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An Examination of a Major All Cargo Airline Energy Management: The Case of Cargolux Airlines International

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Abstract—*Based on the use of a qualitative longitudinal research design, this study examines Cargolux Airlines International, a major global air cargo airline, sustainable energy management. The study covers the period 2012 to 2020. Cargolux Airlines International energy sources are aircraft (Jet A1) aircraft fuel, diesel, cooling energy, electricity, heating energy, industrial fuel, natural gas, and unleaded gasoline 95. The case study revealed that Cargolux's Jet A1 fuel consumption has principally exhibited an upward trend reflecting the growth in the airline's services, route network expansion, and the growth in the aircraft fleet during the study period. Cargolux Airlines International annual cooling energy consumption (kWh) oscillated over the study period reflecting differing cooling requirements. Cargolux Airlines International annual diesel consumption fluctuated quite markedly during the study period reflecting differing vehicle fuel consumption requirements and usage. The case study found that there was a general downward trend in Cargolux Airlines International annual electricity consumption during the period 2012 to 2015, whilst there was a general upward trend in the airline's electricity consumption from 2016 to 2020. The airline's annual heating consumption also oscillated over the study period reflecting differing heating requirements. Cargolux Airlines International annual industrial fuel consumption primarily displayed a general downward trend. The airline's annual natural gas consumption has fluctuated throughout the study period reflecting differing consumption patterns at the airline. Cargolux annual 95 gasoline consumption displayed a general downward trend from 2012 to 2015, and a general upward trend from 2015 to 2020. Throughout the study period, Cargolux Airlines International implemented a range of energy savings measures that enabled the airline to optimize its energy consumption.*

Keywords— ***All-cargo airlines, case study, Cargolux Airlines International, energy consumption, sustainable airline energy management.***

I. INTRODUCTION

The air transportation of goods/freight for commercial purposes plays a very vital role in the global economy and the global supply chain (Alemán, 2010; Dewulf et al., 2019; Heng, 2016; Lee et al., 2019). In the world air cargo industry, air cargo capacity is provided by combination passenger airlines, all-cargo airlines, and the integrated carriers. three distinct types of airline operators (Baxter, 2021a; Baxter & Wild, 2021). Combination passenger airlines are airlines that carry passengers on the main deck and transport air cargo in their passenger aircraft lower lobe belly-holds. Some combination airlines, for example, Cathay Pacific Airways, Korean Airlines, Qatar Airways, and Singapore Airlines, also operate freighter aircraft in addition to their passenger services. Shippers may also decide to use dedicated all-cargo airlines, for example, Cargolux International Airlines or Nippon Cargo Airlines (NCA). The final type of air cargo carrying airline operator is the integrated carriers, for example, DHL Express, FedEx and United Parcel Service (UPS) (Baxter & Wild, 2021; Dresner & Zou, 2017; Merkert & Alexander, 2019). All-cargo services are operated with freighter aircraft where all the available capacity is dedicated to air cargo transportation (Dresner & Zou, 2017; Tretheway & Andriulaitis, 2016). A freighter aircraft is an aircraft that has been expressly designed or which has been converted to transport air cargo, express, and so forth, rather than passengers (Wensveen, 2016). Dedicated all-cargo services play a very significant role in the aviation industry, and to the global economy (Davies, 2013). Freighter aircraft carry around 56 per cent of global air cargo revenue ton kilometres (RTKs) (Boeing Commercial Airplanes, 2020).

Cargolux International Airlines, one of the world's major global all cargo airlines, was selected as the case airline in this study due to its long-term commitment to sustainable energy management. The sustainable management of its energy consumption is a key part of the airline's sustainability policy. The objective of this paper is to analyze how Cargolux International Airlines manages its aircraft fuel and ground-based facility energy consumption. A further objective of the study is to examine the energy savings measures implemented by Cargolux International Airlines to optimize its energy consumption, and thus, mitigate its impact on the environment. The study period was from 2012 to 2020.

The remainder of the paper is organized as follows: The literature review is presented in Section 2. Section 3 describes the study's research methodology that underpinned the study. The case study is presented in Section 4. Section 5 outlines the study's conclusions.

II. BACKGROUND

2.1 Airline Jet Fuel Consumption

The global airline industry is highly energy intensive (Baxter et al., 2021). Jet fuel accounts for the major share of an airline's energy consumption. There are various types of jet fuel used in the airline industry as well as for military aviation. During the 1960s, Jet-A fuel became the standard fuel used in the United States and by many commercial airlines (Brooks et al., 2016). This type of fuel was selected over the more highly flammable JP-4 for passenger safety reasons (Yildirim & Abanteriba, 2012). Jet A-I fuel is available globally, including in the United States (Brooks et al., 2016). Jet fuel typically represents the highest cost for an airline (Turner & Lim, 2015; Vasigh & Rowe, 2020).

2.2 Aircraft Fuel Efficiency

Growing environmental concerns has motivated the air transport industry to the judicious use of aviation fuel. As a result, both economic and environmental sustainability concerns have led to significant improvements in aviation fuel efficiency in recent times (Singh et al., 2018). In the global airline industry, airlines want to fly the most efficient aircraft possible, and thus, saving fuel inflight plays a key role for airlines (Hardiman, 2022). According to Oliveria et al. (2021), "fuel efficiency has become one of the most important policy goals for airline operations management". To improve aircraft fuel efficiency, airlines and the aircraft manufacturers have invested in recent times in new technologies and strategies to reduce aircraft fuel consumption (Zou et al., 2016).

At a worldwide level, the peak airline industry body – the International Air Transport Association (IATA) – have recognized the requirement to address the global challenge of climate change and has subsequently adopted a set of ambitious targets to mitigate carbon dioxide (CO_2) emissions from air transport. The association has targeted an average improvement in aircraft fuel efficiency of 1.5% per year from 2009 to 2020. IATA has implemented a multi-faceted approach: the four-pillar strategy to ensure that this objective is met (International Air Transport Association, 2021a). The strategy entails:

- Improved technology, including the deployment of sustainable low-carbon fuels.
- More efficient aircraft operations.
- Infrastructure improvements, including modernized air traffic management systems.
- A single global market-based measure, to fill the remaining emissions gap (International Air Transport Association, 2022a).

The term fuel efficiency for an airline refers to the consumption between the observed and least possible volume of fuel consumed in the production of a given level of output for the airline. Due to the complexity of airline operations, fuel efficiency is dependent upon a range of factors including aircraft size, market characteristics (short-haul versus long-haul services), service network structure (hub-and-spoke or point-to-point [P2P]), and so forth (Zou et al., 2016, p. 320). Fuel efficiency is also largely dependent upon aircraft fuel burn, the average aircraft speed, and other technical design factors. It is important to note that fuel efficiency can be controlled by an airline by the flying techniques that are employed, the distances flown, as well as other variables (Vasigh et al., 2012).

2.3 Airline Ground Service Equipment (GSE) Energy Consumption

To perform ground handling services of aircraft when they are being serviced on the ground in between flights, sophisticated technical equipment is required to perform the aircraft turnaround handling (Ashford et al., 2013; Kazda & Caves, 2015; Roberts, 2018). The ground service equipment (GSE) used in servicing an aircraft includes push-back tugs, lower deck loaders, (main deck loaders for freighter aircraft), toilet and water truck, tugs (for towing cargo to and from the air cargo terminal and for towing baggage to and from the airport's baggage makeup area), aircraft container and pallet dollies, ground power unit, aircraft tail stand (for freighter aircraft), and aircraft bulk hold loaders (Baxter et al., 2021). Ground service equipment (GSE) refers to vehicles and equipment that are used in the airport precinct to service whilst they are at the gate in between flights (Hazel et al., 2011). Ground service equipment (GSE) is generally powered by diesel or petrol engines. Vehicles used by airlines are also often petrol-powered (Baxter et al., 2021).

2.4 Airline Property and Facilities Energy Consumption

To support their operations, airlines typically have extensive ground-based properties and facilities. These buildings include office buildings, aircraft and ground service equipment (GSE) maintenance facilities and hangars, air cargo terminals, and flight catering centres. As a result, airlines require a reliable and highly efficient source of energy to power their airport and non-airport located buildings, facilities, and equipment. Electrical power is also required to run machinery, heating, ventilating, and air conditioning (HVAC) systems, building lighting, computers and so forth (Baxter et al., 2021).

Aside from leasing airport terminal(s), airlines can potentially be one of several tenants in other airport-located multi-tenant buildings (Crider et al., 2011). Airports are very energy-intensive areas (Baxter et al., 2018; Ortega Alba & Manana, 2017; Sreenath et al., 2021). Thus, an airline's airport operations can be extremely energy intensive (Baxter et al., 2021).

III. RESEARCH METHODOLOGY

3.1 Research Approach

This study used a qualitative longitudinal research design (Derrington, 2019; Hassett & Paavilainen-Mäntymäki, 2013; Neale, 2019). The key objective of a longitudinal research design is to collect and analyze qualitative data on growth, change, and development over time. The major advantage of this research approach is that it reveals change and growth in an outcome over time (Kalaian & Kasim, 2008).

3.2 Data Collection

The data used in the study was obtained from a range of documents, company materials available on the internet and records as sources of case evidence. Documents included the Cargolux International Airlines Annual Reports, Cargolux International Airlines Annual Sustainability Reports, and the airline's websites. A comprehensive search of the leading air cargo and air transport journals and magazines was also conducted in the study. A search of the SCOPUS and Google Scholar databases was also performed in the study.

The key words used in the database searches included "Cargolux environmental policy", "Cargolux sustainability policy", "Cargolux annual aircraft fuel consumption, "Cargolux annual cooling energy consumption", "Cargolux annual diesel consumption", "Cargolux annual electricity consumption", "Cargolux annual heating energy consumption", "Cargolux annual industrial fuel, "Cargolux annual natural gas consumption", "Cargolux annual unleaded gasoline 95 consumption "Cargolux membership of CORSIA", "Cargolux's use of sustainable aviation biofuels", and "Cargolux energy conservation measures".

The study therefore used secondary data. The three principles of data collection as recommended by Yin (2018) were followed: the use of multiple sources of case evidence, creation of a database on the subject and the establishment of a chain of evidence.

3.3 Data Analysis

The qualitative data collected for the case study was examined using document analysis. Document analysis is a research technique that is regularly used in case study research (Baxter, 2021a). Document analysis focuses on the information and data from formal documents and company records that are gathered by a researcher when conducting their study (Andrew et al., 2011; Yin, 2018). Following the guidance of Scott (2014) and Scott and Marshall (2009), the documents collected for the present study were examined according to four key criteria: authenticity, credibility, representativeness and meaning.

The document analysis was conducted in six discrete stages. The first phase involved planning the types and required documentation and ascertaining their availability. The second phase involved gathering the documents and developing and implementing a scheme for the document management. Following the conclusion of Phase 2, the documents were reviewed to assess their authenticity, credibility and to identify any potential bias. In Phase 4, the content of the collected documents was interrogated, and the key themes and issues were identified. Phase 5 involved reflection and refinement to identify any difficulties associated with the documents, reviewing sources, as well as exploring the documents content. The analysis of the data was completed in Phase 6 of the document analysis process (O'Leary, 2004).

The documents gathered for the study were downloaded and stored in a case study database (Yin, 2018). The documents were all in English. Each document was carefully read, and key themes were coded and recorded (Baxter, 2021b).

IV. RESULTS

4.1 A Brief Overview of Cargolux Airlines International

Cargolux Airlines International commenced commercial operations in March 1970 when it began operating world-wide air cargo charter services from its home base located at Luxembourg's Findel Airport (Green & Swanborough, 1975). At the time if its inception, Cargolux's shareholders were Luxembourg's national airline Luxair, Swedish shipping line Salen Shipping Group, Icelandic airline Loftleider Icelandic and private interests (Buyck, 2004). Each shareholder held a third of the shares with the balance held by private interests (Belson, 1977). Cargolux began operations in May 1977 (Flight International, 1979) with a single Canadair CL-44D4 aircraft (Belson, 1977; Nelms, 1996).

Cargolux took delivery of its first jet-powered aircraft, a McDonnell Douglas DC8-61F, in 1973. The first Boeing 747-200F freighter aircraft joined the airline's fleet in 1979. The airline also added two Boeing B707-331 "combi aircraft" to its fleet in 1979. In 1985, Cargolux withdrew its fleet of McDonnell Douglas DC8F and Boeing 707' aircraft, and in the process became Europe's first all Boeing 747-200F air cargo operator (Nelms, 1996).

Cargolux took delivery of its first Boeing B747-400 freighter aircraft in 1993. This aircraft model provided Cargolux with a better range capability and increased air cargo capacity (Nelms, 1996). Cargolux was the first all-cargo airline to take delivery of the Boeing B747-400 freighter aircraft. Initially, it was envisaged that the Boeing B747-400F would rationalize the Cargolux fleet. This fleet rationalization would be achieved through operating its fleet of Boeing B747-200 freighter aircraft on shorter routes and the Boeing 747-400 freighter aircraft on longer air routes. However, costs savings arising from the operation of a two-crew cockpit, 18% fuel savings, lower maintenance costs, and greater capacity of the Boeing B747-400 led to the decision to replace the Boeing 747-200 fleet with the Boeing B747-400 freighter aircraft (Air Transport World, 1998).

Cargolux Airlines International together with Japan-based Nippon Cargo Airlines (NCA) were the launch customers for the Boeing 747-8 freighter aircraft (Ostrower, 2011). Following the orders for 13 Boeing 747-8 freighters by Cargolux and 14 by Nippon Cargo Airlines, Boeing officially launched the 747-8F program (Conway, 2012). Cargolux took delivery of its first Boeing 747-8 aircraft on October 12, 2011 (Boeing Commercial Airplanes, 2011).

At the time of the present study, Cargolux Airlines International operated a fleet of 14 Boeing 747-8 freighters, 10 Boeing 747-400 and 6 Boeing 747-400ERF freighter aircraft (Cargolux Airlines International, 2021a). The airline's worldwide route network covers some 75 destinations. In addition to its scheduled flights, Cargolux also operates full and part-charter services as well as aircraft maintenance services (Cargolux Airlines International, 2021b).

Cargolux Airlines International established a joint venture all cargo airline Cargolux Italia S.p.A with Italian-based interests in December 2008. The airline operates a fleet of four Boeing B747-400 freighter aircraft (Cargolux Italia, 2021).

Figure 1 presents Cargolux Airlines International annual enplaned air cargo tonnage and freight tonne kilometres performed (FTKS) for the period 2012 to 2020. According to Daley (2016, p. 36), a freight tonne kilometre (FTK) is defined "as the mass of air cargo multiplied by the distance that the cargo is carried". Cargolux's annual enplaned air cargo tonnage and FTKs grew from 644,613 tonnes and 5.2 billion FTKs in 2012 to 1,107,071 tonnes and 8.934 billion FTKs in 2020 (Figure 1). From 2012 to 2018, the airline has recorded growth in both their annual enplaned air cargo tonnage and FTKs performed reflecting the patronage of the airline (Figure 1). Figure 1 shows that the airline's enplaned freight tonnage and freight tonne kilometres performed (FTKs) declined in 2019. World air cargo demand declined in 2019 and the air cargo modes performance was dampened by the weak growth in world trade of just 0.9% (International Air Transport Association, 2020). Cargolux International Airline's enplaned freight tonnage and freight tonne kilometres performed (FTKs) returned to positive growth in 2020 (Figure 1).

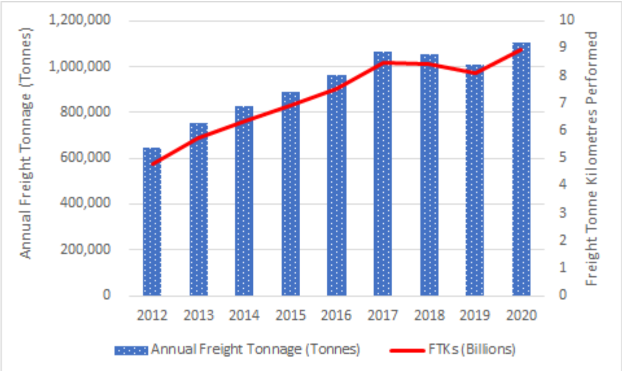

Fig.1: Cargolux Airlines Airline's annual enplaned freight tonnage and freight tonne kilometres performed (FTKs): 2012-2020.

Source: Data derived from Cargolux Airlines International (2012, 2016, 2019, 2021b)

4.2 Cargolux Airlines International Sustainability Policy and Related Measures

Throughout its history, Cargolux Airlines International has taken responsibility for its impact on climate change and the role that commercial air transport plays on the environment. As a result, the airline has a policy of operating a fleet of the most environmentally friendly and energy efficient freighter aircraft. The company has also sought to mitigate its environmental impact at its office and facilities through energy savings measures and the strengthening of environmental awareness amongst its employees. Cargolux has adopted near and long-term goals that are in accordance with the International Air Transport Association (IATA) targets for airlines to reduce carbon dioxide (CO_2) emissions with the ultimate objective of achieving carbon neutral growth (Cargolux Airlines International, 2017a).

Cargolux Airlines International has implemented an Environmental Management System (EMS) that establishes and monitors key environmental performance indicators. Cargolux's Environmental Management System (EMS) is in accordance with the requirements of the ISO 14001:2015 certification standard (Cargolux Airlines International, 2015). ISO 14001 is a worldwide meta-standard for implementing Environmental Management Systems (EMS) (Dentch, 2016; Grover & Grover, 2017; Heras-Saizarbitoria et al., 2011).

On 20 October 2006, Cargolux Airlines International signed a "Charter on Corporate Social Responsibility and Sustainable Development agreement". The Charter incorporates an important element of modern management by which large firms and corporations not only have a responsibility to the many stakeholders that are affected by the firm's activities, including its employees, customers, the local community, and the environment. With this Charter, Cargolux acknowledged its responsibilities, and the company stressed its commitment towards supporting the well-being and the sustainable development of each stakeholder and the environment (Cargolux Airlines International, 2007).

The environmental dimension of the Charter stipulates that the signatory firm undertakes to:

- Minimize the impact of its activities on the environment by controlling its usage of water, power and raw materials, by restricting its waste production and by promoting recycling.
- The firm should select its partners, suppliers, and sub-contractors according to ecological criteria, that is, good environmental practices, and/or offer of goods and services that are beneficial to the environment; and
- The firm should encourage its employees to travel to work by means of transport that limit the damage to the environment (public transport, car-pooling, bicycle, coach and so forth) (Cargolux Airlines International, 2009, p.33).

In 2007, Cargolux Airlines International joined the United National Global Compact. As a signatory to the Compact, firms pledge to embrace, support, and enact a set of values in the areas of human rights, labor standards, anti-corruption, and the environment (Cargolux International Airlines, 2008). In signing up to the UN Global Compact, Cargolux pledged to apply 10 key principles of sound management from both the environmental and social perspectives (Cargolux Airlines International, 2009; 2019). In 2012, Cargolux became a gold contributor to the UN Global Compact Foundation (Cargolux Airlines International, 2015). Cargolux has embraced the 2030 Agenda and the company has pledged its support of the United Nation's 17 Sustainable Development Goals (Cargolux Airlines International, 2018).

Cargolux Airlines International is also a member and participant in the International Civil Aviation Organization (ICAO) "Carbon Offsetting and Reduction Scheme for International Aviation" (CORSIA) program (International Civil Aviation Organization, 2022). Effective from 2021 onwards, an increased share of the carbon emission growth in the international air transport industry will be subject to offsetting under the International Civil Aviation Organization (ICAO) "Carbon Offsetting and Reduction Scheme for International Aviation" (CORSIA) program (Kováčik et al., 2021; Maertens et al., 2019). Effective from 1 January 2021, all international flights will become subject to offsetting obligations under the CORSIA program (International Air Transport Association, 2022b)

Cargolux Airlines International is also fully compliant with the European Union "Emissions Trading System" (EU-ETS) reporting requirements (Cargolux Airlines International, 2019). In accordance with the EU-ETS Emissions Trading System, all member airlines are required to produce and submit a mandatory Emissions Monitoring Plan. This plan describes the fuel consumption monitoring and reporting process together with the method applied to calculate the related carbon dioxide (CO_2) emissions (Cargolux Airlines International, 2012).

Throughout its history, Cargolux has been awarded the "LEAN and GREEN" award, which was established by the Dutch Ministry for Infrastructure and Environment in 2008. This international award recognizes efforts made by a firm to reduce their carbon footprint (CO_2 emissions) in aviation logistics' by at least 10 percent in a 5-year period (Cargolux Airlines International, 2018).

Cargolux Airlines International also continuously assesses the environmental commitment of its appointed ground handling agents throughout its route network (Cargolux International Airlines, 2015).

4.3 Cargolux Airlines International Aircraft Fuel Consumption

Cargolux Airlines International annual Jet A1 aircraft fuel consumption (tonnes) and the year-on-year change for the period 2012 to 2020 is presented in Figure 2. As can be observed in Figure 2, Cargolux's Jet A1 fuel consumption has principally exhibited an upward trend reflecting the growth in the airline's services, route network expansion, and the growth in the airline's aircraft fleet. This overall upward trend is demonstrated by the year-on-year percentage change line graph, which is more positive than negative, that is, more values are above the line than below. Figure 2 shows that there was a single year in the study period, when the airline's annual fuel consumption decreased on a year-on-year basis. This decrease occurred in 2018, when aircraft fuel consumption decreased by 0.62% on the 2017 levels. There were four spikes in Cargolux's aircraft jet fuel consumption during the study period. These increases were recorded in 2013 (+14.84%), 2014 (+11.04), 2015 (+9.44%), and 2017 (+9.94%) and reflected higher fuel usage requirements in those years (Figure 2).

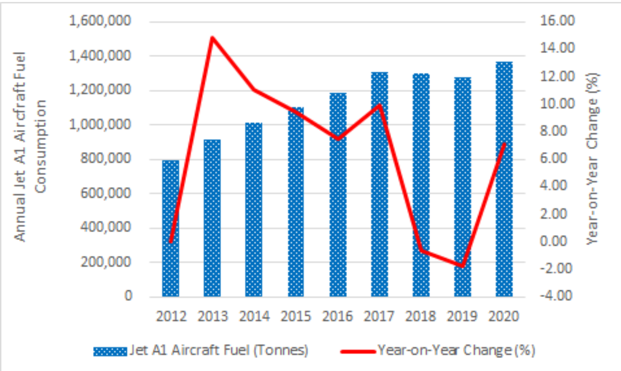

Fig.2: Cargolux Airlines International annual Jet A1 aircraft fuel consumption and year-on-year change (%): 2012-2020.

Source: Data derived from Cargolux Airlines International (2012, 2016, 2019, 2021c)

4.4 Cargolux Airlines International Cooling Energy Consumption

Summer months can be very hot in Luxembourg with temperatures in July and August reaching around 30 degrees Celsius (86°F) (World Weather & Climate Information, 2022). Cargolux Airlines International annual cooling energy consumption (kWh) and the year-on-year change for the period 2012 to 2020 is depicted in Figure 3. As can be observed in Figure 3, Cargolux Airlines International annual cooling energy consumption (kWh) fluctuated throughout the study period reflecting differing cooling requirements. The lowest annual cooling consumption was recorded in 2017, when the airline consumed 426,900kWh of cooling energy (Figure 3). The highest annual cooling consumption was recorded in 2018, when the airline consumed 527,000 kWh of cooling energy (Figure 3). During the study period, there were several pronounced annual increases in this metric, with these spikes occurring in 2013 (+8.19%), 2016 (+9.06%), and 2018 (+23.44%), respectively (Figure 3). These increases reflected the necessity for higher levels of cooling energy in these years. Figure 3 shows that there were two quite significant annual decreases in Cargolux Airlines International annual cooling energy consumption during the study period. These decreases were recorded in 2017 (-11.74%), and 2019 (-8.53%) (Figure 3) and could be attributed to more favorable temperatures that resulted in lower cooling requirements for the airline in 2017 and 2019, respectively.

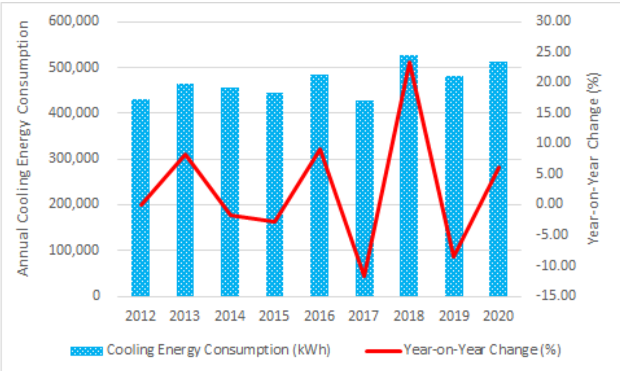

Fig.3: Cargolux Airlines International annual cooling energy consumption and year-on-year change (%): 2012-2020.

Source: Data derived from Cargolux Airlines International (2012, 2016, 2019, 2021c)

4.5 Cargolux Airlines International Diesel Consumption

Cargolux Airlines International annual diesel consumption for its ground service equipment (GSE) and vehicles together with the year-on-year change for the period 2012 to 2020 is presented in Figure 4. Figure 4 shows that the airline's annual diesel consumption oscillated quite markedly during the study period. The lowest annual diesel consumption was recorded in 2014 (13,542 litres), whilst the highest annual diesel consumption was recorded in

2016 (20,851 litres) (Figure 4). As can be observed in Figure 4, there were quite pronounced increases in the airline's diesel consumption in 2015 (+11.67%), 2016 (+37.87%), and 2018 (+30.13%), with these increases reflecting greater ground service equipment (GSE) and vehicle usage patterns. Figure 4 also shows that there were several significant annual decreases in diesel consumption during the study period. These decreases occurred in 2014 (-22.40%), 2017 (-29.70%), and 2020 (-13.79), respectively (Figure 4) and could be attributed to lower ground service equipment (GSE) and vehicle usage patterns.

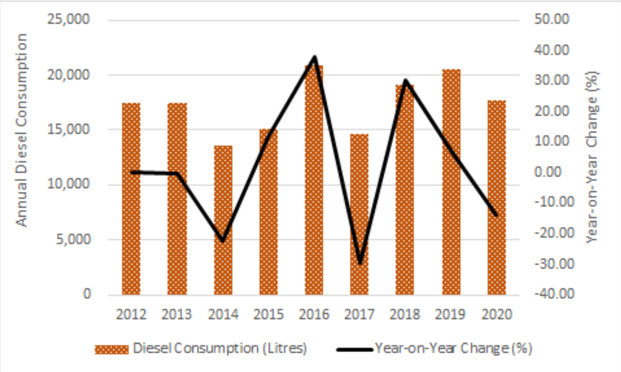

Fig.4: Cargolux Airlines International Airline annual diesel consumption and year-on-year change (%): 2012-2020.

Source: Data derived from Cargolux Airlines International (2012, 2016, 2019, 2021c)

4.5 Cargolux Airlines International Electricity Consumption

Cargolux Airlines International annual electricity consumption (kWh) and the year-on-year change from 2012 to 2020 is presented in Figure 5. As can be observed in Figure 5, there were two discernible trends in the airline's electricity consumption during the study period. There was a general downward trend from 2012 to 2015, when the annual electricity consumption decreased from 5,844,467 kWh in 2012 to a low of 5,582,725 kWh in 2015. There was a general upward trend in the airline's electricity consumption from 2016 to 2020, when it increased from 5,787,954 kWh in 2016 to a high of 6,107,273 kWh in 2020 (Figure 5). This overall upward trend between 2016 and 2020 is demonstrated by the year-on-year percentage change line graph, which is more positive than negative, that is, more values are above the line than below. Figure 5 shows that there were three years in the study period when Cargolux's electricity consumption decreased on a year-on-year basis. These decreases occurred in 2013 (-1.08%), 2015 (-3.54%), and 2019 (-0.67%) and these decreases reflected lower electricity consumption patterns by Cargolux.

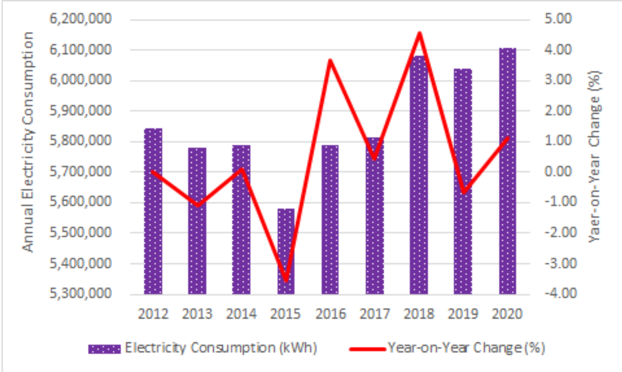

Fig.5: Cargolux Airlines International annual electricity consumption (kWh) and year-on-year change (%): 2012-2020.

Source: Data derived from Cargolux Airlines International (2012, 2016, 2019, 2021c)

Figure 6 presents Cargolux Airlines International annual electricity consumption per workload unit (WLU) and the year-on-year change (%) for the period 2012 to 2020. One workload (WLU) is equivalent to 100 kilograms of air cargo handled (Doganis, 2005; Graham, 2005; Teodorović & Janić, 2017). As can be observed in Figure 6, Cargolux Airlines International annual electricity consumption per workload unit (WLU) has largely exhibited an overall downward trend throughout the study period. This downward trend is demonstrated by the year-on-year percentage change line graph, which is more negative than positive, that is, more values are below the line than above. The largest single annual decrease in this metric was recorded in 2013 when Cargolux Airlines International Airline annual electricity consumption per workload unit (WLU) decreased by 15.24% from a high of 0.905 kWh/WLU in 2012 to 0.767 kWh/WLU in 2013. Figure 6 also shows that there were two years in the study period when this metric increased on a year-on-year basis. These increases were recorded in 2018 (+5.87%) and 2019 (+3.63%) (Figure 6). The overall downward trend is very favorable given the increases in air cargo traffic handled, and fleet and network expansion throughout the study period.

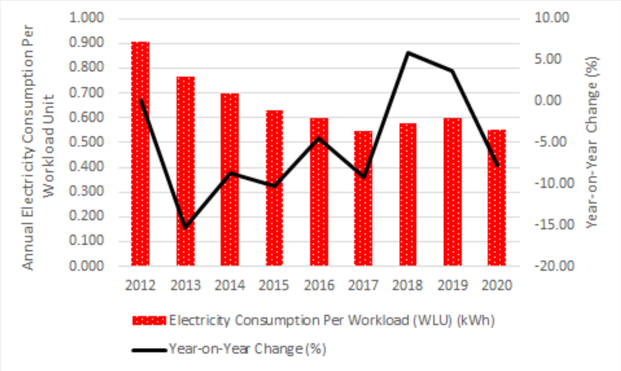

Fig.6: Cargolux Airlines International annual electricity consumption per workload unit (WLU) and year-on-year change (%): 2012-2020.

Source: Data derived from Cargolux Airlines International (2012, 2016, 2019, 2021c)

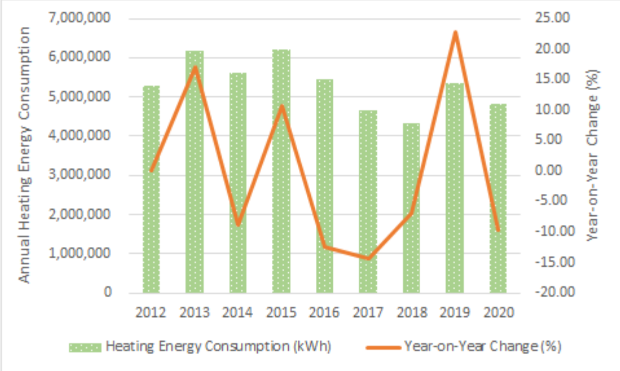

Fig.7: Cargolux Airlines International annual heating consumption and year-on-year change (%): 2012-2020.

Source: Data derived from Cargolux Airlines International (2012, 2016, 2019, 2021c)

4.6 Cargolux Airlines International Heating Energy Consumption

Luxembourg has cold winters (Climates to Travel, 2022; Eccardt, 2005), and hence, there is a requirement by Cargolux Airlines International to heat its offices and facilities. Figure 7 presents Cargolux Airlines International annual heating consumption and the year-on-year change for the period 2012 to 2020. As can be observed in Figure 7, Cargolux Airlines International annual heating consumption has oscillated over the study period in line with the requirements to heat its facilities during the winter periods. Figure 7 shows that there were three quite pronounced spikes in this metric during the study period. The first spike occurred in 2013 when the airline's annual heating consumption increased by 17.09% on the 2012 levels. This was followed by the second spike in 2015 when the annual heating consumption increased by 10.66% on the 2014 levels. The most significant annual increase in this metric was recorded in 2019 when Cargolux annual heating consumption increased by 22.83% on the 2018 levels. Figure 7 shows that there were four quite significant decreases in Cargolux annual heating consumption during the study period. These decreases were recorded in 2014 (-8.89%), 2016 (-12.55%), 2017 (-14.28%), and 2020 (-9.69%) (Figure 7). These decreases may be attributed to the more favorable weather conditions that mitigated the airline's heating requirements.

4.7 Cargolux Airlines International Industrial Fuel Consumption

Cargolux Airlines International annual industrial fuel consumption and year-on-year change (%) from 2012-2020 is depicted in Figure 8. Figure 8 shows that the airline's annual industrial fuel consumption has largely displayed a general downward trend, decreasing from 85,633 litres in 2012 to a low of 56,469 litres in 2020. The general downward trend is demonstrated by the year-on-year percentage change line graph, which is more negative than positive, that is, more values are below the line than above. Figure 8 shows that there were four quite significant annual decreases in Cargolux Airlines International annual industrial fuel consumption throughout the study period. These decreases occurred in 2013 (-11.94%), 2016 (-19.26%), 2019 (-13.36%), and 2020 (-14.18), respectively (Figure 8). These decreases could be attributed to lower consumption patterns by the airline. Figure 8 shows that there were two quite significant annual increases in this metric during the study period. The most significant annual increase was recorded in 2015, when the airline's annual industrial fuel consumption increased by 28.91% on the 2014 levels. In 2015, Cargolux Airlines International consumed 91,926 litres of industrial fuel, which represented the largest single annual consumption of industrial fuel. Figure 8 also shows that there was a 9.24% increase in this metric in 2018, and once again this increase was the result of higher consumption patterns.

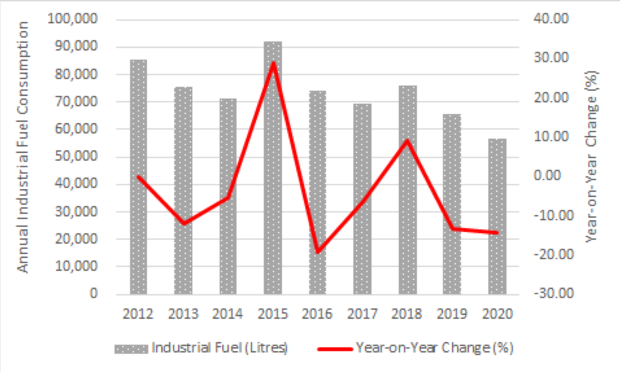

Fig.8: Cargolux Airlines International annual industrial fuel consumption and year-on-year change (%): 2012-2020.

Source: Data derived from Cargolux Airlines International (2012, 2016, 2019, 2021c)

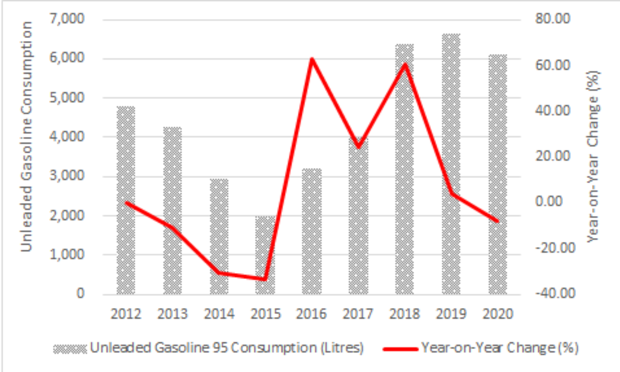

Fig.10: Cargolux Airlines International annual unleaded gasoline 95 consumption and year-on-year change (%): 2012-2020.

Source: Data derived from Cargolux Airlines International (2012, 2016, 2019, 2021c)

4.8 Cargolux Airlines International Natural Gas Consumption

Cargolux Airlines International also purchases natural gas as part of their energy procurement strategy. Natural gas is a mixture of hydrocarbon gas (primarily composed of low molecular hydrocarbons) as well as a small number of non-hydrocarbon gases (Li & Yu, 2022). Figure 9 presents Cargolux Airlines International annual natural gas consumption and the associated year-on-year change for the period 2012 to 2020. As can be observed in Figure 9, Cargolux annual natural gas consumption has fluctuated throughout the study period reflecting differing consumption patterns. Figure 9 shows that there were three quite significant annual increases in the airline's natural gas consumption during the study period. These increases were recorded in 2013 (+9.52%), 2019 (+7.95%), and 2020 (+7.95%) (Figure 9) and were the result of natural gas requirements in these respective years.

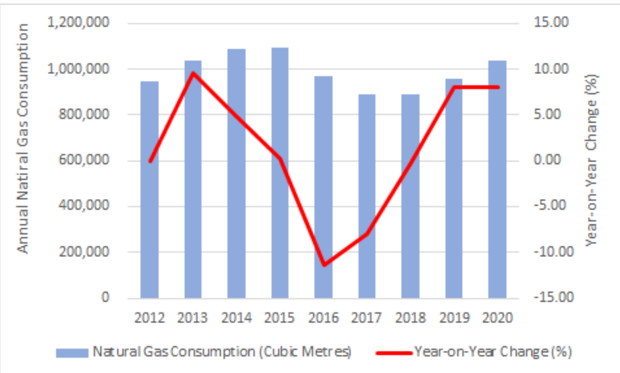

Fig.9: Cargolux Airlines International annual natural gas consumption and year-on-year change (%): 2012-2020.

Source: Data derived from Cargolux Airlines International (2012, 2016, 2019, 2021c)

4.9 Cargolux Airlines International Unleaded Gasoline 95 Consumption

To support its operations, Cargolux Airlines International operates a fleet of ground service vehicles which are powered by unleaded 95 gasoline. Cargolux Airlines International annual unleaded gasoline 95 consumption and year-on-year change from 2012 to 2020 are depicted in Figure 10. Figure 10 shows that there were two discernible trends in Cargolux annual unleaded 95 gasoline consumption during the study period. Cargolux annual 95 gasoline consumption displayed a general downward trend from 2012 to 2015, decreasing from 4,785 litres in 2012 to a low of 1,970 litres in 2015. This downward trend is demonstrated by the year-on-year percentage change line graph, which is more negative than positive, that is, all the values are below the line. Figure 10 shows that there were two quite significant decreases in this metric during this period. These decreases occurred in 2013 (-10.84%), and 2014 (-30.87%) (Figure 10) and were in line with lower vehicle fuel requirements. Figure 10 shows that there was a general upward trend in the airline's unleaded 95 gasoline consumption during the period 2015 to 2020, when it increased from 1,970 litres in 2015 to 6,125 litres in 2020. This overall upward trend is demonstrated by the year-on-year percentage change line graph, which is more positive than negative, that is, more values are above the line than below. Figure 10 shows that there were three pronounced increases in this metric during the period 2015 to 2020. These significant increases were recorded in 2016 (+62.94%), 2017 (+24.12%), and 2018 (+60.46%), respectively, and were the result of higher vehicle fuel consumption (Figure 10). Figure 10 shows that there was a very significant annual decrease in this metric in 2015, when it decreased by 33.19% on the 2014 levels. There was a smaller decrease in the airline's annual unleaded 95 gasoline consumption in 2020, when it decreased by 7.74% on the 2019 levels. Once again, this decrease reflected lower ground service vehicles fuel requirements in 2020.

4.10 Cargolux Airlines International Energy Consumption Mitigation Measures

4.10.1. Aircraft Fleet Renewal

The most significant reductions in Cargolux Airlines International energy consumption have been achieved through the airline's fleet renewal program. As previously noted, Cargolux was the launch customer for the next generation Boeing 747-8F freighter aircraft. Cargolux had ordered 13 of these aircraft and held options to purchase two more. Cargolux was the first airline to operate this aircraft type. The 13 aircraft were scheduled to be delivered in 2014 (Cargolux Airlines International, 2009). Cargolux commenced a fleet rollover program in 2011 that entailed the introduction of the Boeing 747-8 freighter, which is the most fuel efficient and environmentally friendly aircraft in its class. The new Boeing 747-8 freighter aircraft would gradually replace Cargolux's 747-400 freighter fleet (Cargolux Airlines International, 2015). In 2016, Cargolux concluded its fleet rollover program following the delivery of its 14th and final Boeing 747-8 freighter aircraft entering its fleet (Cargolux Airlines International, 2017b).

4.10.2 Cargolux – SkyCell Partnership

Cargolux Airlines International has partnered with the Swiss company SkyCell to offer Cargolux's pharmaceutical shippers' temperature-controlled container solutions. The "SkyCell" aircraft containers offer a lower tare weight, thereby reducing fuel consumption (Cargolux Airlines International, 2018).

4.10.3 Continuous Descent Operation (CDO): Fuel Saving Reduction Initiative

In 2018, Cargolux Airlines International participated in the inaugural meeting to establish "continuous descent operations (CDO) at Luxembourg Airport Cargolux subsequently cooperated with the local air navigation service provider (ANSP) to develop CDOs arrivals into Luxembourg (Cargolux Airlines International, 2019). A continuous descent operation (CDO) is one in which the arriving aircraft descends from its cruise level to an airport with its engines at near-idle thrust (Itoh & Uejima, 2013). With the Cargolux CDO program a number of waypoints on the flight route were established that enable pilots to efficiently plan the descent of their aircraft. Both CDOs and CDAs (Continuous Descent Operations and Approach) methodologies offer the potential for significant fuel savings. For example, a CDO(F) arrival can provide fuel savings of approximately 250 kg per flight for a Boeing B747 freighter aircraft, as the engines remain at a near-idle thrust during the process (Cargolux Airlines International, 2019).

4.10.4 Engine Compressor Washing

In 2007 and 2008, research undertaken by Cargolux's Engineering Department found that certain aircraft engine types consume less fuel if the engine core is regularly washed and cleaned. This cleaning removes the deposits that have accumulated over time on the compressor blade airfoils. The washing of the engine core also improves air flow and overall engine performance. Cargolux have noted that washed General Electric engines consume 0.18% less fuel. The same procedure applied to Rolls Royce engines did not provide substantial fuel savings. In 2008, Cargolux began to regularly clean both General Electric and Rolls Royce engines. Based on the company's aircraft fuel consumption and the General Electric fleet composition, annual savings of around 500 tonnes of fuel per year were achieved (Cargolux Airlines International, 2009, p. 31).

The "Core Engine Compressor" wash was perfected by Cargolux in 2018. This cleaning process is performed on the airline's GENX-2B, CF6-80C2B5F, and selected RB211-524H2-T engines (Cargolux International Airlines, 2019). Like earlier initiatives, this practice is a further fuel-saving measure.

4.10.5 Environmentally Friendly Beam Solution

In 2017, Cargolux Airlines International ratified an agreement with Trinkaus-Solutions (Germany) for the use of the company's "squAIR" -timber product. With a tare weight of only 1.2 kilograms per metre, the beam is 80% lighter than conventional wood, and thus, lowers fuel consumption. Cargolux has estimated that its use of the "squAIR"-timber product potentially reduces its fuel consumption by approximately 1,200 tonnes per year (Cargolux Airlines International, 2018).

4.10.6 Fuel Consumption Reduction Initiative

Cargolux Airlines International has established a "Fuel Efficiency Round Table" initiative. In 2016, Cargolux's fuel-saving initiative saved 2,031 tons of fuel from its flight operations (Cargolux Airlines International, 2017a).

4.10.7 Future Air Navigation System (FANS) Operations

In 2010, Cargolux Airlines International completed a program to equip all aircraft in its own aircraft fleet with the Iridium onboard satellite communications system. The Iridium system offers global coverage, including over the polar regions. Hence, in June 2010, Cargolux aircraft were able to operate on "Future Air Navigation System"

(FANS) routes and thereby achieve significant savings in flying time (Cargolux Airlines International, 2011). The "Future Air Navigation System" (FANS) is an operational concept which relies upon satellite-based navigation and communication to provide the improvements required in communication, navigation, and surveillance (CNS) to efficiently handle the projected increase in traffic levels (Golmohammad & Mehdizadeh Dastjerdi, 2012).

At the time of the introduction of this new service, the most important FANS route throughout the Cargolux network was located over the Gobi Desert between Almaty and Hong Kong. In 2010, this route was served on four to six flights per week. The fuel savings were very significant as flight time is reduced by 30 to 35 minutes on each flight. The fuel savings that could be achieved are estimated at 700 tonnes per year. Cargolux aims to extend FANS flights throughout its worldwide network, wherever air routes can support this system and offer a shorter alternative routing (Cargolux International Airlines, 2011).

4.10.8 Performance Improvement Package (PIP)

Cargolux International Airlines has implemented a retrofit program for the airline's GEnx engines from the early Boeing 747-8Fs that had entered the airline's fleet. This initiative improves both the efficiency and life of the engine, but also has a positive impact on fuel consumption (Cargolux Airlines International, 2018).

4.10.9 Reduction in Aircraft Weight

In 2008, a weight reduction program was undertaken for the entire Cargolux International Airlines aircraft fleet. Around 250kg of material was removed from each aircraft through a modification of the aircraft's bulk hold compartment, the removal of unused cargo locks, and through a modification of the airline's "fly-away maintenance kit (Cargolux International Airlines, 2009).

4.10.10 The Use of Fixed Electrical Ground Power Systems

A number of handling activities are performed at airports. The activities associated directly with the aircraft itself include the provision of power, cleaning, loading or unloading of baggage/air cargo (Doganis, 2005), lavatory services, aircraft marshalling, aircraft towing or pushback, and aircraft fueling (Ashford et al. 2013; Kazda & Caves, 2015; Thompson, 2007). Consequently, electrical power is required on the airport apron for the servicing of aircraft prior to engine start-up. External electrical power is also often used for aircraft engine start-up (Ashford et al. 2013). The auxiliary power unit (APU) is a small gas size turbine engine or small powerplant located near the belly of an aircraft (Anvekar, 2016). APU's are units that supply the essential requirements of the aircraft whilst it is on the ground at the airport and without the main engines operating, or when no external power source is available (Smith, 2004). These essential services include electricity, compressed air, and air-conditioning (Filippone, 2012). In 2007, Cargolux launched a network wide campaign to ensure that, wherever possible, electric ground power was obtained from the airport, from either a diesel-powered ground power unit (GPU), or from a fixed electrical ground power unit (FEGP). Ground power is far more fuel efficient (Cargolux International Airlines, 2009). Consequently, a ground power unit is used to supply electricity to the aircraft wherever possible (Cargolux International Airlines, 2018).

4.10.11 The Use of Sustainable Aviation Fuels

A very important development in the air transport industry in recent trends has been the growing trend by airports and airlines to use aviation biofuel as a key environment sustainability measure (Baxter et al., 2020). The move towards the use of sustainable aviation fuels has been driven by the growing concerns on climate change and energy supply by the industry (Brooks et al., 2016). Consequently, alternative jet fuel (AJF) technologies have gained strong interest (Staples et al., 2014). Aviation biofuels are therefore becoming an important substitute for fossil fuel in the Cargolux Airlines International Cargolux was one of the founding members of the "Sustainable Aviation Fuel Users Group" (SAFUG). This body is a cross industry initiative whose objective is to promote and bring to market sustainable aviation biofuels (Cargolux Airlines International, 2019). The Sustainable Aviation Fuel User's Group (SAFUG) brings together airlines and other stakeholders all of whom have a common interest in developing a long-term, renewable source of aviation fuel. An important objective of this group is that proposed aviation biofuels does not compete with agricultural food production, does not pose a threat to fragile eco-systems, and also provides a positive socio-economic impact (Cargolux Airlines International, 2011).

On 25 October 2021, Cargolux announced the launch of its sustainable aviation fuel (SAF) program. A key aim of this policy was to reduce carbon dioxide (CO_2) emissions and provides the foundation for a customer sustainability program, that will offer more sustainable options for the airline's customers transportation requirements (Cargolux Airlines International, 2021b; Turner, 2021).

4.10.12 Three Engine Taxing to Aircraft Parking Position

Cargolux Airlines International has implemented a procedure whereby aircraft shut down one of four engines during the taxi to the parking position on the ramp (Cargolux International Airlines, 2018).

V. CONCLUSION

Based on a qualitative longitudinal research design this study has examined how Cargolux Airlines International, a major global air cargo carrying airline, manages its aircraft fuel and ground-based facility energy consumption. The study covered the period 2012 to 2020.

Cargolux Airlines International procures eight different types of energy to support its operations. The energy sources are cooling energy, diesel, electricity, heating energy, industrial fuel, jet A1 aircraft fuel, natural gas, and unleaded gasoline 95. The most significant energy source is the jet A1 aircraft fuel used to power its flights around the world. The second most significant energy source is the electricity used to power its ground-based facilities. A further key energy source is natural gas.

The case study revealed that Cargolux's Jet A1 fuel consumption has principally exhibited an upward trend reflecting the growth in the airline's services, route network expansion, and the growth in the aircraft fleet during the study period. Cargolux International Airlines annual Jet A1 fuel increased from a low of 792,719 tonnes in 2012 to a high of 1,367,937 tonnes in 2020.

Cargolux Airlines International annual cooling energy consumption (kWh) oscillated over the study period reflecting differing cooling requirements. The lowest annual cooling consumption was recorded in 2017, when the airline consumed 426,900kWh of cooling energy. During the study period, the airline's highest annual cooling consumption was recorded in 2018, when the airline consumed 527,000 kWh of cooling energy

Cargolux Airlines International annual diesel consumption fluctuated quite markedly during the study period reflecting differing vehicle fuel consumption requirements and usage. The lowest annual diesel consumption was recorded in 2014 (13,542 litres), whilst the highest annual diesel consumption was recorded in 2016 (20,851 litres).

The case study found that there was a general downward trend in Cargolux Airlines International annual electricity consumption during the period 2012 to 2015, when the annual electricity consumption decreased from 5,844,467 kWh in 2012 to a low of 5,582,725 kWh in 2015. There was a general upward trend in the airline's electricity consumption from 2016 to 2020, when it increased from 5,787,954 kWh in 2016 to a high of 6,107,273 kWh in 2020. Cargolux Airlines International annual electricity consumption per workload unit (WLU) has also largely exhibited an overall downward trend over the period 2012 to 2020.

Cargolux Airlines International annual heating consumption also oscillated over the study period in line with the requirements by the airline to heat its facilities during the winter periods. The lowest annual heating consumption was recorded in 2018 (4,346,000 kWh), whilst the highest annual heating consumption was recorded in 2015 (6,227,000 kWh).

Cargolux Airlines International annual industrial fuel consumption primarily displayed a general downward trend, decreasing from 85,633 litres in 2012 to a low of 56,469 litres in 2020, reflecting lower industrial fuel usage patterns.

Cargolux Airlines International annual natural gas consumption has fluctuated throughout the study period reflecting differing consumption patterns at the airline. The lowest annual natural gas consumption was recorded in 2018 (887,631 cubic metres), whilst the highest annual natural gas consumption was recorded in 2015, when the airline consumed 1,090,762 cubic metres of natural gas.

Cargolux Airlines International annual 95 gasoline consumption displayed a general downward trend from 2012 to 2015, decreasing from 4,785 litres in 2012 to a low of 1,970 litres in 2015. There was a general upward trend in the airline's unleaded 95 gasoline consumption during the period 2015 to 2020, when it increased from 1,970 litres in 2015 to 6,125 litres in 2020. The highest annual gasoline 95 consumption occurred in 2019, when the airline consumed 6,639 litres of gasoline 95.

Throughout the study period from 2012 to 2020, Cargolux Airlines International implemented a range of energy savings measures that enabled the airline to optimize its energy consumption, whilst at the same time mitigating its impact on the environment. A major energy saving measure has been the modernization of its aircraft fleet. Cargolux concluded its Boeing 747-8 freighter aircraft fleet rollover plan in 2016. The case study showed that Cargolux Airlines International has been able to optimize its jet fuel consumption through enhanced air traffic control management measures. These measures include the continuous descent operation (CDO) at Luxembourg Airport and the implementation of the future air navigation system, with this system providing significant savings in aircraft flying times. Other energy saving measures implemented by Cargolux include the General Electric powered aircraft engine performance improvement package, aircraft engine compressor washing, the reduction in the weight of its aircraft fleet, the use of fixed electrical ground power (FEGP), the use of lighter weight "SkyCell" aircraft containers, the use of sustainable aviation fuel, and the use of three engines when aircraft are taxiing to their parking stand.

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