. Relevant regulation is also found in the US policy framework with the Net-Zero Energy Commercial Building Initiative calling for all newly built commercial buildings and all aged ones to achieve "net zero" energy operation by 2030 and 2050 respectively [5]. Building stakeholders need to comply with the above regulations and, therefore, a detailed understanding of the emission sources associated with building operation is needed. The paper develops a framework on how businesses operating under the UK policy can measure the carbon performance of their commercial buildings by outlining a methodology to quantify operational emissions and also investigates how these emissions can be offset for an eventual net zero carbon operational performance. The practical implementation of this methodology is showcased with an industry-sourced example and specifically by quantifying and mitigating the carbon performance of a food retail building through two contradicting carbon operational scenarios. The food-retailing sector is specifically chosen as a case study since it is carbon intensive and accounts for 3% of the total consumed electricity across the UK while representing 1% of the country's generated emissions as well [6,7].

2. Literature review

2.1. Classification of (net) zero energy/carbon definitions

Although national policies mandate for "zero" or "net zero" buildings, there is controversy around the definition of these terms [8-12]. Firstly, the expression "net zero" implies the connection of the building to a utility grid (on-grid case) and their balanced interaction [8,9,11-14]. On the other hand, an off-grid Zero Energy Building (ZEB) has to balance its energy requirements only through on-site renewable energy generation combined with energy efficiency and conservation measures [14-16]. In the context of a building's operation, the Zero Carbon Building (ZCB) term can be used interchangeably with the zero emissions building term [10]. As a result, in the off-grid case a ZCB is identical to an off-grid ZEB, while in an on-grid ZCB the emissions from the imported energy have to be equal with the emissions saved from the exported renewable energy.

Although literature [8,12] has identified the importance of accurately defining the scope and the boundaries of a net ZEB/ZCB, there is lack of applicable and robust frameworks. In particular, the innovative contribution of this paper is the development of such a framework by coupling the boundaries and the different emissions responsibility levels among the operational areas of a ZEB/ZCB with the corporate accounting and reporting criteria. The technical feasibility and applicability of such a framework is also analysed through a (net) zero carbon performance assessment. The assessment takes into account the fact that the scope and the boundaries of a ZEB/ZCB have not been arbitrarily defined, but rather obey to certain accounting and reporting standards set by policy makers.

2.2. Emissions accounting and reporting framework

The compliance with the emissions accounting and reporting guidelines of the Greenhouse Gas (GHG) Protocol [17] is of vital importance in defining the scope and setting the different responsibility levels for the generated emissions and consumed energy within a commercial building's system. The GHG Protocol [17] – supported in the UK by the Department of Energy, Food and Rural Affairs (DEFRA) [18] – classifies carbon related activities in three different scopes. Scope 1 includes the "direct" emissions, which are produced by assets that are managed by the reporting company. For instance, emissions generated at the reporting company's facilities or emissions generated by the company's vehicles should be included in the company's scope 1 directory. For every business, its scope 1 emissions constitute its higher emissions accountability layer and the reduction of those emissions should attract the highest priority among all the others. Scope 2 includes the emissions from the generation of electricity or heat that is supplied to the reporting company. Scope 2 emissions occur at assets not owned by the reporting business but it has to include those emissions in its scope 2 because it makes use of the generated energy [17]. Scope 3 includes the indirect emissions that come from the upstream processes of the reporting business's value chain and comprises mostly the emissions during the extraction, transportation and refining of the raw resources before they actually reach the business's facilities [19]. The boundaries between the three different scopes should be established according to one of the following criteria: (a) organizational; (b) operational; (c) business. The classification of the emissions in this paper follows the organizational criterion and specifically the equity share approach. This approach offers the most precise specification of the boundaries, since it implies that a reporting commercial business accounts for the GHG emissions of a building's operational field according to its percentage equity share in that field.

2.3. Technology review for delivering zero carbon performance

On-site renewable energy generation units are important components in the development of net ZEBs and ZCBs [11]. Due to the fact that, for an average commercial building, electricity demand accounts for 55% of its total energy requirements [20] – with this percentage becoming 80% for a UK supermarket [6] – low carbon electricity provision technologies should form the cornerstone in the realisation of a ZEB or a ZCB. Acha [21] developed a multiple criteria decision approach for the available low-carbon technologies by focusing on the technical, operational and commercial constraints along with their suitability for ZCBs. A grouped overview of this approach [21] is shown in Table 1 by indicating the classification of the available technologies as well as the performance of each of them with respect to different criteria. The "✓" symbol indicates that the technology fulfils that criterion while the "?" and "X" symbols indicate an uncertain and negative performance respectively.

Table 1. Comparison of promising electrical power supply options in multiple criteria.

	Dispatchability	*Reliability*	*Capacity*	*Suitability*	*Maturity*	*Emissions*
Hydro-generation	✓	✓	?	X	✓	✓
Geothermal	✓	✓	?	?	✓	✓
Bioenergy CHP	✓	✓	✓	✓	?	✓
Fuel cell CHP	✓	?	✓	?	?	?
Wind turbines	X	?	?	X	✓	✓
Solar PV	X	✓	✓	✓	✓	✓
Hybrid PV	X	?	?	✓	X	✓

Table 1 suggests that, currently, bio-energy fuel as input to a Combined Heat and Power (CHP) engine would be the best alternative to decarbonize the operations of a building.The selection of the fuel is vital for that choice and it is the benchmark that enables the CHP technology to shift from an energy efficient technology to a real low carbon solution [22]. Biofuels are low carbon energy carriers and the fact that biomass energy driven products, like biofuels, are recognised as almost CO_2-free by the UK policy scheme [23] provides a great opportunity for CHP concepts which are based on sustainable energy sourcing [24-26]. Solar PV could also be an alternative since it meets many of the criteria requirements. However, since it is a non-dispatchable technology, it has the major drawback of not always being available when needed, while meeting capacity requirements can also be a challenge based on space availability [21]. The present work will draw focus on how bioenergy CHPs can maximize their value by both satisfying the electricity and heating load of a commercial building and at the same time exporting low carbon electricity which offsets part of the on-site generated emissions.

3. Methodology

Energy efficiency and saving measures play an important role in reducing carbon emissions of commercial buildings' operations. The above was the outcome of earlier work conducted by Acha et al. [27] who focused on energy saving strategies by analysing the sub-energy systems (e.g. HVAC, refrigeration, etc.) of a food retail building, analogous to the one used for the case study of this paper. However, the case study performed under that work [27] detailed the limitations of energy efficiency strategies and highlighted the need for robust tools for measuring and offsetting the carbon performance of a commercial building. As a result, that prior work [27] in energy efficiency evaluation created the baseline for the case study of this paper where the emissions accounting and offsetting framework is developed and implemented. The methodology pathway of the developed framework could be structured as a two-step process, as presented in Fig. 1. The first step is the emissions accounting and measurement methodology, which consists of the qualitative and quantitative sub-processes. The second step involves the emissions offsetting methodology, which details how to offset the already measured carbon emissions of the first step.

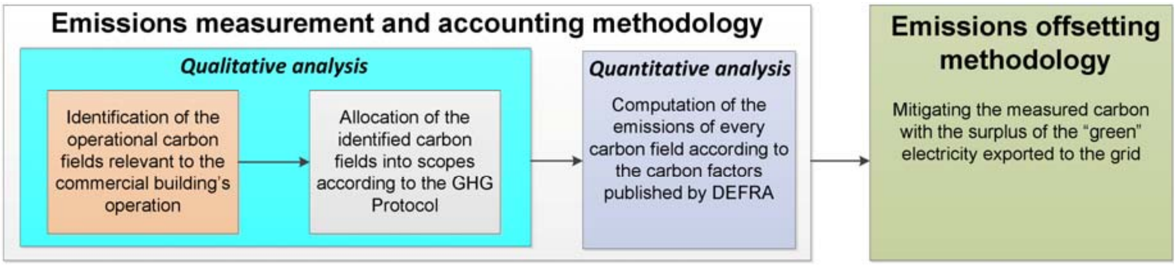

Fig. 1. Operational diagram illustrating the followed methodology.

3.1. Emissions measurement and accounting methodology

A consistent and accurate framework for quantifying the carbon fields associated with the operation of a commercial building requires a systems approach to the problem [10]. For this reason, the paper investigates the implementation of zero carbon operational concepts, for commercial buildings, by using such a systems approach. In particular, the present work integrates into the emissions' accounting framework not only the carbon associated with the building's inherent energy consumption (i.e. electricity supply, on-site fuel use etc.) but also the carbon resulting from the building's commercial use (i.e. transport operations, waste management, water use).

3.1.1. Qualitative analysis

The qualitative categorisation requires both the determination of the boundaries of the systemically approached building's commercial operation as well as the classification of the identified emissions sources. The focus is on recognizing the share of carbon responsibility that a business has on the energy use arising from its building's commercial operation. Classification of the emissions into scopes allows also clarity on the level of the zero carbon performance. This means that by allocating the emissions into different accountability layers it is possible to prioritize the decarbonisation of a commercial building's operation as well as to determine the degree of its zero carbon operation. The classification follows the DEFRA [18] and GHG Protocol guidelines [17,19]. Table 2 presents how the identified carbon fields can be allocated into different scopes by following the equity share approach.

Table 2. Qualitative classification of the primary emission sources occurring from a commercial building's operation.

Operational Carbon Fields	***Scope 1***	***Scope 2***	***Scope 3***
Electricity use	–	✓	✓
On-site fuel use	✓	–	✓
Water use	–	–	✓
Transport operations (with business's fleet)	✓	–	✓
Transport operations (with third party fleet)	–	–	✓
Waste management & Disposal	–	–	✓

As can be seen in Table 2, all the operational carbon fields are associated with emissions found in Scope 3 for the reason that scope 3 reflects the carbon consequences on the wider ecosystem into which the commercial building belongs. However, more focus should be given in scopes 1 and 2 where the reporting business has the highest levels of ownership for the generated emissions. Scope 1 consists of emissions from the on-site fuel use (e.g. gas) and from the transport operations by business's fleet. Scope 2 includes the emissions from the generation of the consumed grid-electricity because the emissions from the transmission and distribution of that energy are included in scope 3 [18]. It should be highlighted that the transport operations are differently categorised depending on the ownership of the used fleet. This classification provides a first-class opportunity to practically clarify the equity share approach when determining each scope's boundaries. Scope 1 includes the emissions from the transport activities performed by vehicle fleet that belongs to the equity of the reporting business. On the other hand, scope 3 transport emissions include the emissions that are also required for the building's commercial operation but are generated by vehicle fleet owned by third parties (e.g. suppliers, contractors); as a result, from an equity perspective, these emissions cannot be included in scope 1.

3.1.2. Quantitative analysis

The quantitative, as opposed to the qualitative, analysis details the computational component of the emissions accounting methodology. According to the UK policy plan, DEFRA publishes annual energy and fuel emissions (or carbon) factors according to the type of fuel and the selected supply source [23]. In addition, the published emissions factors, applied in (1), differ even for the same energy source depending on the scope where the calculated emissions will be allocated. The following formula is indicative:

$$(PI)\times(EFAS)=TES\ , \qquad (1)$$

where PI stands for the performance indicator (i.e. kWh, litre, m^3, tonne) of the operational carbon fields presented in Table 2; EFAS stands for the corresponding carbon factor (i.e. $kgCO_2e$ / kWh) for a particular scope each time of every operational carbon field of Table 2 (e.g. scope 2 electricity emissions etc.); and TES stands for the final emissions of that operational carbon field in that scope (e.g. $kgCO_2e$).

As can be seen in Fig. 2, apart from the electricity supplied through the utility grid that has no scope 1 emissions, any fuel consumption related to a building's commercial use is followed by scope 1 and scope 3 emissions. The reason is that scope 1 includes the highest responsibility level emissions from the on-site fuel burning. On the contrary, scope 3 emissions or the Well-To-Tank (WTT) emissions – as introduced in 2010 DEFRA guidelines [28] – comprise the indirect emissions from the fuel or resource preparation before its actual combustion at the business's premises.

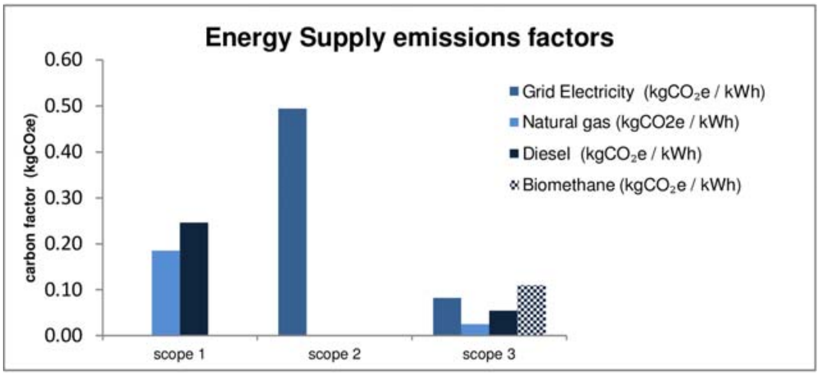

Fig. 2. The emissions factors of selected fuels and grid-electricity categorised into scopes [23].

The selection of fuels presented in Fig. 2 highlights how UK legislation considers the scope 1 (direct) CO_2e emissions of biofuels (e.g. of biomethane) to be negligible[1], as compared to conventional energy fuels (e.g. diesel). This offers the opportunity to maximise the carbon benefit from potential use of biofuels in ZCB concepts. Possible decrease of operational emissions included in scopes 1 and 2 is crucial for accounting and reporting, since these emissions are mandatorily reported, in contrast to scope 3 emissions, whose reporting is encouraged but not yet mandatory by the UK regulation [18].

However, the methodology of this paper also addresses the emissions of scope 3 in order to investigate the feasibility of a totally zero carbon operation. Hence, Fig. 3 presents the carbon intensiveness of water use and waste discarding in a commercial building. Water supply refers to the procurement of the water resource to a building while water treatment refers to the return of the

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[1] There are some minor Scope 1 CO_2e emissions from the on-site burning of the biofuels, consisting of CH_4 and N_2O gases. However, the UK legislation assumes that CO_2 gases (normally responsible for the majority of the CO2e emissions) are zero due to the assumption that the CO_2 absorbed during the growth of biofuel crops offsets the CO_2 produced during their on-site burning [23].

used water to the sewerage system [18,23]. On the other hand, waste management emissions depend on both the type of material as well as the selected disposal route, a parameter which radically diminishes the waste management emissions, if handled sustainably, contributing to the zero carbon performance in the case study of Section 4.

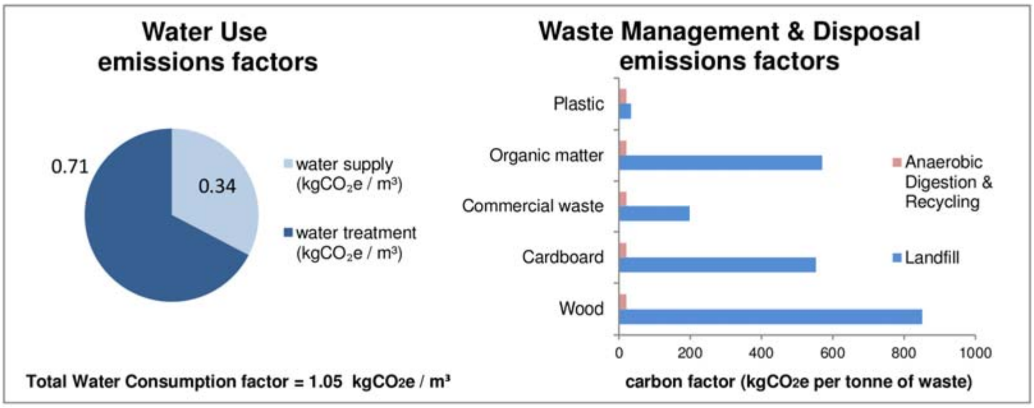

Fig. 3. Scope 3 emissions factors accounting for water use and waste management in a commercial building [23].

3.2. Emissions offsetting methodology

Since scope 1 and 2 emissions are regulated by the UK legislation [18], the first priority of every zero carbon or sustainable concept should be to diminish or offset these emissions. The next priority of such a concept should be the development of plans for scope 3 emissions at later stages. As a result, the operational carbon fields with scope 1 and 2 emissions (Table 2) should attract the highest attention. The methodology developed in this paper discusses CHP systems interacting with an energy grid [29,30] while running on low carbon fuel in order to meet sustainably the on-site energy demand and create carbon credits from exporting low carbon electricity to the grid. The objective is to correlate the current CHP policy plan [31] with the emissions' allocation into scopes. In this way, a coherent framework can be developed, which will allow a business to accurately quantify its carbon credits and decarbonise its prioritised emissions generated from any buildings' commercial operation.

The key factor, for the above objective, is the type of fuel that is used as input to the CHP system. If this fuel (e.g. biomethane) has an emissions factor lower than the emissions factor of the grid-electricity, then a business could claim as carbon credits the difference between the two emissions factors multiplied by the number of kWh supplied to the grid. As a necessary condition, the electricity supply of the CHP engine must overcome the required electrical needs of the building enabling the excess electricity to be exported to the grid. The mathematical formulation of the above process is outlined in (2):

$$(EL)\times(ELF - FF) = CC\,, \qquad (2)$$

where EL denotes the exported electricity (kWh); ELF represents the scope 2 emissions factor[2] of the grid-electricity ($kgCO_2e$ / kWh); FF represents the scope 1 emissions factor of the low-carbon fuel (e.g. biofuel) used as primary input to the CHP engine, which produces the exported electricity ($kgCO_2e$ / kWh); and CC represents the gained carbon credit ($kgCO_2e$) which will be used for achieving a net zero carbon performance.

[2] Grid-electricity supply is responsible for emissions in both Scope 2 and Scope 3 (Fig. 2). However, during the carbon credit calculation, we only offset Scope 2 emissions that represent the emissions from the electricity generation. Scope 3 emissions that represent the transmission and distribution emissions continue to exist, for the reason that even the on-site low-carbon electricity when exported continues to makes use of the grid.

4. Case study - Results

4.1. Operational scenarios

Table 3 presents an overview of the two carbon contradicting operational scenarios as well as the energy profile of the commercial building where the emissions accounting and offsetting methodology detailed in Section 3 was implemented. The case study was performed in a 30,000 ft^2 supermarket store located in the south-east UK.

Table 3. The operational scenarios developed according to the commercial building's profile.

Operational Carbon Field	Annual Values	Business As Usual (BAU) scenario	Sustainable scenario
Electricity use	1,467 MWh	Supplied from the grid	Biomethane CHP option (covering on-site demand + exporting green electricity to the grid)
On-site fuel use	58,519 m^3	Natural gas (~ 87% boiler efficiency)	
Water use	2,501 m^3	Sourced in total from the grid	Using both water from the grid and collected rainwater
Transport operations (with business's fleet)	63,477 litres	Diesel fuelled vehicles	Biomethane fuelled vehicles
Transport operations (with third party fleet)	40,035 litres		
Waste Management & Disposal♣	132.9 tonnes	Landfill disposal	Anaerobic digestion & Recycling

♣The discretisation of the waste material performed according to [32]

The Business As Usual (BAU) scenario represents the carbon intensive options for the commercial operation of the store in comparison with the low-carbon solutions of the sustainable scenario. The latter comprises both on-site renewable energy generation plans (i.e. biomethane CHP) and sustainable options for meeting the remaining operational fields of the commercial food retail building. Two different sized CHP engines (i.e. 300 kW & 530 kW) were used in order to investigate the boundaries of a zero carbon operation, depending on the amount of the on-site renewable energy generation. The emissions quantification for both operational scenarios followed the latest (i.e. 2014) DEFRA carbon factors [23], as published in June 2014.

4.2. Results

As can be seen in Fig. 4, the total emissions of the BAU scenario are classified both per scope and per operational carbon field of the commercial building.

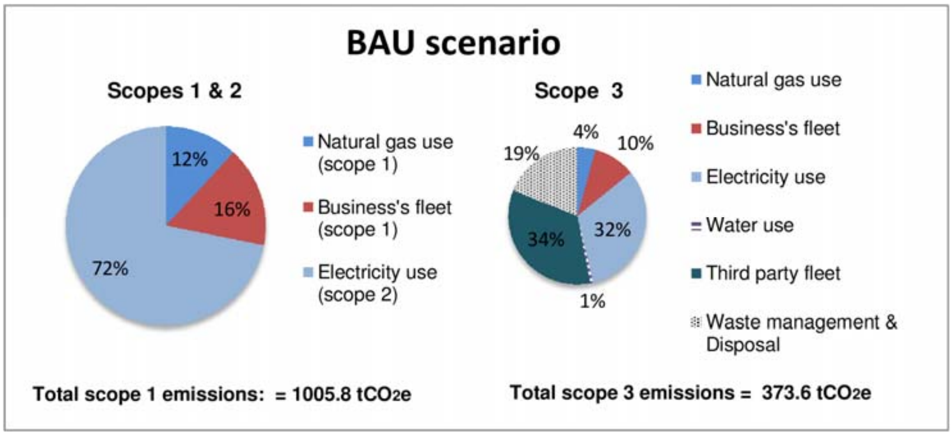

Fig. 4. Emissions classification and allocation into scopes per operational field under the Business-As-Usual (BAU) scenario.

It is important to highlight the nearly three times bigger scope 1 and 2 (1005.8 tCO_2e) comprised emissions compared to those of scope 3 (373.6 tCO_2e). This observation confirms what was mentioned in Section 3 regarding the need for downsizing the emissions bargain of the mandatorily reported scopes 1 and 2. Furthermore, the fact that the grid-electricity emissions dominate the BAU scenario's carbon footprint in scopes 1 and 2 is a quantitative proof that zero carbon performance passes through low carbon on-site electricity generation technologies. In addition, understanding the BAU scenario's emissions helps identify the carbon abatement potential as well as prioritise the solution pathway for each operational carbon field. Moreover, the BAU scenario formulated the baseline of the sustainable scenario. The main aim was to identify how in-depth can go the boundaries of a zero carbon building's operation while finding sustainable pathways to meet the store's commercial carbon fields. The cornerstone of the targeted zero carbon performance was the 24/7 operation of biomethane fuelled CHP systems. This technology combined with the low carbon biofuel choice, contributed in sustainably meeting the on-site energy requirements by drastically decreasing scope 1 and abating scope 2 emissions. Biomethane was preferred among the other biofuels (e.g. biomass) due to being flexible and easily storable in nature. Additionally it is also an attractive option as it can be fed into normal natural gas networks, minimising the need for additional equipment modifications [33]. Furthermore, from the comparative analysis of the two different sized CHP-engines occurs a contradicting observation. The higher capacity CHP unit (i.e. 530 kW), compared to the 300 kW CHP, increases scope 1 emissions (3.5 to 5.6 tCO_2e); on the other hand, the 530 kW CHP offers such bigger carbon benefit (1548.1 vs. 569.6 tCO_2e) from the exported green electricity to the grid that excessively covers its higher carbon impact. In addition, as can be seen in Fig. 5, the output of the 300 kW biomethane CHP limits the boundaries of the building's zero carbon operation on scope 1 by not exporting enough green electricity and consequently not generating enough carbon credits in order to also offset the total of scope 3 emissions. In contrast, the 530 kW biomethane CHP produced enough carbon credits (1548.1 tCO_2e) to offset not only scope 1 but also the total of scope 3 emissions. It also led to a totally zero carbon performance with a sufficiency of 129.9 tCO_2e for further offsetting if required.

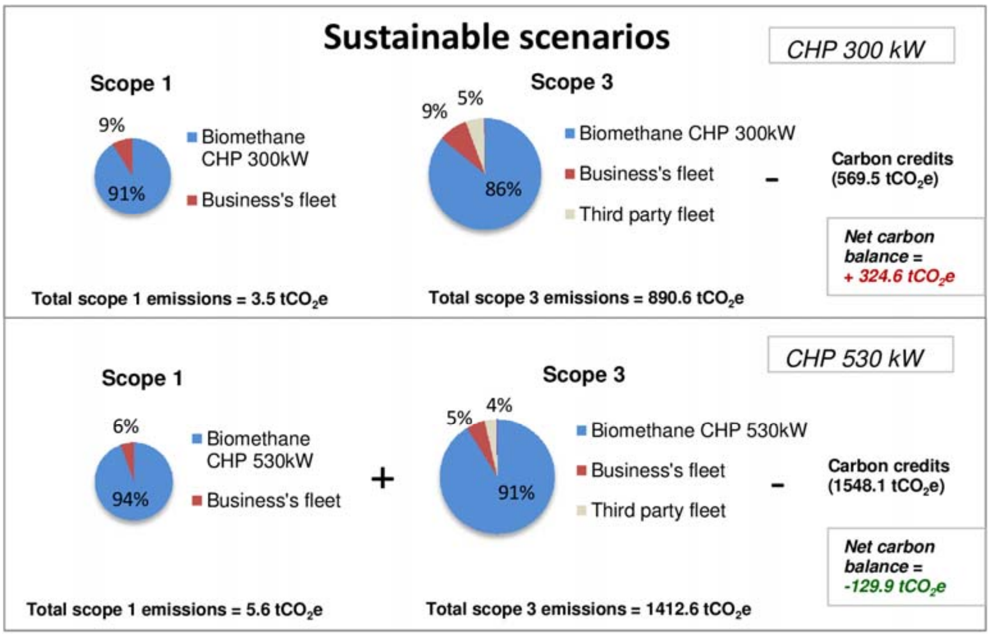

Fig. 5. Emissions classification and comparative quantification of the carbon credits for the two different sized-CHP engines used in the sustainable scenario.

It could be argued that total emissions increase between the BAU scenario and the 530 kW CHP sustainable scenario; however two points can make clear the carbon abatement of the sustainable case. Firstly, the increased emissions are those of scope 3 (not of scope 1), which accounts for the emissions associated with the upstream processes. Upstream processes are the early stages of a supply chain (e.g. during the extraction of a raw material). On the other hand, the reduction of the scope 1 emissions indicates that fewer emissions are physically generated in the urban areas where a building's commercial operation takes place. Secondly, even the increase in the emissions of the upstream processes is avoided. The exported "green" electricity covers electrical demand that would otherwise be met by burning the more carbon-intensive fuel mix (e.g. coal) of the grid-electricity. As a result, the combustion of that carbon-intensive fuel mix is reduced leading to fewer emissions under the sustainable scenario.

The sustainable scenario, apart from the bioenergy CHP, consists of sustainable pathways for the remaining operational fields (e.g. transport operations, water use, waste management). These pathways are included in order to quantify and compare the impact that environmental friendly options could have towards a totally zero carbon performance. The use of biomethane as transport fuel [34] replacing diesel had the most radical effect by minimising the scope 1 business's fleet emissions and reduced the total of transport scope 3 emissions by 25%. A significant effect was also found in the waste management and disposal field where the anaerobic digestion and recycling route almost totally diminished the 70.1 tCO_2e of the BAU scenario. The dominant proportion of this reduction could be attributed to the sustainable handling of two particular types of waste: a) the organic matter and b) the cardboard material. These two types of waste dominate the waste products of a food retail store [32] while their corresponding emissions factors differ significantly depending on which management route is selected. Specifically, the handling of the organic matter is responsible for 96.3% fewer emissions under the sustainable path with the corresponding percentage for the handling of the cardboard material to become 96.2%. The sustainable handling of the wood material could have the biggest impact but this material type represents only a small proportion (6%) [32] of the waste products and as a result its effect is limited. Finally, the rain harvesting system achieved 15% reduction compared to the BAU respective field, although the water supply and treatment emissions are insignificant compared to the remaining fields depicted in Fig. 5. The rain harvest unit decreases only the emissions related to the supply side of the consumed water. The supply side accounts for 32% of the total emissions related to water use. As a result, further reduction could have been achieved through sustainable measures for the wastewater despite the difficulties (e.g. cost) in the development of a decentralised wastewater treatment plant.

An economic analysis was also performed in order to investigate the payback period of the proposed CHP sustainable scenarios (Table 4). The CHP capital costs increase as the capacity of the installed CHP unit gets higher with an average of 790£ per kW installed [35]. However, as the capacity increases the amount of the "green" electricity exported to the grid also increases generating an increased income from this electricity trade-off. Consequently, the net savings compared to the BAU scenario increase by installing a higher capacity CHP, although the increased operating costs combined with the increased capital costs lead to a 4-year payback period for the 530 kW CHP compared to a 3-year period for the 300 kW CHP.

Table 4. Economic analysis.

CHP Capacity	**Capital Costs♣ (£)**	**Annual Operating Costs (£)♣**	**Net Annual Savings (compared to the BAU scenario) (£)♣**	**Payback period**
300 kW	237,000	110,073	98,501	3 years
530 kW	418,700	193,362	111,391	4 years

♣All the fuel prices data have been sourced from the UK National Energy Statistics [36] and Ofgem rates [37] while the CHP data from the CHP Economic Benefits of the US Environmental Protection Agency [35]

The remaining measures of the sustainable scenarios were found to have insignificant capital cost implications (compared to the CHPs costs) by having only a slight effect on the operational costs. However, even that effect was highly dependable on the energy prices of electricity and natural gas. This means that any change in these energy prices would create such an effect on the profits associated with the CHPs operations that would significantly overcome any operational cost effects on the remaining fields.

5. Conclusions

This paper focused on clarifying and quantifying the level of responsibility that an UK firm has on GHG emissions resulting from its day to day commercial buildings operations. The motivation for a business to measure and report its emissions and eventually offset them through low carbon strategies relies both on legislation and on cost reduction measures. Therefore, this paper reviewed the classification of emissions according to GHG protocol while detailing the state-of-the-art on zero carbon buildings. Moreover, an overview of how carbon performance is currently evaluated as well as the technologies that can mitigate these emissions was presented. The methodology framework presented in Section 3 and the implementation of DEFRA's guidelines enabled an integrated approach to account for all operational activities that incur GHG emissions; thus highlighting which activities can be more carbon intensive. However, it is important to stress the need of frequently monitoring and updating DEFRA's carbon factors as they are subject to change.

The carbon accounting and offsetting methodology presented in this paper was applied using a food retail store case study. This case study included two scenarios: (a) the BAU and (b) the sustainable one. In the BAU scenario the adapted choices per carbon field were more carbon intensive compared to those of the sustainable one; reflecting what is standard in today's industry, against a more environmental store design. Different sized CHP engines were employed in the sustainable scenario in order to evaluate the depth of the (net) zero carbon performance that can be achieved. The results indicated that the heat and electricity demands of a store cannot only be met with greener options but also provide a carbon advantage as an inheritance for decarbonising the value chain emissions of a building's commercial operation.

Finally, the carbon accounting methodology presented here can be transferred and implemented onto other building categories (e.g. offices, hotels, hospitals, etc.) in the future. Its wide applicability can help enable comparing buildings of different types; thus complementing Part L regulation goals on how a business that knows in detail its carbon footprint can identify cost-effective solutions to reduce its emissions. The paper also included an economic analysis estimating a 4-year payback period for the 530 kW CHP and a corresponding 3-year period for the 300 kW CHP employed in the sustainable scenario. Multiple stakeholders with different discipline expertise (e.g. architecture, engineering, energy, sustainability, finance, etc.) need to work in coordination to deliver capital constrained sustainable buildings.

Acknowledgments

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