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REVIEW ARTICLE

Developing a sustainable energy strategy for Midtjyllands Airport, Denmark

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ABSTRACT

The operation of airports is considered as particularly energy intensive and with the use of conventional energy sources, significant amounts of greenhouse gases (GHGs) are emitted, fueling the existential crisis of global warming. Hence, this study investigates the energy management system (EnMS) of Midtjyllands Airport with respect to its energy consumption, energy sources, and energy-related GHG emissions. The intention is to develop a sustainable energy strategy to close the gaps in their energy and carbon management by applying the methods of ISO 50001 EnMS and Airport Carbon Accreditation (ACA) Program. The findings reveal a total energy consumption of about 1 GWh including electricity (53%), natural gas (47%), and others (0.1%) while emitted GHGs account for in total 203 tCO_2e. With regard to the developed baseline trends, the designed objectives comprise (1) net zero GHG emissions without offsetting by 2030, (2) 40% reduction in energy consumption by 2025, and (3) 40% reduction of two energy performance indicators (EnPIs) by 2030. The achievement of the objectives is summarized in a nine-point action plan including the major actions of identifying significant energy users (SEUs), improving thermal state of total building envelope and heating system, as well as replacing the current electricity and natural gas contract with a renewable electricity and biogas contract, respectively.

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KEYWORDS
Airport; Airport Carbon Accreditation; energy demand; energy management system; sustainable strategy

Abbreviations: A/S: Joint-stock company; AC: Air conditioning; ACA: Airport Carbon Accreditation; ACI: Airports Council International; ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers; ATM: Aircraft movement; BREEAM: Building Research Establishment Environmental Assessment Method; CEO: Chief Executive Officer; DAT: Danish Air Transport; ELC: Total electricity consumption; EMAS: Eco-Management and Audit Scheme; EnEV: Energy Conservation Regulations; EnMS: Energy Management System; EnPI: Energy Performance Indicator; GHG: Greenhouse gas; GWh: Gigawatt hours; HFC: Hydrofluorocarbon; HVAC: Heating, ventilation, and air-conditioning; I/S: Partnership; IPCC: Intergovernmental Panel on Climate Change; ISO: International Organization for Standardization; $kgCO_2e$: Kilogram of carbon dioxide equivalent; LED: Light Emitting Diode; LEED: Leadership in Energy and Environmental Design; MWh: Megawatt hours; NGC: Total Natural Gas Consumption; PAX: Passenger; PV: Photovoltaic; SEU: Significant Energy User; tCO_2e: Tons of carbon dioxide equivalent; TDC: Airline Services Limited; TEC: Total Energy Consumption; toe: Tons of oil equivalent

1. Introduction

Airports are an essential hub for not only global long-distance flights but also for medium-distance travels to neighboring countries or domestic destinations. From large extended facilities to small-sized airport buildings, the value chain of serving the needs of air transportation consists of similar actors and units, such as the departing and arriving facility, airlines and their aircraft, ground support equipment and agents, air traffic control, as well as airplane maintenance service (Schmitt & Gollnick, 2016). All these components at an air transport system lead to several local and global impacts. On the one hand, the society benefits from an increase of the gross domestic product as well as regional and international involved parties grow economically. On the other hand, crucial negative environmental and social impacts result from the operation of an airport. These include effects to local communities like noise, land use, ground traffic congestion, and global environmental effects (Janić, 2011b).

Due to the fact that fossil fuels for energy use are unsustainable, rapidly declining, and mainly responsible for global warming, renewable sources, and its rational and efficient utilization is indispensable (IPCC, 2021; Koroneos et al., 2010; Morvay & Gvozdenac, 2009). As a consequence, legal obligations arose from climate change and global warming in the past years (Akyuz et al., 2019). In addition, driven by social pressure for living healthier and running the economy more sustainably (Vanker et al., 2013), significant improvements have been made in the aviation industry by initiating new sustainable standards (Monsalud et al., 2015) and reducing the airports carbon footprint (Sukumaran & Sudhakar, 2017). However, estimations by the International Civil Aviation Organization (2018) state that a share of 2% of the global CO_2 emissions is caused by the aviation transport sector, undergoing a rise by approximately 3%–4% in

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every year. This development might cause the risk of reducing or ceasing its operations under the status-quo due to the progressing effects of climate change, the biggest threat the airport industry is going to face in the near future (Preston, 2015).

With focus on the energy demand in the aviation sector, airports are extremely large consumers (Ortega Alba & Manana, 2017), in particular of electric power (Ortega Alba & Manana, 2016). Their huge passenger and non-passenger facilities demand a sizable amount of energy for heating, ventilation, and air-conditioning (HVAC), as well as lighting and air transport-related equipment. Furthermore, aids to air transport operations and aircraft in parking position are supplied by electrical energy and heat provided by the airport (Cardona et al., 2006). Examinations and studies have revealed that airport terminal buildings consume about 70% of its energy for heating, cooling, and air conditioning purposes. As a result, an essential operation element of an airport is an energy management system (EnMS) to control energy-intensive needs (Graham, 2014).

Several energy management tools are under constant development with the aim of monitoring, controlling, and improving local and integrated elements in entrepreneurial organizations including airports (Akyuz et al., 2019). In the 1990s, national and international standards were introduced in order to be in control of energy use and environmental impacts. In general, the ISO 5000 and ISO 14000 family (International Organization for Standardization, 2015, 2018) as well as the eco-management and audit scheme (EMAS) (European Commission, 2016) are common instruments (Falk & Hagsten, 2020). With regard to the aviation industry, airport buildings are specifically assessed by a number of national and international energy certifications, such as LEED, BREEAM, and EnEV (Kı lkı ş & Kı lkı ş, 2016). Moreover, since 2009, the Airport Carbon Accreditation (ACA) started its assessment program, which, according to ISO 14064 for greenhouse gas (GHG) accounting, verifies airports' carbon footprint (ACA, 2018). In recent research, energy benchmarking also became a tool to express the energy efficiency index through Energy Performance Indicators (EnPIs). In the context of an airport, the most common used EnPIs are (kWh/PAX), (kWh/terminal building surface), and (kWh/HVAC surface) (American Institute of Architects, 2012; D&R International, 2012, 2013; USEIA, 2008).

A review conducted by Ortega Alba and Manana (2016) shows that the main essential measures for the reduction of energy are the management systems. At airports, already small projects have the potential to increase efficiency by 30% (Büyükbay et al., 2016). Other important measures are modeling and simulation of energy consumption, which is potentially beneficial for lowering the total consumption. All these examined elements come with the methods of a classical EnMS, such as ISO 50001 (International Organization for Standardization, 2018).

Improvements in energy efficiency and consumption are in particular relevant with respect to national energy and climate objectives. In the given case of Denmark, two national plans provide regulations about the development in terms of energy and climate. The Danish government targets a 70% GHG emissions reduction in 2030 in comparison to 1990 and net zero emissions by 2050 at the latest (Danish Ministry of Climate Energy and Utilities, 2019), while the Danish Aviation Association specifies a 100% CO_2 compensation of airports' operations from 2020 as well as a 30% CO_2 reduction in aviation by 2030 compared to 2017 (Danish Aviation Association, 2019). Equivalent to governmental objective, a 100% carbon neutral aviation industry is targeted in 2050.

Consequently, the objective of this work is to examine how the Danish airport Midtjyllands Airport manages its energy consumption, energy sources, and energy-related carbon emissions with the intention of implementing a sustainable energy strategy to close the gaps in their energy management whilst at the same time align the energy management with the standards of ISO 50001 EnMS and ACA in order to both improve energy efficiency and reduce CO_2 emissions. The first aim is to clarify the steps toward ISO 50001 and ACA certification so that the operational boundaries of the airport are determined in which energy consumption and energy-related carbon emissions occur. The second aim is to inspect Midtjyllands Airport's current energy management and identify distinctions to the EnMS defined by ISO 50001. A further goal is to conduct a multi-year overall energy consumption analysis with regard to all energy fluxes and the resulting carbon emissions within the predefined boundaries. Finally, energy efficiency measures are proposed in form of a sustainable energy strategy.

The remainder of this article is as follows: Section 2 explores the energy management at airports with regard to relevant standards. Section 3 describes the applied methods according to ISO 50001 and ACA as well as defines the research scope and strategy. Section 4 includes the analysis of the energy use, GHG emissions, EnPIs, and baselines. The findings, objectives, and action plan are presented and discussed in Section 5 while a 10-point summary and conclusion are drawn in Section 6.

2. Energy management at airports

Airport's comprehensive activities require energy to perform various tasks (Graham & Morrell, 2016) and therefore they are considered as large energy consumers of electricity, fuel, heat, and cooling (Akyuz et al., 2019; Graham & Morrell, 2016). Controlling the consumption of these demanded forms of energy requires the establishment of an energy management concept, which begins with the segmentation of the airport into two sections: airside (runway, control tower, etc.) and landside (terminals, parking lots, etc.) (Ortega Alba & Manana, 2016). These elements are vital in an air transport environment (Graham, 2014). Thus, it is essential that a secure supply of energy is guaranteed at a reasonable price to all actors within the two sectors in order to maximize the capacity in their operational performance. From a long-term viewpoint, the objective is to reduce operational costs and ensure satisfaction in the needs for energy by increasing the efforts in energy-efficiency measures. Tenants, concessionaires, and service partners are frequently involved in saving initiatives introduced by the airport (Thomas & Hooper, 2013).

Furthermore, novel power-generation systems have been developed and put in operation by various airports, thereby affordable and reliable renewable energy is generated while the energy cost decreases (Budd & Budd, 2013). Nowadays, various energy technologies are available and commercially applied as sources of energy for airports (Koroneos, Xydis, & Polyzakis, 2010). Even though renewable energy technologies are in use, such as photovoltaic (PV), concentrated solar power, and wind power, the extraction of oil, and natural gas is the common approach to generate energy (Baidya & Nandi, 2020; Barrett et al., 2014). Nevertheless, the attractiveness of renewable energy systems has risen due to several factors, such as technological development, investment gains, and market maturity (Barrett, 2015). In this regard, the scientific literature describes solar, geothermal, biofuels, biomass, and biogas as alternative resource, which are applied on large-scale including airports in Copenhagen, Kansai, and Adelaide (Baxter et al., 2018a, 2018b, 2019; Ortega Alba & Manana, 2016). With the given features at an airport area, especially PVs are considered as financially advantageous for on-site energy generation. The possibility of the airport supporting any smart gas grids could be also considered (Lund, 2018). The land around the airport and the facilities offer plenty of space for solar panels, which could be a financial improvement for these unused areas (Thomas & Hooper, 2013).

Besides the on-site generation of power, the literature provides several and specific cases in which monitoring of EnPIs in combination of an implemented EnMS reveals an increase in energy performance: In a case study research, the EnMS of Denmark's busiest airport, Copenhagen Airport, is examined regarding its sustainability in terms of resources efficiency actions. By monitoring all airport buildings using electricity, heat, and water meters, energy-saving measures can be imposed in case of unexpected deviations in the energy consumption. Concerning the airport's design and operations, these measures identified in particular the HVAC and various lighting systems as a major potential for an efficient use of energy and a reduction of energy-related carbon emissions. Further improvements and various energy-saving initiatives have resulted in energy savings of about 26.8 GWh during the period 2009–2016 (Baxter et al., 2018a).

In a study concerning Rome's airport, de Rubeis et al. (2016) examined the performance of the EnMS by analyzing energy-related demand data. With a total energy consumption of about 42,600 tons of oil equivalent (toe) per year (mean 2010–2012), the airport consumes the amount of energy compared to a small-sized European city with 20,000 inhabitants (2.1 toe per inhabitant) (European Environment Agency, 2013). In 2010, the integration of the Environmental Management System ISO 14001 was initiated, followed by the EnMS ISO 50001 two years later. In the subsequent years, the EnMS monitored the airport's energy demand and potential improvements in terms of energy efficiency have been located and implemented. Consequently, a significant increase in electric energy efficiency per capita has been achieved: From 4.31 kWh/PAX in 2012 to 3.75 kWh/PAX in 2015. Furthermore, in correlation with a carbon footprint analysis, a decrease in CO_2-equivalent emissions could be observed (de Rubeis et al., 2016).

From 2002 until 2015, a study investigated mitigations of environmental impacts caused by energy consumption at Kansai International Airport based on an implemented EnMS and various technologies. The airport's objective is an integrated solution between electricity consumption and on-site generation in correlation of energy conservation. The analysis of the EnMS showed that the electricity purchased has declined from about 123 MWh per annum in 2020 to 103 MWh in 2015 while a rise in traveling numbers occurred. Additionally, a decrease in the energy requirements per capita has been observed between 2010 and 2015, mainly due to energy-saving measures, such as the use of light-emitting diodes (LEDs) (Baxter et al., 2018b).

By implementing an adequate EnMS with environmental sustainability policies, not only energy efficiency but also renewable energy generation can be achieved. A study with Adelaide Airport in South Australia as the case subject focuses on PV and their benefits in addition to their existing airport energy management. Installed on the short-term parking facility, the largest rooftop PV system at an Australian airport covers roughly 10% of the airport's energy demand saving about 915 tCO_2e (Baxter et al., 2019).

A benchmarking analysis was conducted by Kılkış and Kılkış (2016) on the basis of a sustainability ranking of airports index in order to assess among others the energy consumption and generation. Nine airports sampled from major airports were analyzed in the benchmarking process. All examined airports are certified with the ISO 50001 EnMS and they actively apply the tool successfully to improve energy savings. With the use of EnMS, Amsterdam, for example, cut over half of their energy consumption of their office building due a renewal of the heating and cooling system. New airport buildings in Frankfurt undercut the regulations of the German energy savings directive by 20%. An airfield operation facility in San Francisco achieved an efficiency level, which is 50% above the national ASHRAE standard (Kılkış & Kılkış, 2016).

Overall, air transport system operators should be generally considered as energetically inefficient. Therefore, the concept of energy management has to be seen as a necessity for all local and integrated segments of an airport especially because various energy monitoring tools offer the proven potential of an increase in energy and financial performance (Akyuz et al., 2019).

3. Methodology

The research was conducted under inductive reasoning with a qualitative and quantitative longitudinal research approach (Hair et al., 2015a, 2015b, 2015c; Lancaster, 2005). The strategy follows the methods of an experimental research design

Table 1. Third-parties at Midtjyllands Airport.

Category	Activity	Main consumer
Airline operator	Flights with ATR72	Charging aircraft batteries Heating aircraft cabin
Airline service	Ticket sale	Counter and office
Aircraft service	Fueling and maintenance	Tanker and service vehicle
Gastronomy	Cold snacks sale	Shop
Car rental companies	Car rental	Offices
Public authorities	Security and police	Office

(Andersen, 2018). The researcher relies on interpretation of the collected data and the presentation of quantifiable and observable results (Ryan, 2018). Regarding the inductive reasoning, findings were observed at the end of the research followed by the presentation of a theory (Hair et al., 2015c).

The EnMS according to ISO 50001 and the ACA accounting program of GHG emissions form the framework of the subsequent analysis. For this reason, their methods are presented and a coherent scope is defined reflecting the relationship between energy and GHG management in a unified matrix. On that basis, a strategy has been developed as an integrated guide for both standards consisting of a five-stage analysis followed by a four-stage outline of the results and finally synthesizing the outcome into a tailored action plan. In closing, the methods of the respective standards are described followed by the scope and strategy as well as the process of data collection.

3.1. Case object

Midtjyllands Airport is located in central Denmark and it is situated within the Air Base Karup, which is the primary base of the Royal Danish Air Force. Due to its history, Midtjyllands Airport uses the runways, air traffic control, and fire department of Air Base Karup to ensure flight operation. The airport side includes the airport building with arrival and departure area (Gates 1 and 2), offices, technical service area, hangar for small aircraft (Hanger 13A), storage hanger for heavy vehicles and equipment as well as a parking lot. The present airport building was constructed during several construction phases over the past 50 years with its final phase in 1991 in which the current glass facade oriented to the north-east was finished. This element has a crucial effect on the cooling management. However, the airport does not operate a central and energy-intensive air-conditioning system. Within the airport environment, several energy-related third parties operate at the airport. Table 1 shows these parties together with their main energy needs. These actors are needed to offer the service of domestic and international flight paths (Bjørn-Thygesen, 2020).

The region around the airport is distinguished through its high number of businesses. Some of the biggest companies in Europe and the most exporting business have their branches closely located to the airport. These enterprises operate internationally with several departments around the world. Their number of international travels per months is higher than the national average. Available international flight paths are considered as crucial service for more than half of the businesses in that region. For that reason, the corporations demand short trips and day-to-day return. Overall, the major share of all airport users is business people (80%), who travel to meetings, conferences, etc., while the minor share consists of private people (9%) and commuters (7%), who travel frequently back and forth to work, and others (4%) (Midtjyllands Airport, 2019).

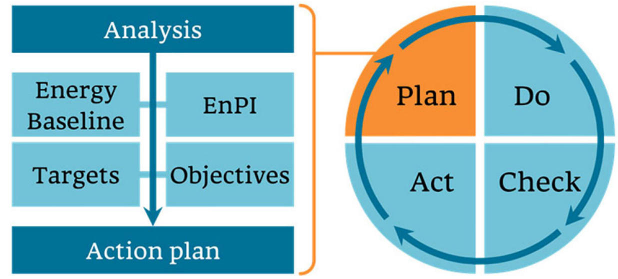

Figure 1. PDCA cycle with focus on Plan in ISO 50001 Energy Management System.

3.2. Methods of ISO 50001 energy management system

Energy management is a process followed by entities in order to enhance energy efficiency (McLaughlin, 2015). The management strategies of ISO 50001 have three general effects on private and public organizations: (1) rise the energy efficiency, (2) reduction in costs, and (3) enhancement in energy performance. The purpose of the ISO 50001 standard is to integrate energy activities into the management of the entities (Kanneganti et al., 2017). The Plan-Do-Check-Act (PDCA) cycle is a frequently applied four-stage process used in management systems (Gopalakrishnan et al., 2014; International Organization for Standardization, 2018; Kahlenborn et al., 2012). Due to the purpose of this work, the focus is on the first step of the PDCA cycle: Plan. This step consists of (i) the definition of energy-saving targets, (ii) development of a strategy, (iii) identification of required measures and accountabilities, and (iv) deployment of needed resources as well as (v) the development of an action plan. Non energy-related elements of the process, such as commitment, awareness, and human resources are described by Akyuz et al. (2019) and Kahlenborn et al. (2012) and excluded from this article.

In detail, the step Plan, short for energy planning, is a process, which was developed in consideration of national and international legal and other regulations to which the airport is obliged to. In this regard, all available energy data needed for energy planning were gathered and analyzed in such a way that useful results are achieved (Howell, 2014). The overall goal was to analyze the data and achieve planning outcomes with respect to energy baselines, EnPIs, targets, objectives, and an action plan (Akyuz et al., 2019) according to ISO 50001, as illustrated in Figure 1.

First, historical and present data was gathered with regard to the use and consumption of energy in combination with the resource of energy. The same accounts for the processes and equipment, which consume these resources. High and intensive energy consumers were identified in order to exploit efficiency potentials and improve saving

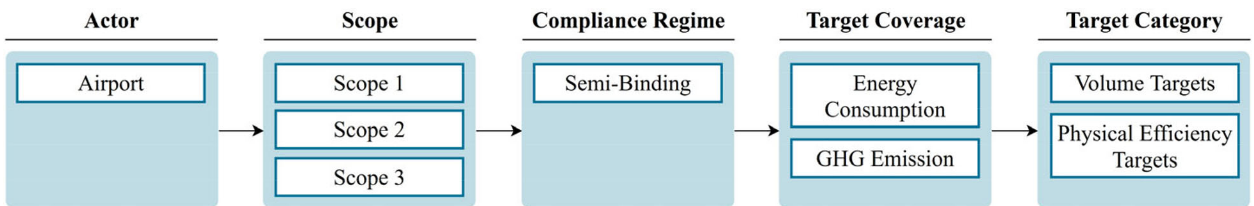

Figure 2. Characteristics of targets for Midtjytllands Airport based on SMART industrial energy targets. The scopes and target coverage are described in Section 3.4, the compliance regime refers to national climate targets in Section 1, and the target category is given by ISO 50001 in form of reduction targets (volume) and efficiency targets (EnPI).

opportunities. Second, energy distributions were created by evaluating the collected energy data and identifying significant energy users (SEUs). The purpose, location, and amount of the used energy were documented with a single energy unit. During the analyzing processes, consumers with the highest share in total energy consumption were the major object of interest regarding efficiency improvements (International Organization for Standardization, 2018).

To assess future changes, an energy baseline was developed using a linear regression analysis within a reasonable period of time (reference period). Each energy point (resource) was assigned to an individual energy baseline. These baselines represent a helpful instrument in monitoring the system and allocating future changes to individual adjustments or replacements of equipment within the system. In this respect, energy savings can be revealed by engineering calculations (Akyuz et al., 2019; International Organization for Standardization, 2018; Kahlenborn et al., 2012).

EnPIs were determined using a statistical regression analysis of historical energy data with respect to several response and explanatory variables. The use of specific EnPIs enables the quantitative measurement of improvements in energy efficiency (Akyuz et al., 2019; Janić, 2011a). The performed analysis uses the indicators coefficient of determination (R^2) and p value to determine the correlation between the variables as proposed by Akyuz et al. (2019). A regression outcome with an R^2 value of close to 0, such as 0.1 is considered a poor model fit due to the fact that the explanatory variable explains the response variable by 10%. In contrast, a R^2 value of close to 1, such as 0.9 refers to a good model fit because the explanatory variable explains the response variable by 90%. Hence, a strong relationship between these variables exists. The p value indicates this significance of this correlation when it is less than .05. In other words, with a p value of .01 there is only a 1% probability that the observed results are purely accidental, which makes the obtained data statistically significant (Akyuz et al., 2019; Smith, 2015).

Objectives and targets represent the roadmap of any EnMS. Following the definition by ISO 50001, targets are equivalent to milestones, while objectives are considered as superordinate and long-term. However, their characteristics are interchangeable in their subsequent use (International Organization for Standardization, 2018; Kahlenborn et al., 2012). The long-term objectives and short-term targets were developed using the concept of SMART targets. The acronym refers to the characteristics of being Specific, Measurable, Appropriate, Realistic, and Timed (Edvardsson & Hansson, 2005; van Herten & Gunning-Schepers, 2000). In this sense, the desired achievements must be specifically defined by the target in order to provide guidance during the period of action. Measurability of the specific achievements and its effectiveness demands constant assessments and compliances with the set trajectory in order to not only motivate but also regulate the development by applying feedback loops. Furthermore, the targets must reflect an appropriate and realistic goal for the persons in charge and the target group. Two factors, namely related costs and time period delineate the leading influential parameters of achieving the target. Short to medium milestones support the development and motivation of its implementation. After all, the objectives and targets were developed with respect to a coherent interaction between its SMART characteristics (Edvardsson & Hansson, 2005; Rietbergen & Blok, 2010).

Considering the various types of SMART targets in an industrial energy context, Rietbergen & Blok (2010) propose distinct characteristics of the targets categorized by actors, scopes, compliance regime, target coverage, and target category. In context of this article, Figure 2 illustrates the specific characteristics of targets for the case object.

The airport is divided into three scopes, which are specified in the upcoming Section 3.4. The compliance regime is considered as semi-binding because national climate targets exist (Section 1) but they do not define specific regulations nor compliance mechanisms for airports. With respect to ISO 50001 and the subsequent ACA program, the energy consumption, and GHG emissions represent the relevant target coverage. The differentiation between quantitative targets is defined by categories and its taxonomy for industrial energy use. In the given case, the volume targets refer to the energy use reduction target and GHG reduction target. Both targets define a reduction by an absolute or relative value compared to a historical level (Rietbergen & Blok, 2010). The previously described baselines serve as measurable reference trend. It has to be highlighted that the volume targets are developed based on a bottom-up approach meaning its individual constituents, such as energy sources or GHG emitters are cumulated to determine the respective volume target. Conversely, a top-down approach starts with the volume targets and projects its magnitude to the influential constituents.

The physical efficiency target is related to the concept of EnPIs and describes a relative target comprising a unit of energy with respect to a relevant domain, such as number of passengers. Similar to the volume target, the baseline serves as

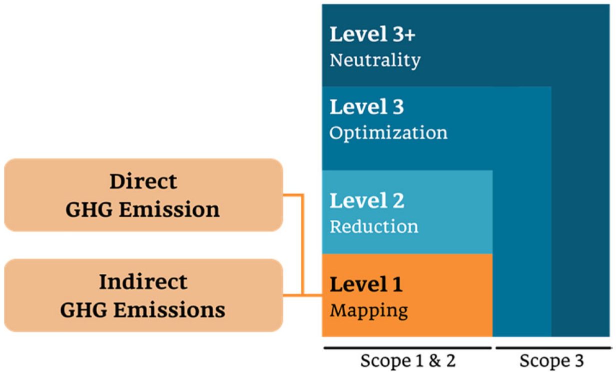

Figure 3. Four levels of the Airport Carbon Accreditation Program with focus on Mapping.

reference measured in the unit of the respective EnPI (Rietbergen & Blok, 2010). In practice, the objectives and targets should be in correlation with the energy policy of the airport. Akyuz et al. (2019) and Kahlenborn et al. (2012) present an example of an energy policy, which is not further elaborated in this work.

3.3. Methods of Airport Carbon Accreditation program

The ACA was created in Europe by Airports Council International (ACI) Europe and had expanded worldwide (ACA, 2016). This standard is developed in line with the GHG Protocol and ISO 14064 principles that set the framework and management system to develop the carbon footprint and identify projects to reduce emissions. The aim is to encourage and enable airports to implement best practices in carbon management having the ultimate objective of reaching carbon neutrality (ACA, 2016).

The four progressively stringent levels of accreditation are provided in Figure 3: (i) Mapping, (ii) Reduction, (iii) Optimization, and (iv) Neutrality. The main focus of ACA is on CO_2 emissions because the major share of airport emissions is made up of carbon-related GHG. In this context, this work considers solely the technical requirements of the first level of accreditation, which refers to the development of a carbon footprint analysis with respect to direct and indirect emissions controlled by the airport. For this purpose, the airport's inventory boundaries were defined consisting of organizational and operational boundaries. This adjusted concept applies the control approach according to GHG Protocol. It defines that the source of emissions accounts to 100% to the airport, when the airport has operational control over these emissions consisting of (i) stationary sources, (ii) mobile sources, (iii) process emissions, and (iv) indirect emissions (ACA, 2016; World Resources Institute, 2004).

The key element of ACA is the carbon footprint calculation representing a 12-month period. As permitted by ACA, the two following worksheet-based carbon footprint data analysis tools were applied, which are based on the GHG Protocol, ISO 14064-1, as well as ACI's Airport Carbon and Emissions Reporting Tool (ACERT): *GHG Protocol tool for stationary combustion* version 4.1 for the combustion of fuel in boilers and other stationary combustion equipment and *GHG Protocol tool for mobile combustion* version 2.6 for vehicles and mobile machinery (World Resources Institute, 2015b, 2015a). Both tools follow the guidelines of the IPCC and this emission inventory addresses the three primary GHGs identified in the Kyoto Protocol: CO_2, methane (CH_4), and nitrous oxide (N_2O), which are converted into CO_2e. An overview of typical sources and emission processes at airports is presented in Table 2. With regard to the indirect emissions caused by the use of electricity, the calculations solely focus on a location-based approach using the national Grid Electricity Emission Factor of 0.2090 $kgCO_2e$ per kWh for the electric gird in Denmark (Association of Issuing Bodies, 2018). The market-based approach is excluded from the analysis.

3.4. Scope and strategy

The analysis of both categories, the energy consumption and the GHG emissions, is conducted under the boundaries defined by ACA in line with the GHG Protocol. Here, scope 1 covers direct GHG emission, while scope 2 consists of indirect GHG emission. In terms of the energy consumption analysis, scope 1 covers *direct* consumed energy, which is represented by nonelectric sources. Scope 2 includes the electric energy, which is generated off-site (*indirect*). Both categories are related to the identical energy sources of the respective scope consisting of the sub-scopes natural gas (scope 1.1) and diesel (scope 1.2) as well as electricity consumed by the airport (scope 2.1) and electricity consumed by third parties (scope 2.2) as visualized in Figure 4. The energy sources, which are related to other activities off-site the airport area, such as aircraft fuel consumption and passenger travel to the airport, are assigned to scope 3 and not considered in this work.

Figure 5 illustrates the strategy of the present research starting with (1) the collection of relevant data about the operational and organizational infrastructure of the airport according to Section 3.5 and presented in Section 4.1. Afterwards, (2) the existing EnMS is identified and evaluated on the basis of the given standards. A comparison to ISO 50001 is executed as well as past and upcoming projects are highlighted (Section 4.2). On that basis, the (3) energy consumption and (4) GHG emission analysis is conducted with respect to the predefined scopes (Sections 4.3 and 4.4). Using statistical analysis on the operational and consumption data, EnPIs are tested on their statistical significance (Section 4.3.3). Lastly, the gathered and calculated energy and emission data are subject to a (5) linear regression analysis to determine the respective energy and GHG emission baselines of the given scopes (Section 4.5). With the completion of the five-stage analysis, the five-stage outline of the results is presented including (i) energy consumption and SEUs, (ii) GHG emissions, (iii) EnPIs, (iv) energy and GHG emission baselines, as well as (v) the final energy and emission objectives and targets with regard to the respective baselines. Finally, the resulting findings are synthesized into

Table 2. GHG emitters at airport by category and scope.

Scope	Category	GHG emitting sources
1	Stationary sources	Boilers, furnaces, burners, heaters, incinerators, engines, firefighting exercises, generators, etc.
1	Mobile sources	Automobiles (airside/landside), trucks, employee buses, etc.
1	Process emissions	On-site waste and wastewater management, etc.
1	Other emissions	Fire suppression CO_2, leakages in air condition system, etc.
2	Indirect emissions	Emissions from purchased electricity

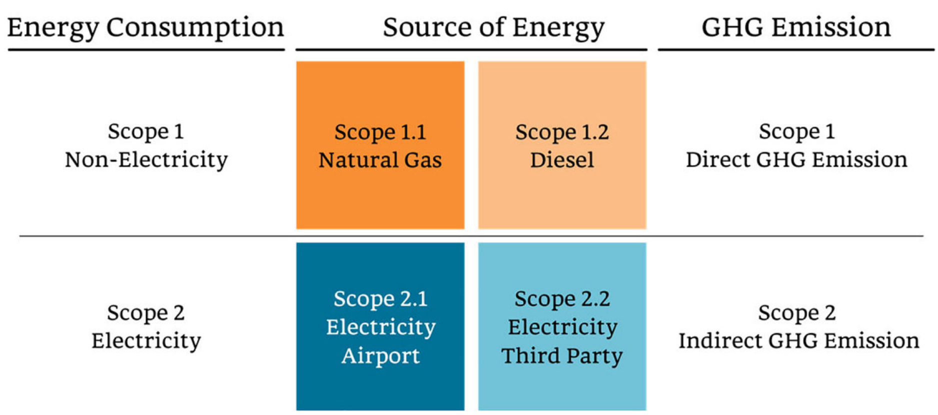

Figure 4. Scopes for energy consumption and GHG emission.

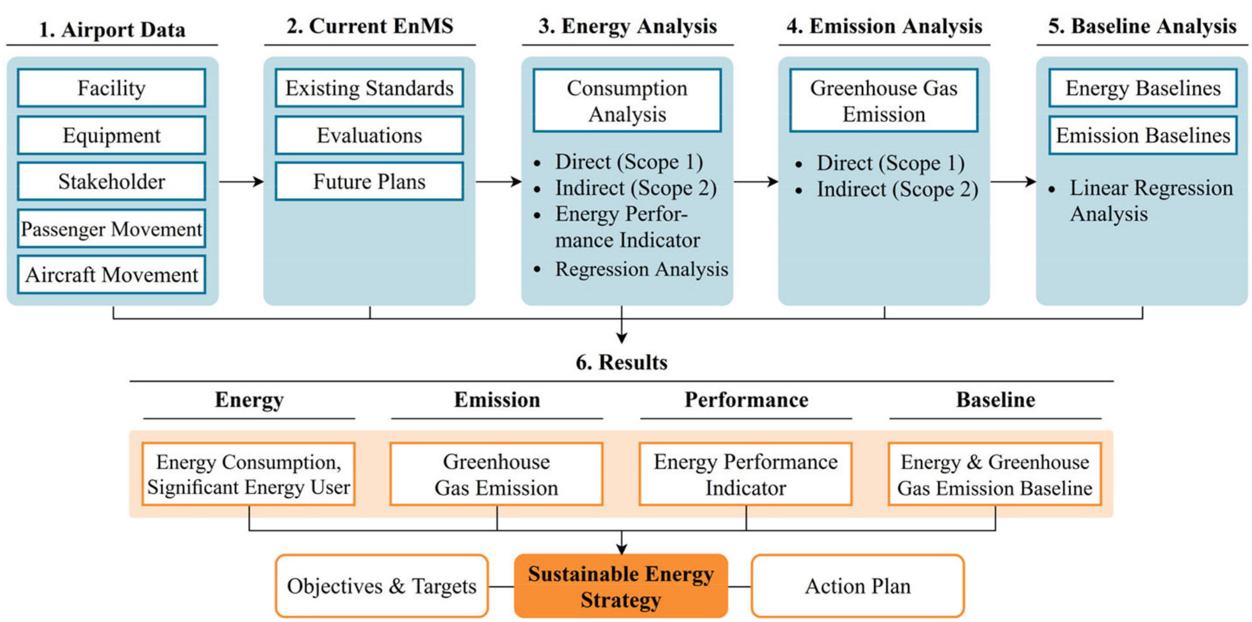

Figure 5. Research strategy consisting of five-stage analysis, four-stage outline of results, and final sustainable energy strategy including objectives and targets as well as the action plan.

a tailored action plan presented in categorized order of action (Section 5).

3.5. Data collection

Qualitative data were gathered by moving on to a semi-structured interview in combination with open-ended questions with the airport's CEO while inspecting the location and relevant energy-consuming utilities on-site, such as the airport building, heating system, ground support vehicle, and support equipment. Energy-related characteristics including year of construction or manufacture, year of replacement, usage profile, source of energy, energy-saving alternatives, etc., were a subject of the interview. Secondary data was gathered in form of energy data, passenger data, and aircraft movement (ATM) data. Data analysis was performed by evaluating the relevance of the dataset, assessing its credibility, and applying the empirical research methods according to Sections 3.2 and 3.3 in order to investigate the research problem (Andersen, 2018; Ryan, 2018; Vartanian, 2010).

Quantitative data were collected by examining documents containing mostly energy consumption data (Hair et al., 2015c; Lancaster, 2005). This kind of document analysis is frequently applied in case studies having the focus on data and information from company records and formal files (Oates, 2006). By applying a type of observation in which surveys were conducted during a specific time period, a longitudinal

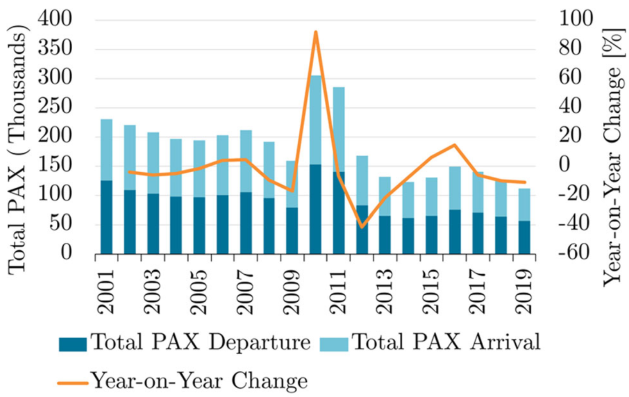

Figure 6. Total annual departing and arriving passenger (PAX) including domestic, international, scheduled, nonscheduled, and other flights as well as the year-on-year change (%) from 2001 to 2019. Historical events: In 2010 and 2011, the only two airline operators increased passenger traffic and competition, leading to a price decline and bankruptcy of one major airline in 2012. The operations of the remaining airline were taken over by a competitor in 2015, which operates since. Source: Danish Transport Authority (2020b).

research method is given, which is the case in this work (Hassett & Paavilainen-Mäntymäki, 2013). Finally, independent variables in form of passenger numbers and ATM are examined in order to assess the impact on dependent variables like energy consumption (Srinagesh, 2006).

The data and documents collected in this case study comprise the time frame from 2001 to 2019 for passenger and ATM data, which are made available by the Danish Transport Authority (2020b, 2020a). Energy data refers to a period from 2006 to 2019 and originates from two sources. Monthly data on electricity and natural gas consumption was provided by Midtjyllands Airport (2020). The same accounts for diesel consumption, which however only includes monthly data for the year 2019. Furthermore, the airport's electric energy provider Energi Danmark (2020) collects and shares *via* an online interface hourly data on the consumption of electricity since mid-January 2017, out of which three hours were missing and filled through simple interpolation. Statistical tools have been applied to guarantee validity and reliability of findings to avoid potential bias. Using this approach, support was given in order to provide verification of the themes that were identified in the study (Wu & Little, 2011; Yin, 2012).

4. Midtjyllands Airport energy management

This section starts with an analysis of the passenger and aircraft traffic at Midtjyllands Airport. Detailed visualizations enable insights about historical operational developments, which represent the main driver of the energy consumption at the airport. Afterwards, the current EnMS and saving initiatives are examined and reflected on the basis of ISO 50001. Subsequently, the energy consumption of the airport is analyzed with respect to the predefined scopes and methods of determining EnPIs. Lastly, the arising energy-related GHG emissions are determined by applying the calculation tools according to the ACA methods.

4.1. Airport traffic

Data about passenger traffic at Midtjyllands Airport on a daily basis are published by the Danish Transport, Construction, and Housing Authority. Figure 6 presents the total PAX from 2001 to 2019, including scheduled, nonscheduled, and other flights for domestic and international flight operations divided into total number of departing and arriving passengers. In 2010, the total annual passenger volumes almost doubled. However, two years later, the airport lost this traffic due to historical series of events: During 2010 and 2011, the Danish airline Cimber Sterling A/S with their aircraft ATR72 and Norwegian Airlines A/S with their Boeing 737 set up a parallel route to Copenhagen. As a result, the passenger traffic increased to 14 departures and 14 arrivals per day. This led to competition, low prices for tickets, and, consequently, an increase in private and business travelers to Copenhagen. Nevertheless, it was not profitable in the end and Cimber Sterling A/S declared bankruptcy in mid-2012, which cut half of all domestic flights in Denmark overnight. Shortly afterwards, Norwegian Airlines A/S took over with few flight operations until spring 2015, when Danish Air Transport (DAT) replaced Norwegian Airlines with their ATR72. Today, DAT is the only operator at Midtjyllands Airport (Bjørn-Thygesen, 2020).

Despite the peaks in 2010 and 2011, a general decreasing trend in passenger numbers is visible from the all-time maximum in 2001 to the all-time minimum in 2019 with a continuous downwards trend based on the latest four years.

Figure 7 visualizes the same data on a daily basis for the years 2017, 2018, and 2019. Due to the major share of business travelers, the main traffic appears during the week whilst travels at the weekend are about 75% lower. Furthermore, the one-week holiday periods in February, April, October, and December are clearly visible. The same applies of the summer months July and August revealing a huge gap in the overall passenger movement.

Figure 8 reveals the annual ATM from 2001 to 2019 categorized in departing, arriving, and other flights. The three historical key events described in the section above explain the peaks in 2010 and 2011 as well as the decline in 2015. Despite of these peaks and a brief regeneration period with a yearly increase of about 13% in 2016 and 2017, an overall negative trend in ATM is recognizable over the whole period.

Figure 9 presents a detailed view of ATM per day for the past three years. First, the distributions reveal a less constant pattern and more peaks compared to the distributions of passenger movement. In this regard, the holiday-gaps vary in different degrees of distinction over the years. Second, even though the summer period has a lower base load of aircraft traffic, several spikes are seen, which are probably not related to regular summer travelers but rather to private jet flights.

4.2. Current energy management and saving initiatives

The last energy assessment of Midtjyllands Airport was conducted in form of an Energy Management Handbook in 1998. The analyzed data cover a period from approximately 1994–1996. An Energy Action Plan for 1998–1999 was

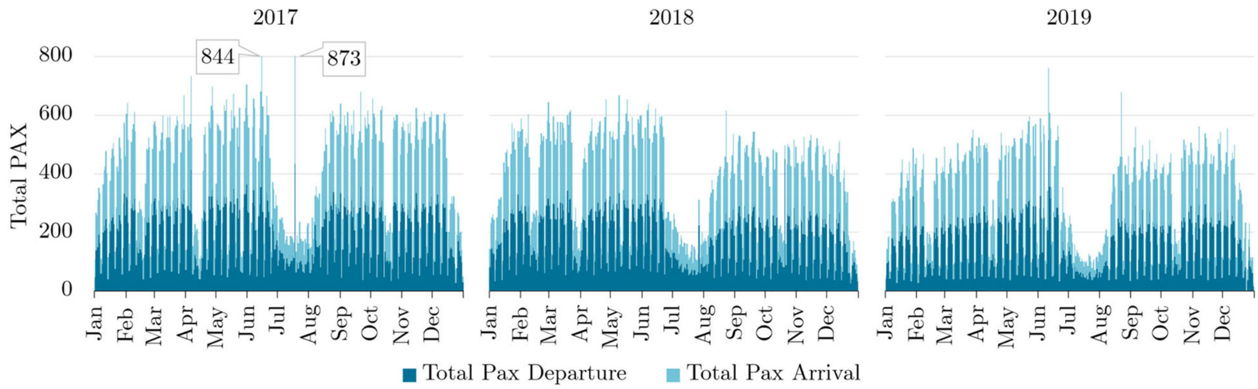

Figure 7. Total departing and arriving passenger (PAX) per day including domestic, international, scheduled, nonscheduled, and other flights in 2017, 2018, and 2019. The narrow gaps indicate weekends, while the gaps in February, April, October, as well as the summer months July and August are related to holidays. Source: Danish Transport Authority (2020b).

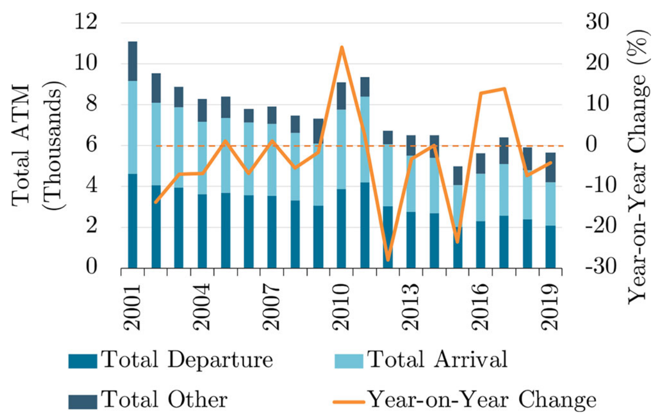

Figure 8. Total annual aircraft movement (ATM) including departing, arriving, and other flights as well as the year-on-year change (%) from 2001 to 2019. Historical events: In 2010 and 2011, the only two airline operators increased passenger traffic and competition, leading to a price decline, and bankruptcy of one major airline in 2012. The operations of the remaining airline were taken over by a competitor in 2015, which operates since. Source: Danish Transport Authority (2020a).

created without any long-term strategy. Due to the fact that the data set is older than 25 years and the documentation is incomplete to not existing, any further investigation about the energy management handbook is carried out. Today, an EnMS as described in Section 3.2 does not exist. One point worth mentioning in this context is the ventilation and air conditioning system at the roof of the airport. The system is out of order and an investigation is highly recommended because commonly hydrofluorocarbons (HFCs) are used as coolant, which are significant contributors to global warming effects when exposed to the atmosphere (Burkholder et al., 2020; Montzka et al., 2019; Saengsikhiao et al., 2020; H. Zhang et al., 2011).

Even though the natural gas as well as the electricity consumption is documented on a monthly basis in a digital Excel format since 2005, neither simple visualizations nor basic evaluations have been executed. The same applies for the diesel consumption, which is digitally documented only since 2019. In addition, the data management is conducted by storing energy data in individual Excel files, which revealed unsystematic structures. Frequently, energy data is only documented in single energy invoices. Furthermore, the electricity supplier offers an online service by which the airport can access its hourly consumption since 2017 using a web interface. This database has never been accessed before and, hence, no value has been generated by using the free and digital monitoring service.

In the past two years, Midtjyllands Airport announced and implemented a number of climate protection measures at both airside and landside. For the reason that this article is mainly focusing on the land side of the airport, only one applied measure is considered as relevant for later analysis: Over the past 5 years, the airport has optimized the energy consumption of the terminal by as much as 50% due to investments in energy-efficient lighting, new technologies, and improvements in the energy consumption after traffic times.

Overall, the airport handles its energy resources and energy consumers in a way, which requires an urgent need to act. Even though improvements have been achieved by replacing the old lighting system, a comprehensive and detailed energy strategy has not been designed neither in the past years nor in the last three decades. Fundamental measures have to be taken into action in order to close the gap between an insufficient management of energy sources and highly efficient EnMSs. For that reason, the following sections analyze Midtjyllands Airport's energy profile and its carbon-related emissions with the goal of taking the first step toward the profiled ISO 50001 EnMS and the ACA certification.

4.3. Energy consumption analysis

4.3.1. Scope 1: Natural gas and diesel consumption

This section covers the direct energy consumption of the energy sources natural gas (scope 1.1) and diesel (scope 1.2), which are related to scope 1 of ACA boundaries. While diesel is consumed by heavy vehicles and aircraft supply equipment, natural gas is used for local production of central heating. The data was gathered and documented by Midtjyllands Airport. The values in cubic meters were converted with the 2019 average calorific value for Karup (11.93 kWh/Nm^3) published by Energinet, Midtjyllands Airport natural gas provider (Energinet, 2020). Figure 10 shows the total natural gas consumption from 2006 to 2019,

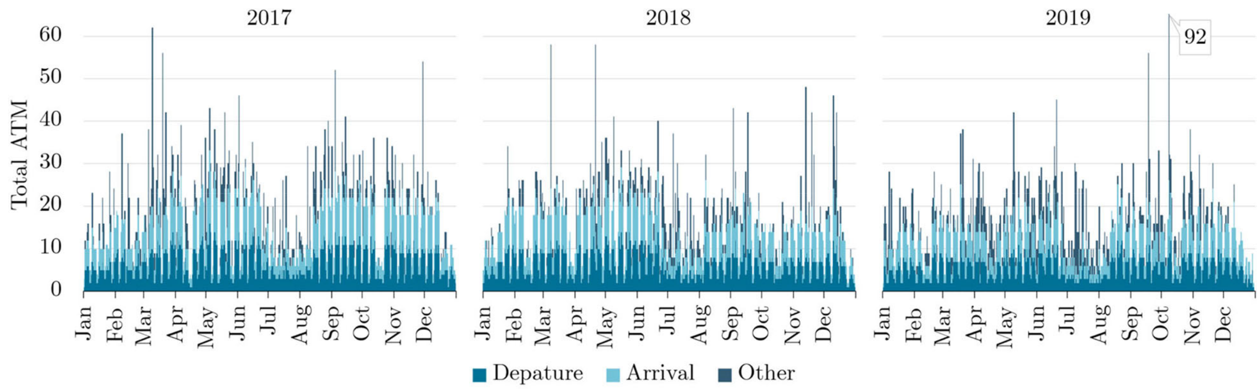

Figure 9. Total aircraft movement (ATM) per day including departing, arriving and other flights in 2017, 2018, and 2019. The narrow gaps indicate weekends, while the gaps in February, April, October, as well as the summer months July and August are related to holidays. Source: Danish Transport Authority (2020a).

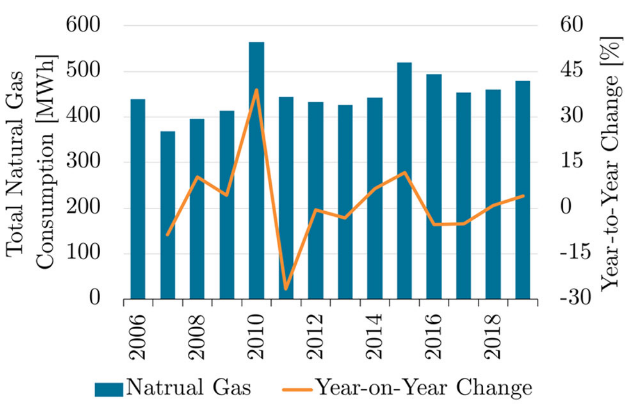

Figure 10. Total annual natural gas consumption (scope 1.1) and year-on-year change (%) from 2006 to 2019. Source: Midtjyllands Airport (2020).

which covers the period since the new gas heater was installed. Regardless the events in 2010 and 2015, a consumption between 370 and 495 MWh is visible including a slight upwards trend in the past three years. Hence, this trend behaves contrary to the decline in the number of passengers and ATM during the same period (Figures 6 and 8).

Figure 11 shows a detailed illustration of these three years on a monthly basis together with a five-year average from 2015 to 2019 and a 10-year average from 2010 to 2019 for each month. The distinctive difference between the summer and winter period is visible. The summer months June, July, and August are a reasonable indicator of the hot water consumption at the airport. Both averages are almost equal while the reference summer periods slightly deviate from the averages in a negative and positive way. However, it can be estimated that an average of 7 MWh (600 m^3) of natural gas is needed throughout the year to cover the hot water demand. All three years reveal a fluctuated consumption during the spring and autumn period, which is to be expected due to changing weather and temperature conditions. The month with the highest consumption of natural gas is most likely the coldest month, which is in this case January based on the mean values. Even though the 5- and 10-year average of January and February are close to each other, the data of the three latest years strongly fluctuated. The month of December may show a deviation between the mean values, but the yearly consumption is almost equal. These fluctuations make a profound interpretation difficult.

Figure 12 presents the monthly diesel consumption (left) and the total consumption (right) of operating equipment and vehicles in 2019. This year was the only available data set by Midtjyllands Airport. The values are converted from liter to kWh using the calorific value 277.77 kWh per ton and the conversion factor 1.185 liter per ton (International Energy Agency, 2005). According to the chart on the right-hand side in Figure 12, it is clearly visible that the heaters (multiple) consume over 50% of the diesel demand in 2019. The heater is a device that increases or keeps the air temperature in the aircraft cabin at comfortable level before and while passengers enter the cabin. Therefore, it is mainly used in the colder periods of the year as the left-hand side of Figure 12 illustrates. From January to May and October to December 2019, the heaters are used intensively due to low outdoor temperatures consuming 577 kWh (2460 l) diesel – more than half of the total diesel consumption. The fuel tanker (151 kWh; 646 l) and the deicer (85 kWh; 362 l) account together for less than one-quarter of the diesel consumption while vehicles for passenger transport and other heavy vehicles share the remaining quarter.

4.3.2. Scope 2: Electricity consumption

The analysis of the electricity consumption was conducted using two main data sets. The first set is gathered by Midtjyllands airport on a monthly base and divided into the consumption of the airport building and third-party consumption, such as airline operators and aircraft services (Table 1). Both categories of airport and third-party consumption belong to scope 2 because the electricity generation occurs off-site and the airport has control of this source of energy and emission, respectively, even though the airport cannot control the consumption of the third party. For further analysis, these two categories are classified into the terms scope 2.1, which includes the electricity consumption the airport is paying for such as light, security scanner, and electric ground support vehicles and scope 2.2, which consists of the electric energy consumed by third parties, which the airport bills (offices of tenants, charging batteries for aircraft, etc.) (Figure 4). The second main data set is

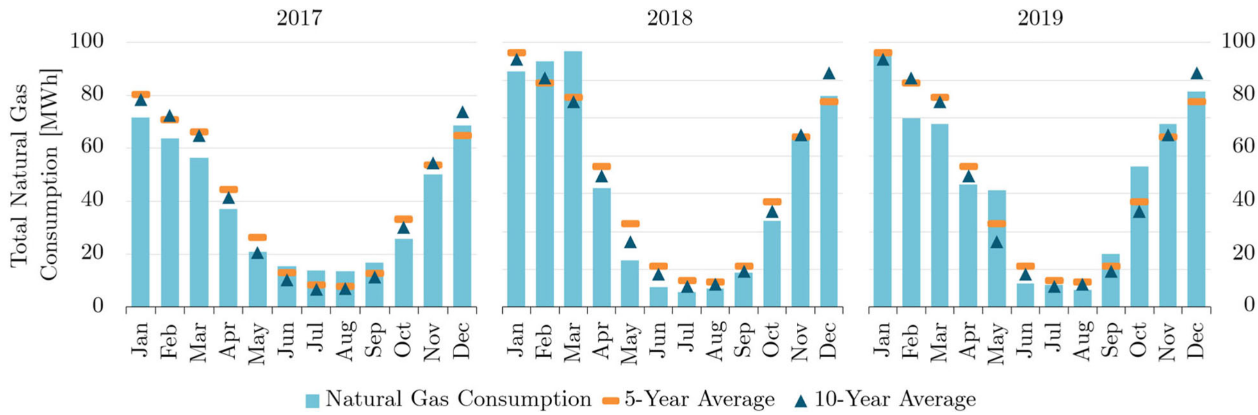

Figure 11. Total natural gas consumption (scope 1.1) on a monthly basis with 5-year (2015–2019) and 10-year (2010–2019) average. Source: Midtjyllands Airport (2020).

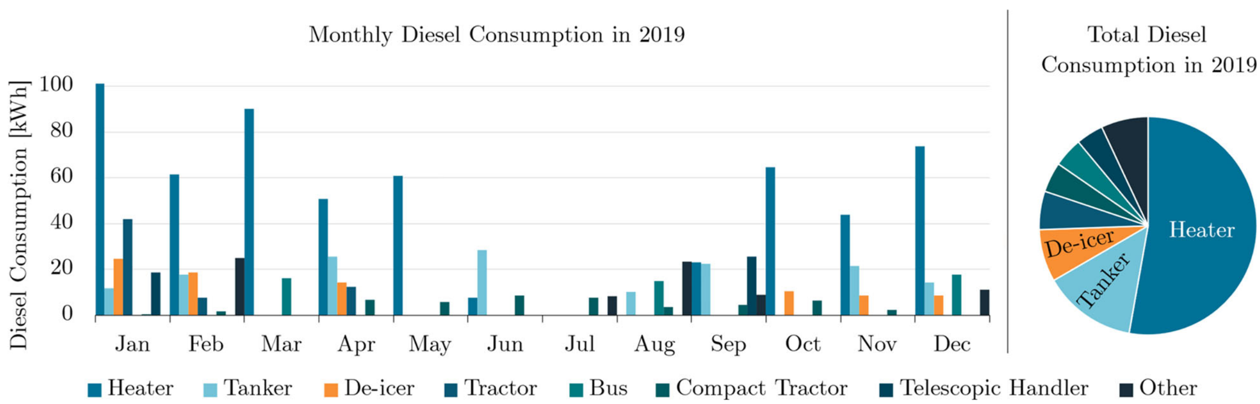

Figure 12. Monthly diesel consumption (left) and total diesel consumption (right) (scope 1.2) in 2019. Source: Midtjyllands Airport (2020).

Figure 13. Total annual electricity consumption and year-on-year change (%) from 2006 to 2019. Source: Energi Danmark (2020); Midtjyllands Airport (2020).

accessible online through Midtjyllands Airport electricity provider that monitors the energy consumption per hour, which allows a detailed analysis. However, this data set includes the total airport's energy demand including third parties (scope 2.1 + 2.2). At this point, a separation is not possible. Nonetheless, both data sets are equal when comparing the monthly values.

Figure 13 illustrates the total energy consumption of scopes 2.1 and 2.2 separately from 2006 to 2019. The peak in 2010 and 2011 are caused by the events mentioned in Section 4.1. Despite that, the electricity consumption for both scopes remains almost constant over the 14 years period – a very slight decline is recognizable. The past five years show clearly constant developed in total. However, the airport's demand increases slightly while the third-party demand declined. This behavior is contrary to the rise in PAX and ATM (Figures 6 and 8).

The detailed analysis in Figure 14 shows the consumption per hour of the airport and third parties combined (scope 2) for the years 2017, 2018, and 2019. In all three years, the consumption pattern is roughly similar with a higher base load and peak demand in the winter period compared to the summer months. The consumption peaks, mainly above 40 kWh, are clearly distinguishable from the base load. The small gaps between these peaks are the operation at night. Slightly bigger gaps are weekends with less passenger traffic, especially visible in for example September 2017 and 2018. These weekend-gaps are barely not identifiable in 2019. Interestingly, neither the one-week holiday gaps of passenger movement in spring, autumn, and winter nor the huge summer-gap is evident in 2019 (Section 4.1). Even though July 2017 and 2018 reveal a reduced intensity in consumption peaks, the consumption in 2019 has no changes at all. Furthermore, during these periods, the base load stays constantly high with over 40 kWh for 95% of all hourly values.

By sorting the values of Figure 14 in a descending order, the electrical load profile in Figure 15 is resulting for the years 2017, 2018, and 2019, with the highest value on the left at hour 0 and the lowest value on the right at hour 8760. In addition, the base load coverage for 99.99% and

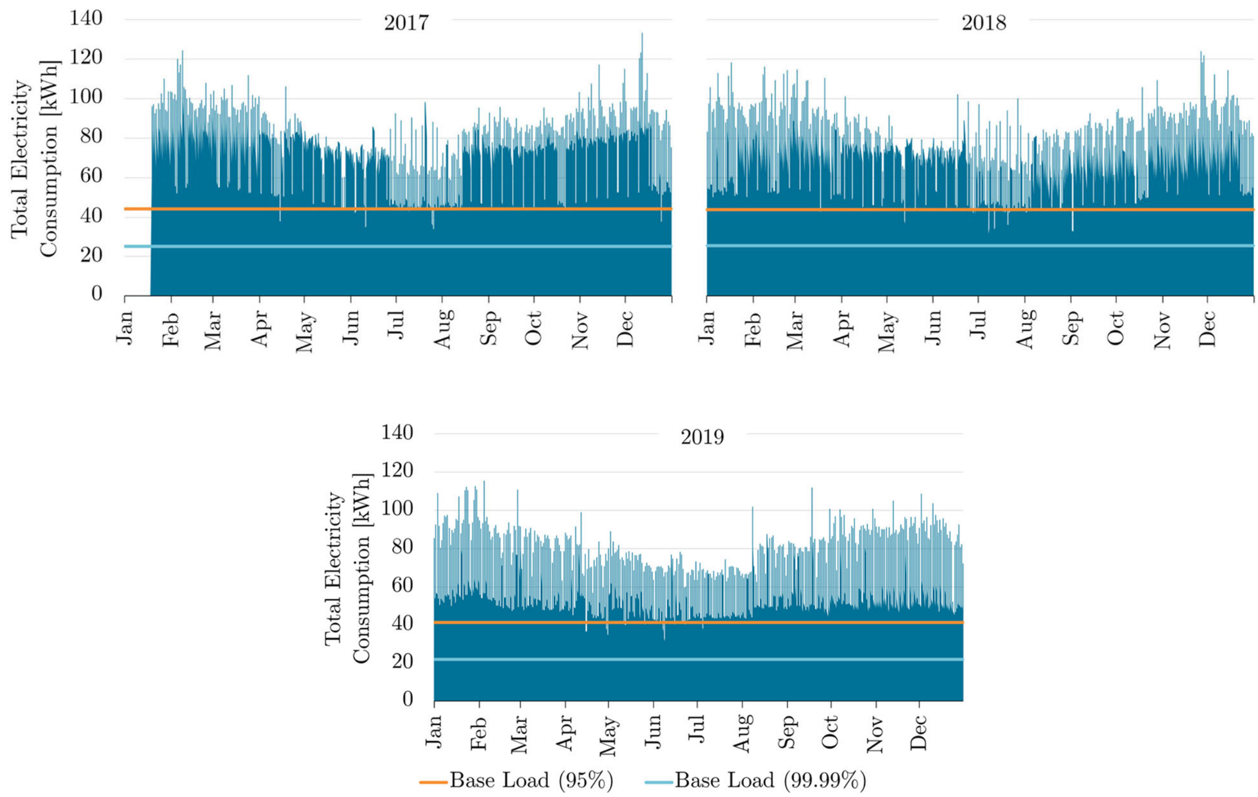

Figure 14. Total electricity consumption on an hourly basis of scope 2 including airport and third-party. (Scope 2.1 + 2.2) in 2017, 2018, and 2019. Source: Energi Danmark (2020).

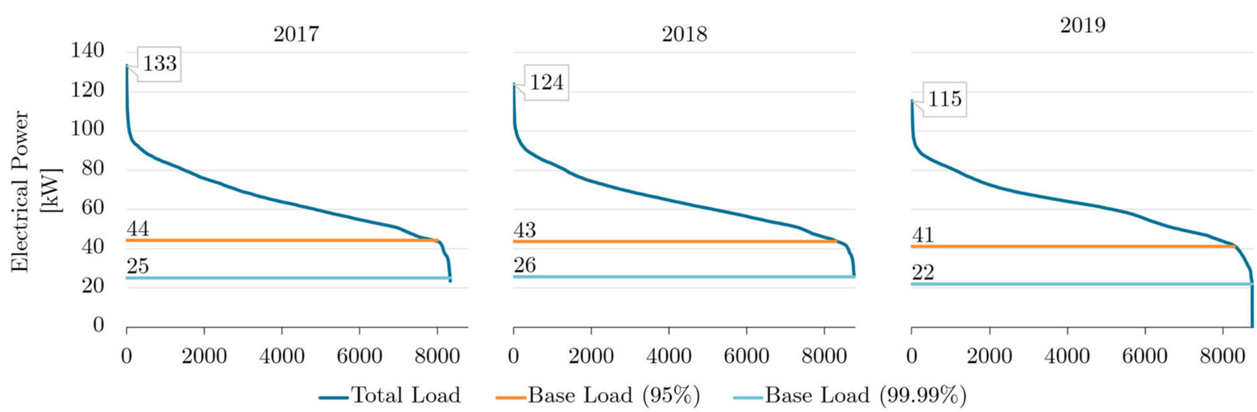

Figure 15. Electrical load profile of scope 2 including airport and third-party (scope 2.1 + 2.2) with 100% and 95% base load for 2017, 2018, and 2019. Source: Energi Danmark (2020).

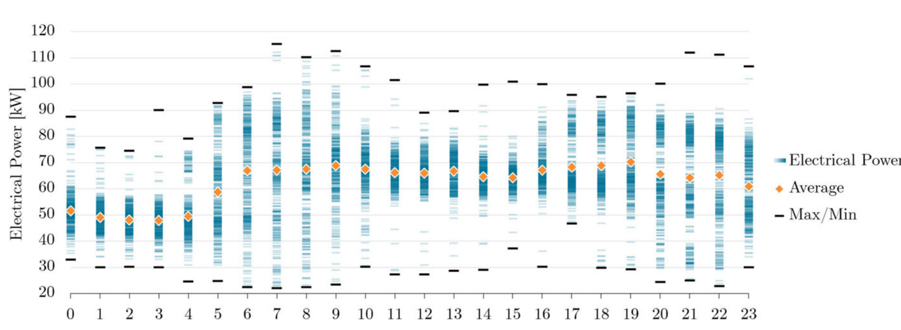

Figure 16. Total electrical power demand of scope 2 including airport and third-party (scope 2.1 + scope 2.2) in 2019, categorized in individual daily hours including maximum, minimum, and average. Color intensity represents distribution of electrical power demand within a single hour of the day. Source: Energi Danmark (2020).

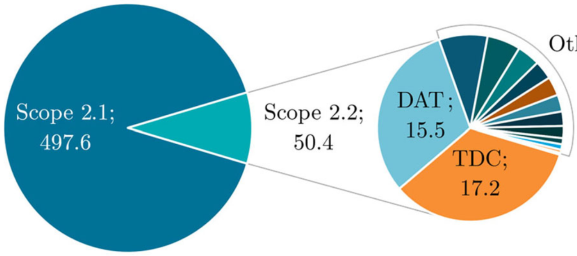

Figure 17. Total electricity consumption (in MWh) in 2019, divided in electricity consumed by airport (scope 2.1) and electricity consumed by third parties (scope 2.2). Source: Energi Danmark (2020); Midtjyllands Airport (2020).

95% of all data points are plotted. Figure 15 reveals a maximum load of 133 kW and a minimum load of 22 kW throughout the three years. Moreover, by skipping the lowest 5% values, the base load nearly doubles. As a result, the airport's load profile is mostly characterized by a base load profile. This has a crucial effect on future energy sources and technologies, which are potentially able to cover the present demand profile.

Even though scopes 2.1 and 2.2 are combined in the hourly data set, valuable information is hidden in the previous analysis and figures. Therefore, the goal is to determine specific distributions of significant power values, which can be illustrated using the benefits of the high resolution in combination with a particular visualization approach that was developed for this specific purpose. Figure 16 reveals the result of this approach. The x-axis displays the daily hour of all days in the year 2019, from 00:00 to 23:00 o'clock. The power values are plotted in this scheme using a partly transparent data point. This leads to the effect that overlapping data points increase the color intensity of the specific power value. In addition, the absolute maxima and minima together with the hourly average are displayed. Starting with the period 00:00–03:00 o'clock, it is visible that even though some high maxima are present, most of the power values are located around the average. Moreover, these average values build the bottom line of all other mean values. This means that a significant improvement in energy efficiency can be made when the average values after 04:00 o'clock decline because the values before 04:00 reflect the power demand at night with the least amount of airport activity.

Continuing with 4–7 h, it is clearly visible that the power distribution is starting to scatter below and above the average. Power hot spots are forming at about 80 kW at 06:00 and 85 kW at 07:00. This means that even though at 07:00 o'clock the highest absolute maxima are present, the focus should be on these power hot spots. They may occur with a 22% lower power than the maxima, but the quantity of the values is significantly higher, recognizable by the higher color intensity. From 07:00, these color spots scatter in the next 2 h until they gather around the average from 10:00 to 15:00. During this morning period from 05:00 to 10:00, the highest passenger number is handled by the airport preparing the aircraft for departure. Single large electrical consumers or several smaller consumers are operated during this time. Therefore, in the first place, the goal is to control and reduce these power hot spots regardless of the absolute maximum in order to shrink the average consumption of that hour. The hours from 11:00 to 15:00 show the power hot spots around the average, which illustrates the airport's base load during daytime. From 16:00, arriving aircraft with passenger reach the airport. Power hot spots form again below and above the average. This time, the color intensity of the hot spots above the average is significantly higher and even a gap between average and hot spots is visible, which almost remain until 23:00. This highlights the fact that by controlling these consumers causing the power hot spots, a significant energy reduction can be achieved.

As a result, consumers, which are responsible for the power hot spots above the average, have to be identified and tackled in the first place. However, it is also possible that these consumers are third-party consumers (Table 1), such as aircraft, which are charged at the gate. By analyzing the only common data set of the electricity consumption of the airport (scope 2.1) and third-parties (scope 2.2), it reveals that scope 2.2 consumes the minor share of 50.4 kWh (9.2%) of the total electricity consumption in 2019 (Figure 17). The airline operator DAT has only the second-highest electricity demand with 15.5 MWh (total 2.8%). The airline service company Airline Services Limited (TDC) (ticket sales) consumes the most with 17.2 MWh (total 3.1%). Nevertheless, it is critical to assign hourly power peaks (Figure 16) to an annual amount of energy. Consequently, it is beneficial to invest resources in order to distinguish consumers within scope 2.1 and scope 2.2 starting with TDC and DAT so that the hourly electricity consumption of scope 2 is separated.

4.3.3. Determining energy performance indicator

EnPIs are identified on the basis of the given scopes of the energy consumption per PAX and per ATM with respect to the sample size of 14 annual observations for each case. The process of determining EnPIs conducted under the regulation of ISO 50001 is described in Section 4.5. The system boundaries are set as follows: The used energy data set consists of the annual natural gas consumption (scope 1.1) as well as the annual electricity consumption by the airport (scope 2.1) and by third parties (scope 2.2) within the period of 2006–2019. Because of missing historical data, the diesel consumption (scope 1.2) is assumed to be equal for all years using the existing value of 2019, which takes up a share of 4.8% of total energy consumption. Changes of this small share have minor effects on the total consumption because a linear relation can be assumed. However, it is strongly recommended to document and include the diesel consumption in future analysis. For both passenger and ATM, the annual data sets of Section 4.1, respectively, are considered. The analysis applies only annual data because monthly or even daily intervals take seasonal fluctuations into account, such as changing light and temperatures conditions, which have an impact on energy demand while being not correlated to passenger and aircraft numbers.

Before starting with the regression analysis of the total energy consumption and the two variables, all three data sets are normalized and plotted in Figure 18. This

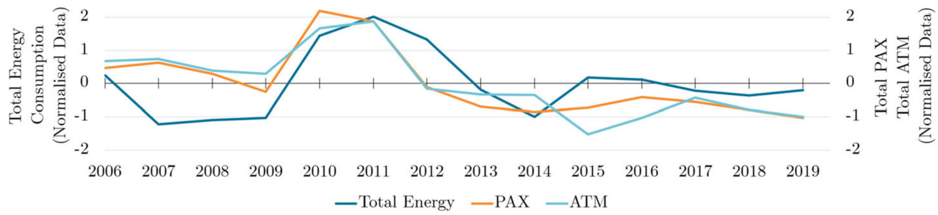

Figure 18. Total energy consumption, total passenger (PAX) and total aircraft movement (ATM) from 2006 to 2019, normalized data.

comparison is suggested in the literature (Farquhar, 2012) and it allows a direct visualization of the qualitative analysis of the sections above (Baxter et al., 2018a). The total energy demand increased with rising number of passengers and aircraft over the period 2006 to 2011. In 2011, the energy consumption crossed both PAX and ATM, and remained above these lines with an exception in 2014. As such, crossing curves with PAX and ATM declining indicate a deterioration in energy efficiency at the airport. Furthermore, the displayed downward trend of passengers and aircraft in the last three years in combination with upward trend of energy consumption intensifies the decrease in energy efficiency.

The performed regression analysis was conducted with single and multiple regressions including the dependent variables of total energy, electricity, and natural gas consumption (response variable), as well as the independent variables of passenger and ATMs (explanatory variables or predictors) (Crawley, 2012). The constellation of the regression is shown in Table 3 together with the relevant output values R^2, coefficient and p value.

First, the coefficient of the ATM variable in line 2, 5, 10, and 12 appears negative which indicates a growing energy consumption while PAX or ATM increases. Therefore, these variables can be eliminated. The same applies for the lines if the p value is greater than .05 – line 4, 6, 7, and 11 – because this indicates a statistically insignificant relationship between the variables. After this separation, line 1, 3, 8, and 9 remain. The variables in line 1 and 9 are analyzed in correlation with previous eliminated variables and, therefore, the variables are also omitted. Finally, a statistically significant relationship exists between the total energy consumption and PAX (line 2) and between electricity consumption and ATM (line 8). However, the values of R^2 are far below 0.9, which indicates a rather poor model fit. This means that the variable PAX explains the current and future energy consumption by about 33% and the variable ATM explains the electricity consumptions by 32%. In contrast, a good model fit is reached with an R^2 over 90%. The annual development of these EnPIs resulting from the regression analysis is presented in Section 5.3.

4.4. Carbon emissions arising from energy consumption

The following analysis is conducted using the methodology of ACA in line with the GHG protocol described in Section 3.3. The carbon footprint calculation of level 1 (Mapping) covers the emissions of natural gas and diesel (scope 1) as well as electricity (scope 2). The input parameters are specified in the GHG calculation tools for

Table 3. Regression analysis with annual values from 2006 to 2019 (14 observation each) including total energy consumption (TEC), electricity consumption (ELC), natural gas consumption (NGC) as response variable, and passenger (PAX) and aircraft movement (ATM) as explanatory variable, revealing line 3 and 8 as appropriate EnPIs.

Line	Response variable	Explanatory variables	R^2	Coefficient	p Value
1	TEC	PAX	0.46	1.30	.03
2		ATM		−39.14	.13
3	TEC	PAX	0.33	0.53	.03
4	TEC	ATM	0.15	16.53	.17
5	ELC	PAX	0.33	−0.22	.69
6		ATM		32.02	.23
7	ELC	PAX	0.23	0.41	.08
8	ELC	ATM	0.32	22.56	.04
9	NGC	PAX	0.53	1.52	.01
10	NGC	ATM	0.53	−71.16	.01
11	NGC	PAX	0.02	0.11	.64
12	NGC	ATM	0.02	−6.04	.60

stationary combustion and mobile combustion including years, sector, fuel type, amount of fuel, etc. The output is given in $kgCO_2e$. The emissions caused by the use of electricity are determined by the multiplication of the annual electricity consumption value (Figure 13) and the national grid electricity emission factor of 0.2090 $kgCO_2e$ per kWh (Section 3.3). The results of both scopes 1 and 2 for the historical years and in detail for the latest year are presented in Section 5.2.

4.5. Determining energy and emission baseline

According to ISO 50001, an appropriate reference period (energy baseline) is to be determined to ensure representative changes in the energy performance. For that reason, a statistical analysis is performed to determine a statistically justified period for the following indicators: (A) total GHG emissions, (B) total energy, (C) natural gas and (D) electricity consumption, (E) total energy EnPI, and (F) total electricity EnPI.

The analysis uses the assumption of an absolute constant diesel use per year, which is based on the single available data set of 2019, as described in Section 4.5. Besides that, it has to be mentioned that the total error of GHG emissions by diesel increases due to an increasing relative share of 6.1%. Nonetheless, even major changes in the diesel consumption would have minor effect on the total GHG emissions. A linear regression analysis is applied for the reference periods from each year before 2018 to the latest year 2019 (e.g. 2017–2019 ($x = 3$), 2016–2019 ($x = 4$), etc.) with focus on the coefficient of determination R^2. If this indicator is closer to 1 then precise predictions of ongoing trends can be made. The reference period is defined with

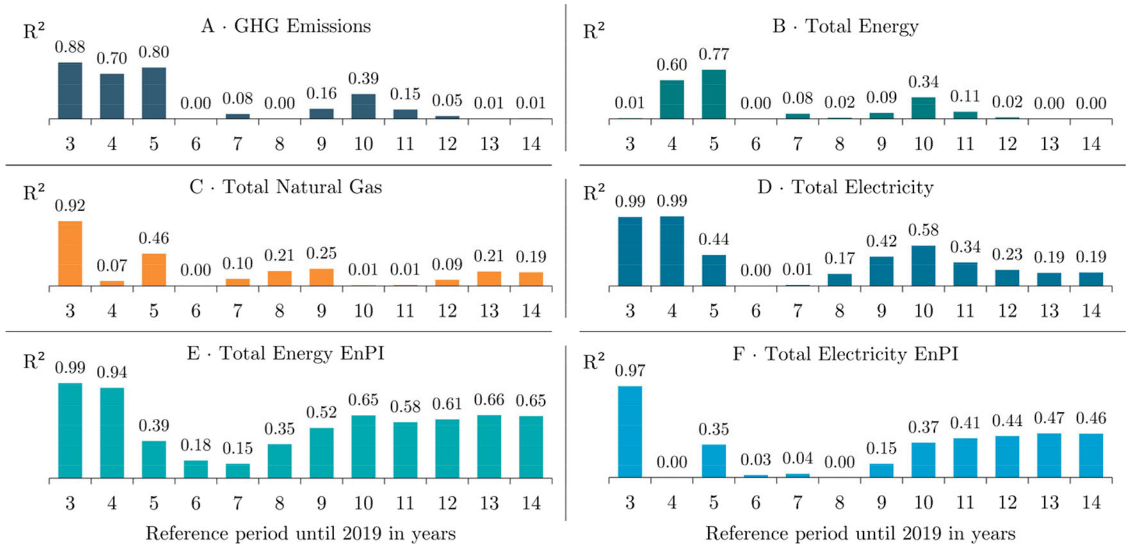

Figure 19. Linear regression analysis of each indicator for the reference periods from each year before 2018 to the latest year 2019 with the focus on R^2.

2019 as the end year due to changing operational events in the years before 2015, which led to high fluctuations. Figure 19 shows the results of this analysis. Beginning with Chart B in Figure 19, it reveals the highest R^2 value of 0.77 for the period 2015–2019 ($x = 5$). This indicates that a further trend of the energy consumption can be predicted with accuracy of 77%. The GHG emissions in Chart A have the highest value at $x = 3$ and the second-highest value at $x = 5$ with 0.80. For a better comparability, the baseline from 2015 to 2019 ($x = 5$) is chosen for both total energy consumption and GHG emissions. With regard to Chart C–F, all of them display R^2 values over 0.90 in the period from 2017 to 2019 ($x = 3$) and, therefore, this period is opted as their energy baseline.

5. Results and discussion

Based on the analysis in Section 4.3, the energy consumption, GHG emissions, and EnPIs of the airport are presented. In combination with the energy and GHG baselines, the resulting sustainable energy strategy is revealed and discussed considering the objectives and targets of the individual sources of energy, total energy consumption, and total GHG emissions, as well as the determined EnPIs. The final action plan summarizes the major findings of the strategy.

5.1. Total energy consumption and significant energy user

Figure 20 (left chart) presents the outcome of the total energy consumption. Despite the peak in 2010 and a slight increase in 2015, statistically speaking, the energy consumption remains constant over the entire time frame. The variations are caused by operational changes with airline companies (Section 4.1). Except 2015 and 2016, the airport's electricity consumption (scope 2.1) accounts for the major share closely followed by the natural gas consumption (scope 1.1). The significantly smaller share of electricity use by third parties and the nonvisible consumption of diesel (only available in 2019) form the remaining energy use. A closer look at the total energy consumption of about 1029 MWh in 2019 (right chart) highlights the historical development with almost equal shares of natural gas and airport's electricity consumption. In addition, the airline service company TDC and the airline operator DAT form the biggest share of third-party consumers, which covers in total energy use a minor share of about 1.5% for each.

Due to not existing consumption data of individual electricity users, only assumptions can be made: It is to be expected that besides the new in-door lighting system, most likely the out-door lighting system (floodlight), electric ground support vehicle, old escalator, security scanner systems, and airport's office department are the major SEUs. Moreover, focusing on the relatively high base load (both 95% and 99.99%, Figure 15) in combination with analysis of the individual daily hours (Figure 16), it can be assumed that, at night, several electrical consumers still consume energy even though they are not in use because of reduced or any passenger movement. The same accounts for holiday periods in which the passenger traffic generally decreases while the absolute base load remains equally high. Furthermore, large amount of electric energy is consumed during the late afternoon and evening. This is most likely caused by arriving passengers after regular workdays. However, the frequent energy peaks form in total a large share of the daily energy profile and, therefore, further examinations are needed.

The thermal energy consumption is only represented by the natural gas use, which is used to heat the entire building of the airport including every party. Electrical heating is unknown. It can be assumed that a vast amount of thermal energy is lost through the enormous glass facade manufactured in 1991. In addition, due to several construction phases over the past 50 year, the general quality of the thermal insulation of the building can be considered as low to very low. In this context, losses in the heating system through, for example, uninsulated pipes, which were identified at the airport, increase further significant losses. An

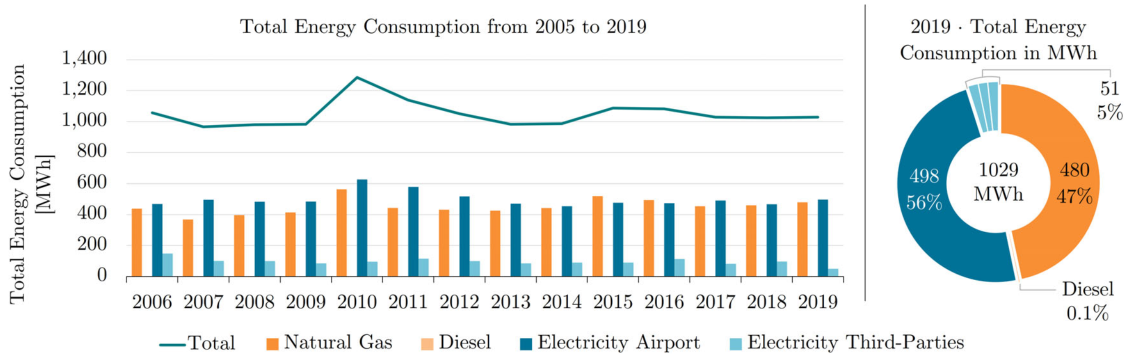

Figure 20. Total energy consumption including all scopes from 2006 to 2019 (left) and detailed view of 2019 (right).

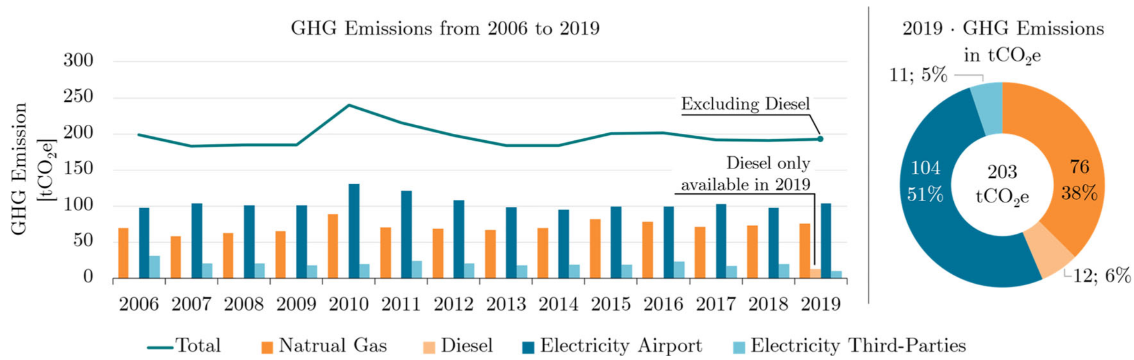

Figure 21. Total greenhouse gas (GHG) emissions including all scopes (left) and detailed view of 2019 (right) in tons of carbon dioxide equivalent (tCO_2e).

Table 4. Individual GHG emissions of each scope and its sub-categories in 2019.

Scope 1: Direct emissions			Scope 2: Indirect emissions		
Sub-scope	Emission source	tCO_2e	Sub-scope	Emission source	tCO_2e
1.1 Natural gas	Central heating	76.03	2.1 Electricity	Airport	104.00
1.2 Diesel	Service equipment	12.47	2.2 Electricity	Third-party	10.53
	Aircraft heater	6.58	–	Airline service	3.60
	Tanker	1.73	–	Airline operator	3.24
	Deicer	0.97	–	Car rental	2.08
	Tractor	0.71	–	Aircraft service	0.42
	Bus	0.56	–	Other	1.20
	Compact tractor	0.54	–	–	–
	Telescopic handler	0.51	–	–	–
	Other	0.87	–	–	–
	Subtotal	88.50	–	Subtotal	114.53
Total 203.02 tCO_2e					

energetic analysis of the thermal building envelope including the heat system with heater, transmitter, and pipe network is highly recommended.

5.2. Total greenhouse gas emissions

Figure 21 presents the results of both scopes 1 and 2 for the historical years and individually for the latest year. Because of missing data, the diesel consumption (scope 1.2) is only available for the year 2019.

Due to the historical events described in Section 4.1, the median is used in the following analysis in order to reduce the impact of these events in 2010 and 2011. It is apparent that the GHG emissions caused by natural gas (scope 1.1) fluctuate around the median value of 70 ± 8 tCO_2e over the entire time frame with an increase in the latest three years. The emissions caused by diesel (scope 1.2) are only available for 2019. The total electricity-related emissions (scope 2) reveal similar fluctuations around the median of 121 ± 11 tCO_2e. However, 2017–2019 shows a total growth of about 5.6% during these years. In the latest year, approximately, 50% of electricity-related emissions by third parties (scope 2.2) shifted to the airport's electricity-related emissions (scope 2.1), whereby the total GHG emissions remain constant during the same period. With the inclusion of diesel (scope 1.2) in the final year, Midtjyllands Airport GHG emissions add up to 203 tCO_2e with a slightly larger share of emissions caused by electricity (56%; scope 2) than by natural gas and diesel (44%; scope 1). Table 4 presents a detailed list of the occurred GHG emissions in 2019.

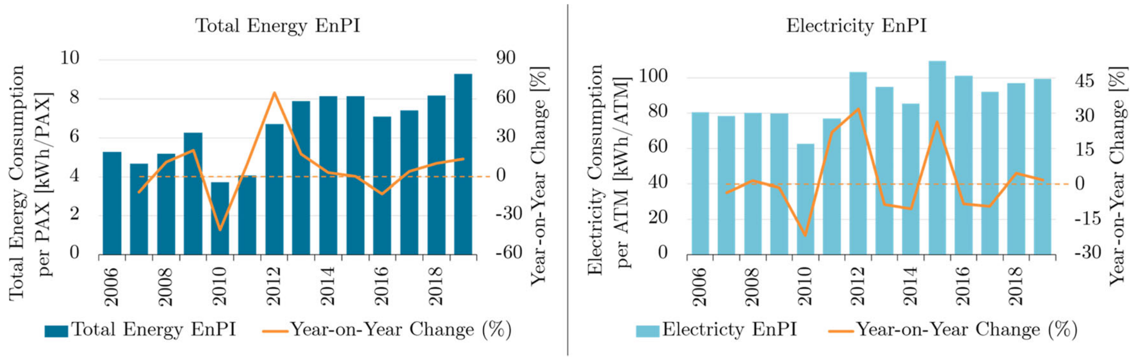

Figure 22. EnPI for total energy demand per passenger (PAX) and electricity demand per aircraft movement (ATM) with year-on-year change (%).

Table 5. Baseline period for each indicator with coefficient of determination R^2 and trend function.

Indicator	Baseline period	R^2	Regression function
Total GHG emissions	2015–2019	0.80	$y = -3.10x + 6454$
Total energy consumption	2015–2019	0.77	$y = -17588x + 36526278$
Total natural gas consumption	2017–2019	0.92	$y = 12816x - 25396747$
Total electricity consumption	2017–2019	0.99	$y = -13032x + 26860298$
Total energy per PAX (EnPI)	2017–2019	0.99	$y = 0.94x - 1891$
Total electricity per ATM (EnPI)	2017–2019	0.97	$y = 3.77x - 7514$

5.3. Energy performance indicator

The performed regression analysis in Section 4.3.3 reveals the following EnPIs:

1. Total energy consumption per passenger (kWh/PAX)
2. Total electricity consumption per ATM (kWh)

Figure 22 visualizes both EnPIs from 2006 to 2019. The total energy EnPI (left) reveals high fluctuations with an overall increase from 2006 to 2015. After a 13% drop in 2016, a constant growing trend is clearly visible. With regard to the electricity EnPI (right), the first 4 years of the total period show barely any changes. From 2010, a high degree of scatter remains until 2017. Afterwards, a clearly recognizable upward trend is present. The course of both curves is mainly explained by the development of PAX and ATM, which fluctuate due to historical operational events (Section 4.1). A comparison with major airports can be drawn with the findings by Kılkış and Kılkış (2016).

5.4. Energy and greenhouse gas emission baseline

The baselines of all analyzed indicators are statistically determined in Section 4.5 and displayed as a regression function in Table 5. Every baseline is characterized by the trend function (regression function) of the respective period. The first coefficient of this function indicates a growing trend (positive value) or declining trend (negative value). The baseline with its trend is visualized in the following Section 5.

5.5. Sustainable energy strategy

The main energy and climate objectives of the Danish Aviation Association and the Danish government are to achieve net-zero GHG emissions by 2050 (Section 1). However, the urgency of the dramatically progressing climate crisis requires instant action and profound objectives, which mirror the latest scientific findings on the physical science basis of global warming (IPCC, 2021). Furthermore, the common tool of carbon offsetting especially in the aviation industry is considered as an invalid measure in the given context due to carbon fraud, low sustainability implications, and harmful impacts on local communities (Blum & Lövbrand, 2019; Cames et al., 2016; Goldtooth et al., 2019; Lohmann, 2009; Newell & Paterson, 2010). For that reason, the subsequent objectives for Midtjyllands Airport set higher standards in order to do justice to the necessity for action in an effective and thoughtful manner. In this sense, objectives were developed under consideration of the concept of SMART targets (Section 3.2) with regard to the respective target category (Figure 2). Considering ISO 50001, the target refers to a short-term goal, while the objective is described by a superordinate long-term goal. For that matter, the following presentation refers to objectives in order to guarantee alignment with ISO 50001. The objectives are:

1. Net-zero GHG emissions without offsetting by 2030 instead of 2050 as stated by national and aviation objectives (volume objective).
2. A 40% reduction in the total energy consumption by 2025 compared to the baseline trend and afterward keeps the total energy consumption at that level at least (volume objective).
3. A 40% of the two EnPIs by 2030 compared to the baseline trend of 2020 reaching the value of 2007 (physical efficiency objective).

The GHG emission objective (1) is directly linked to the energy consumption (2) as well as to the sources of energy and its origin. According to Section 3.2, these volume objectives follow a bottom-up approach comprising the individual

Table 6. Constituents of volume objective (1) and (2) comprising total natural gas consumption (NGC) (scope 1.1), diesel consumption (scope 1.2), and total electricity consumption (ELC) (scope 2.1 + 2.2).

	Illustration	Year	Objectives (O) and Targets (T)
NGC (1.1)	Figure 23	2021	(T) Stop upward trend
	–	2022	(T) 30% reduction compared to baseline trend
	–	2024	(T) 100% substitution of natural gas with sustainable energy source
	–	2025	(T) 50% reduction compared to 2022
	–	2030	(O) Remain value of 2025
Diesel (1.2)	–	2030	(O) 100% replacement with non-fossil fuels
ELC (2.1 + 2.2)	Figure 24	2022	(T) 8.5% reduction compared to baseline trend and 100% use of renewable sources
	–	2025	(T) 30% reduction compared to baseline trend
	–	2030	(O) Remain value of 2025

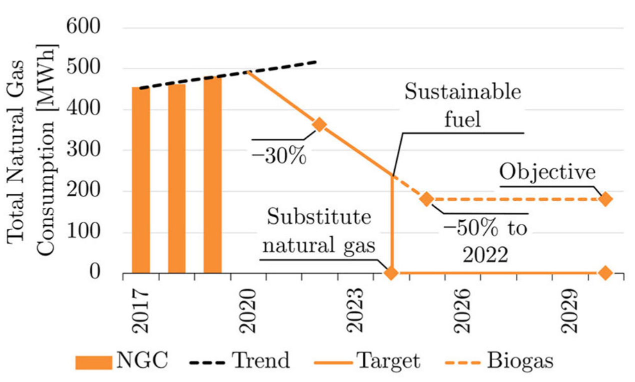

Figure 23. Objective and targets for total natural gas consumption (NGC).

constituents natural gas, diesel, and electricity as a starting point.

5.5.1. Natural gas, diesel, and electricity

Beginning with the volume objectives and its constituents, Table 6 summarizes the long-term objectives and short-term targets with reference to the respective source of energy and visual illustration. The COVID-19 crisis in 2020 and the resulting total operational shutdown have significantly influenced the years 2020 and 2021. Nonetheless, the mid- and long-term goals are still valid expecting first achievements under regular operation at the end of 2021.

The reduction of NGC (scope 1.1, Figure 23) can be achieved by a series of actions. First, a professional analysis of the building envelope and heating system is required to identify thermal leakages and performance losses. On that basis, a 30% decrease in energy use is already possible through small projects by remedying energy weak points resulting from the thermal analysis (Büyükbay et al., 2016). These projects include the improvement of the heating system by insulating the utility room and heating water pipes to reduce heating losses, performing a hydronic balancing to increase efficiency of the pipe system, as well as replacing inefficient circulation pumps. The implementation of these actions is required for the 2022 target. The replacement of the gas-fired boiler technology with an alternative heating technology is not scheduled before 2035 and thus beyond the considered timeline. However, alternative renewable technologies are discussed below.

Second, a steady step-by-step improvement process of the thermal condition of the total building envelope has to be carefully planned over the period from 2021 to 2025. The installation of so-called external thermal insulation composite system, a multi-layer constructive system to insulate the facade, in combination with the insulation of the roof and replacement of doors and windows are considered as common thermal modernization measurements. It has to be noted that the use of crude oil-based polystyrene as insulator is to be avoided and non-fossil-based materials should be given preference, such as stone wool for the facade and cellulose for the roof (Jelle, 2011; Lee et al., 2018; Pal et al., 2021; Sierra-Pérez et al., 2016). After the implementation of these measures, it is targeted to at least remain the 2025 demand value until the final 2030 objective.

Besides the energy efficiency improvements, a major target is scheduled in 2024. Here, the supply contract of natural gas ends, which provides the opportunity to replace the current contract with a biogas contract that supplies gaseous fuel made from renewable sources. The concept of a biogas contract is discussed below in relation to the GHG objective (scope 1 + 2) in Figure 25.

The 2022 target of ELC (scope 2.1 + 2.2, Figure 24) requires the identification, mapping, and documentation of SEUs before any energy improvements can be considered. To this date, a missing monitoring system of SEUs is not present. However, the integration process can start immediately by gathering (i) technical information from manuals, such as power requirements, (ii) collecting manufacturing dates and predicting year for replacement, as well as (iii) evaluating potential locations for energy metering devices. Without further knowledge about the SEUs, specific actions are considered challenging. Nonetheless, the detailed TEC analysis in Section 4.3.2 with respect to Figures 14 and 15 reveals a high base load demand over an entire year including hours without operation, such as during the night. This finding is a typical indicator of active SEUs, which do not support the operational business. Moreover, Figure 16 specifies this assumption by highlighting high energy demand during off-peak hours from midnight to 4 a.m. in the morning and from 8 p.m. until midnight. In particular, frequent and high energy peaks occur from 5 to 9 a.m. and 5 to 11 p.m. during the year suggesting intensive activity of single SEUs or multiple smaller-sized consumers. Either way, both cases represent typical conditions to decrease the base load demand and reduce the frequency and intensity of power peaks in order to reach the 2025 target. Besides electricity efficiency improvements, the 2022 target also accounts the replacement of the existing electricity contract comprising the national electricity mix with a fully renewable electricity

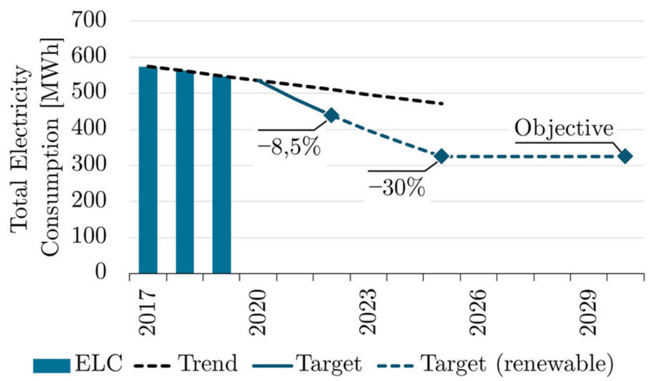

Figure 24. Objective and target for total electricity consumption (ELC).

Table 7. Volume objectives (1) and (2) comprising total GHG emissions (scope 1 + 2) and total energy consumption (TEC) (scope 1 + 2).

Source (scope)	Illustration	Year	Objectives (O) and targets (T)
GHG (1 + 2)	Figure 25	2022	(T) 50% reduction compared to baseline trend
	–	2024	(T) 90% reduction compared to 2022
	–	2030	(O) Net-zero GHG emissions
TEC (1 + 2)	Figure 26	2022	(T) 10% reduction compared to baseline trend
	–	2024	(T) 33% reduction compared to baseline trend
	–	2025	(T) 40% reduction compared to baseline trend
	–	2030	(O) Remain value of 2025

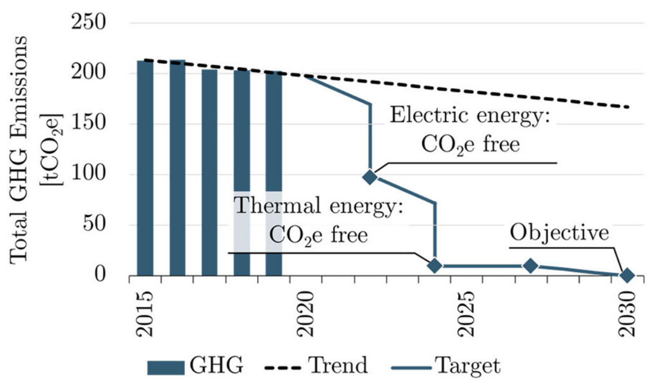

Figure 25. Objective and targets for total greenhouse gas (GHG) emissions resulting from electricity, natural gas, and diesel.

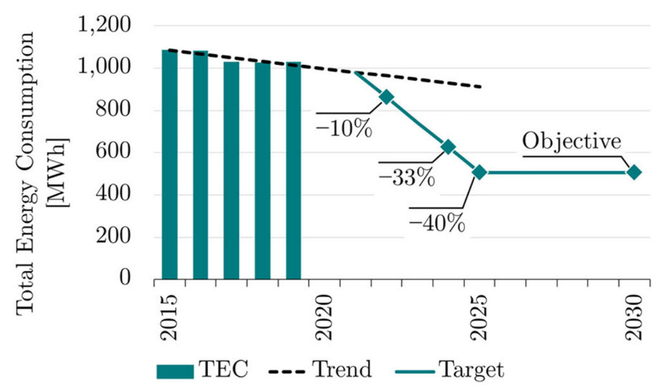

Figure 26. Objective and targets for total energy consumption (TEC) consisting of electricity, natural gas, and diesel.

contract. The concept behind this contract and the effects on the GHG emission are discussed below in relation to Figure 25.

Diesel (scope 1.2) accounts solely 0.1% of TEC and therefore is not considered as a major source for improvements from an energy perspective. However, its relevance in relation to GHG emission is discussed with respect to the volume objective (1) and Figure 25.

With regard to the integration of renewable energy technologies, the airport shows interest in setting up an on-site geothermal power system for heat generation as well as a PV system for electricity production at the roof of the airport building. However, a capital-intensive geothermal system must be considered in correlation with future improvements in thermal energy efficiency resulting from modernization measures of the building envelope. Therefore, it is highly recommended to optimize the thermal envelope before investing in a new heat-generating technology with high investment costs in order to avoid an oversized system. With regard to a PV system, prior thermal modernization measures of the roof are recommended before the installation in order to guarantee full access to the rooftop. Furthermore, the hourly data set of the electricity demand should be taken into account during the development and dimensioning of the PV system design. PV surplus production is unlikely considering the limited roof area and the high base-load electricity demand. Nevertheless, a professional analysis is recommended to guarantee an optimal self-consuming system.

5.5.2. GHG emissions, energy consumption, and EnPIs

The GHG emission objective (1) is composed of the accumulation of emissions from natural gas, diesel, and electricity. Thus, the previously described measures in NGC (Figure 23) and ELC (Figure 24) form the base for the targets in Table 7 and Figure 25 leading up to the final objective in 2030. Here, the steady decrease of emissions from 2020 to 2022 occurs due to efficiency improvements in NGC and ELC. In 2022, the entry in the renewable electricity contract causes the instead drop in emissions followed by a further constant decrease caused by additional efficiency measures. The start of the biogas contract eliminates the emissions in thermal energy domain resulting in a second instead decline in emissions in 2024. The emissions by the consumption of diesel are considered as residual emissions and due to the complexity of decarbonizing the mobility sector especially heavy vehicles a transition period of 6 years is proposed until reaching carbon neutrality in 2030. Despite this relatively long transition period, solely a fraction of about 5% will be emitted from 2024 compared to the baseline trend. 95% of the emissions are already eliminated in 2024 through the introduction of a renewable electricity contract and a biogas contract.

The idea behind both contracts follows an identical strategy: Displacing fossil fuels with renewable energy sources from the respective energy mix through the macroeconomic law of supply and demand (Beveridge, 2013; Hauser et al., 2019). With regard to the electricity contract, the airport has

Table 8. Physical efficiency objective (3) comprising energy performance Indicators (EnPIs) namely total energy consumption (TEC) per passenger movement (PAX), and total electricity consumption (ELC) per aircraft movement (ATM).

EnPI	Illustration	Year	Objectives (O) and targets (T)
TEC/PAX	Figure 27	2021	(T) Stop upward trend
	–	2025	(T) 20% reduction compared 2021
	–	2030	(O) 25% reduction compared 2025 reaching value of 2007
ELC/ATM	Figure 28	2021	(T) Stop upward trend
	–	2025	(T) 20% reduction compared 2021
	–	2030	(O) 25% reduction compared 2025 reaching value of 2007

entered a contract with an electrical energy provider that supplies the airport with 100% electricity from renewable sources. Technically, the airport still obtains the Danish national electricity mix with 78% renewables and 22% fossil fuels (BP & Ember, 2020) but the energy provider ensures that the entire consumed amount of electricity over a specific short- to mid-term period (e.g. annually, monthly, etc.) is substituted with 100% electricity from renewable sources (Energinet, 2021d, 2021c). This approach guarantees that every consumed conventional kWh will be replaced with a renewable kWh. By implication, a greater demand in renewable electricity contracts results in a greater demand in the supply of renewable energies and potentially its supporting technologies, such as energy storages.

Hauser et al. (2019) investigated this concept of renewable electricity contracts in the German electricity market. Their findings reveal among others that (i) the demand and supply of green electricity products has increased since 2013, (ii) the guarantees of origin is a functioning tool in the market, and (iii) new positive impulses in the energy transition are potential outcomes. In contrast, (iv) the pricing of such products is still considered as unpredictable. Furthermore, (v) Germany made the experience of importing almost half of their green electricity products from Norwegian hydroelectric power, which might be a pitfall for a Danish use case. Local and national electricity from renewable energy source should be the major solution. Besides the gained experiences with green electricity products, (vi) the specific contribution demands further differentiated investigation with respect to accelerating the transition toward green energy (Hauser et al., 2019).

The concept of a biogas contract operates on a similar accounting measurement displacing natural gas from the national gas mix with refined biogas (biomethane). In 2020, Denmark already holds a share of 21% refined biogas in the gas grid (Statistics Denmark, 2021). With the entry of the contract, the airport continuously operates the existing heating system and supplying pipe infrastructure. From a technical perspective, the national gas mix with 79% natural gas and 21% refined biogas (Statistics Denmark, 2021) will still be burned but the biogas supplier guarantees that the amount of consumed gas mix from the gas grid will be replaced with the identical amount of biogas resulting in a displacement of fossil natural gas. However, a number of vital criteria must be fulfilled by the contract to ensure a functioning concept. First, the guarantees of origin of biogas with respect to the raw materials require a careful investigation to ensure sustainability and to reduce the harm to biodiversity in order to avoid a shift of emissions from burning natural gas to cultivating biomass for the biogas production. Widely controversial topics with regard to biomass for energy uses account among others land use, food *versus* fuel, carbon life cycle, ground water contamination, and water consumption (Antar et al., 2021; Ceballos et al., 2015; Gaurav et al., 2017; Nonhebel, 2012; Roth et al., 2018; X. Zhang et al., 2015). Second, the cultivation of biomass, its processing to biogas, and the injection into the gas gird must take place on a local or national level with respect to the location of the consumer. For example, cultivating biomass in tropical regions, transporting, and converting the material within Europe, and finally injecting the biogas into the European gas gird does not account as valid method of a biogas contract for Midtjyllands Airport in Denmark. In particular, the displacement of natural gas requires the direct injection of biogas in the Danish gas grid system. So-called bio methane certificates are already applied in Denmark ruling the guarantees of origin and unbroken supply chains (Energinet, 2017, 2021b, 2021a).

The volume objective (2) and trajectory of TEC (Figure 26) is the result of the summation of NGC and ELC. The respective targets in 2022, 2024, and 2025 (Table 7) are given by the series of events described and discussed above in relation to Figures 23 and 24. In contrast, diesel is assessed as a minor contributor to TEC with a fraction of 0.1% and hence not included in the trajectory.

The objectives of the two EnPIs in Table 8 comprising TEC per PAX (Figure 27) and ELC per ATM (Figure 28) follow the simplified strategy of reaching the lowest historical value during regular operation. According to Figure 22, both EnPIs measure the lowest values in 2010 and 2011. However, this year is not considered as regular due to the historical events of a major operating airline going bankrupt and diminishing the operational cycles. For that reason, the next valid year is 2007 for both EnPIs, which is considered as the target value for the objective 2030. In order to guarantee a realistic trajectory toward that objective, the year 2021 is defined as vital in order to stop the upward trend of the past three years. Afterwards, a linear trajectory is targeted toward to objective. The compliance of this trajectory is directly dependent on TEC and ELC. Detailed options for efficiency improvements of these parameters are extensively discussed above in relation to Figures 23, 24, and 26.

5.5.3. Action plan

The action plan in Table 9 represents the practical guide toward the implementation of the sustainable energy strategy aligning the EnMS of Midtjyllands Airport with the ISO 50001 standard as well as facilitating the integration of a carbon management system required for an accreditation by the ACA program. The plan was established in alliance with the results objectives in Sections 5.5.1 and 5.5.2. Furthermore, its structure follows the recommended approach by the literature (Akyuz et al., 2019; Kahlenborn et al., 2012). The order of action is categorized by the major parameters' financial investments, expenditure of time, degree of complexity, as well as energy and environmental performance outcomes. In this sense, action (1) and (2) presents the activities with no to low investments, low time effort, and low complexity. In particular, the investments rise with action (3)–(6) while at the same time the energy efficiency performance and GHG emission measures increase in effect. Action (7) requires the findings of action (1). Lastly, action (8) and (9) provide further optional measures, which should be considered in future works. After all, the action plan in combination with the discussed measures above enables a strategic approach toward an increase in energy efficiency including the integration of renewable energy sources and the resulting consequents of not only reducing but also fully diminishing GHG emissions.

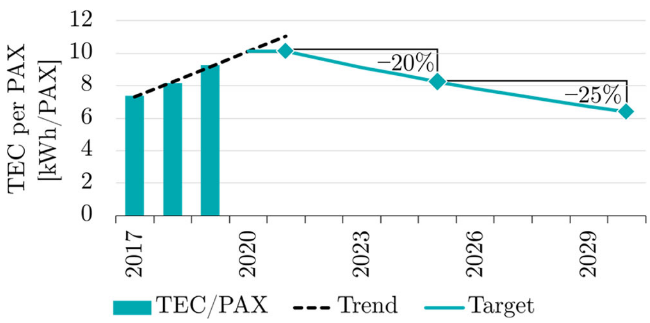

Figure 27. EnPI's objective and targets for total energy consumption (TEC) per passenger (PAX).

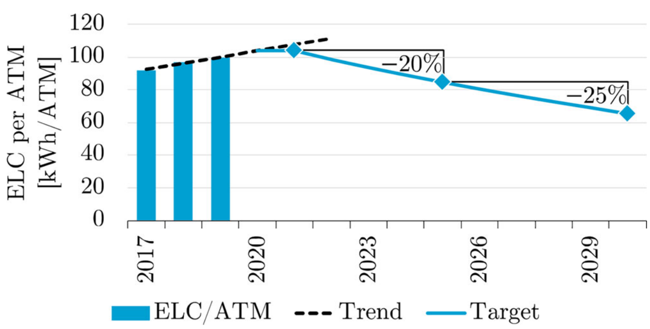

Figure 28. EnPI's objective and targets for total electricity consumption (ELC) per aircraft movement (ATM).

6. Conclusion

This study has empirically analyzed and identified what criteria of a mid-sized airport are relevant in order to establish a sustainable and optimized energy management and how energy-related carbon emissions, which contribute to global warming, can be diminished. To achieve this objective, the study chose Midtjyllands Airport as a case airport. The research was conducted in form of a case study. Energy-related data was analyzed taken from secondary sources, which are the airport, energy providers, and national databases.

For this study, the methods of two common and internationally accepted standards were applied, namely, ISO 50001 EnMS and ACA Program. Several research and case studies of airports have been analyzed that revealed high potentials and achievements in terms of energy savings and carbon reduction by implementing these standards. Based on these methods and findings, the conducted analyses of Midtjyllands Airport energy management, energy consumption, and carbon emissions return the following outcome:

1. The current energy management requires significant increase in effort to achieve improvements in energy performance and reduction in GHG emissions.

Table 9. Action plan including objective and target, specific action, execution period, and order of action.

Objective	Action	Execution
(1) Plans that do not require investments		
TEC 2025	Identify, map, and document SEUs	2020 – 2021
(2) Easy and short-time applicability		
GHG 2022	Replace current electricity contract with renewable electricity contract	2022
GHG 2024	Replace current natural gas contract with biogas contract	2024
GHG 2030[a]	Evacuate coolant (HFC) of the decommissioned air conditioning system by expert[a]	2020 – 2021
(3) High energy performance with low investments		
NGC 2022	Professional analysis of building envelope and heating system to identify leakages and losses as well as rectify weaknesses	2021 – 2022
(4) Plans that do require low to medium investments		
NGC 2022	Improve heating system by insulating heating room and pipes, performing hydronic balancing, and replace circulation pumps	2021 – 2022
(5) High environmental performance (Reference is made to point 2)		
(6) Long-term actions with high investments		
NGC 2025	Improve thermal state of total building envelope through insulation, step-by-step process	2021 – 2025
GHG 2030	Replacing outdated fossil-fuel-fired vehicles and equipment with emission-free alternatives, step-by-step process	2024 – 2030
(7) Plans related to SEUs (reference is made to point 1)[b]		
(8) Plans related to renewable energy technologies		
Optional	On-site geothermal power system for heat generation in combination with a new SEU[c]	–
Optional	PV system at the roof of the airport[c]	–
(9) National and international legal requirements		
Optional[d]	Start carbon offsetting according to Danish Aviation Association (not considered in this work)[d]	–

[a]HFC was not specifically considered in the objective. The stated action is a general recommendation due to significant climate impact of HFCs (Burkholder et al., 2020; Montzka et al., 2019; Saengsikhiao et al., 2020; H. Zhang et al., 2011).
[b]SEUs could not be identified due to missing monitoring systems.
[c]Optional action has to be considered after thermal building modernization.
[d]Carbon offsetting or compensation is not considered as a valid sustainable measure in this context due to carbon fraud, low sustainability implications, and harmful impacts on local communities (Blum & Lövbrand, 2019; Cames et al., 2016; Goldtooth et al., 2019; Lohmann, 2009; Newell & Paterson, 2010).

2. The easiest and most effective measure to cut GHG emissions in the shortest time is to enter into a green electricity and biogas contract using 100% renewable sources for energy generation.
3. Even though the total energy consumption underwent distinctive fluctuations from 2006 to 2019, the value remains almost constant in particular for the last three years.
4. However, passenger (PAX) and aircraft movement (ATM) decreased during the whole period.
5. Two EnPIs have been determined, which illustrate the upward trend of total energy demand per PAX and total electricity demand per ATM.
6. Total GHG emissions revealed a similar trend compared to the total energy consumption.
7. Baseline trends for six indicators have been developed to assess future energy and emission changes.
8. Three ambitious and realistic objectives have been set including (1) net-zero GHG emissions in 2030 and (2) a 40% reduction of total energy demand by 2025 in relation to the baseline trend, and (3) a 40% reduction of two EnPIs by 2030 compared to the baseline trend of 2020.
9. Several targets have been set to accomplish the objectives within the defined period.
10. An action plan has been drawn up including fundamental actions, such as identifying, mapping and documenting SEUs, and performing low, medium, and high efforts.

In the period from 2006 to 2019, various operational events in form of incoming and outgoing airline companies had a significant impact on passenger numbers and ATM. This resulted in variations of natural gas and electricity consumption. In 2019, the total energy use was about 1,029 MWh consisting of the major shares direct airport's electric energy consumption of approximately 498 MWh (48%) and total natural gas consumption of about 480 MWh (47%). On the other hand, electricity consumption by third parties corresponds to minor 51 MWh (5%) while the diesel consumption is significantly minimal with 0.1%. The GHG emissions account for in total 203 tCO_2e comprising the major shares electricity (51%) and natural gas (38%). The detailed analysis of the electrical energy consumption revealed demand gaps during the holiday periods specifically in summer. This fact has to be considered in terms of designing a solar power system as it was proposed by Midtjyllands Airport. In addition, future plans of setting up a geothermal power system for heat production and PV system should be taking into account in correlation with planned energy efficiency improvements by modernizing the airport's building envelope. Generally, future success requires, first and foremost, a comprehensive monitoring concept to detect principal weaknesses of individual energy consumers within the overall EnMS.

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