Article

Assessment of Final Space Cooling Consumption in the European Transportation Sector

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Abstract: The current study aims to investigate one of the most underexplored energy fields in scientific research, i.e., final energy consumption (FEC) of space cooling (SC) in the European (EU27+UK) transportation sector with 2019 as a baseline. The fundamentals of this study include a comprehensive literature review as well as the creation of a dataset characterized by completeness and reliability. Different essential input parameters have been investigated and the encountered data and information gaps have been filled. The transportation sector has been broken down into three main categories, namely, light, medium, and heavy vehicles. Throughout the EU27+UK, the number of vehicles, equivalent full load hours (EFLHs), system power capacities, and their related energy efficiency levels have been collected. The collected data and information have been computed and the EU27+UK FEC for space cooling in the transportation sector resulted in more than 125 TWh/year. It is worth underlining that the light vehicles category accounted for the majority of the total FEC, followed by the medium and heavy vehicle categories, respectively.

Keywords: space cooling; transport; Europe; energy consumption; assessment

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1. Introduction

It has been decades since the European Union (EU) focused its efforts on achieving ambitious climate and energy goals. Particularly, the EU 2020 objectives included a 20% improvement in energy efficiency as well as a 20% increase in the share of renewable energy sources (RES) and a 20% reduction in greenhouse gas (GHG) emissions compared with 1990 levels by the year 2020.

Significant support to achieve the above-mentioned goals came from the Energy Efficiency Directive (EED), set in 2002 and revisited in 2018 when it became the revised Energy Efficiency Directive (EED II), with an increase in energy efficiency improvements from 20 to 32.5% [1–3]. Moreover, in 2018 the Renewable Energy Directive (RED-2009/28/EC) was updated to the revised Renewable Energy Directive (RED II), which concerns the 2021–2030 timeframe and increases the target share of RES required by the EU Member States (MSs) from 20% to 32.5% [4]. Lastly, in 2018, the EU's GHG emissions were targeted to be reduced by 55% until 2030 in addition to plans for Europe to be the first continent to achieve a net-zero target by 2050 [3].

According to the above-mentioned acts, EU scientific experts noticed that, in 2018, GHG emissions reduced by 23% from 1990 levels and that the implementation of the EED II could lead to lower utility bills and more efficient energy use throughout all the sectors. In addition, the RED II could push the EU to generate more than 80% of energy from RES while reducing the external market's dependence on oil and gas (O&G) suppliers, therefore increasing climate change resilience. Particularly, the current EU's energy production from RES requires an increase of up to 2.5 times above the present level [2].

The RED II entails different energy sectors. In 2018, the heating and cooling (H&C) energy sector was responsible for the greatest portion of the primary energy consumption (PEC) [5]. In more detail, the RED II requires EU MSs to raise the RES share in the H&C sector by an average of 1.3 percentage points (ppt) from 2021 to 2030 [6]. The EU's total PEC, in 2016 accounted for around 1600 Mtoe/y, of which about half (800 Mtoe/y) is accounted by the H&C sector—which includes space heating (SH) and space cooling (SC) for buildings comfort, the residential and tertiary sectors, domestic hot water (DHW), and process cooling (PC) for the industry sector. The transportation sector is responsible for around 490 Mtoe/y, while the electricity sector is responsible for around 310 Mtoe/y, accounting for the remaining EU's total PEC [7].

The main topic of the current study is referred to as “space cooling”, which refers to the removal of heat from the indoor air of an enclosed space (e.g., buildings) resulting in a lower temperature and/or a phase change for thermal comfort of the occupants. In addition, the typical set-points of an indoor air temperature are between 20 and 30 °C. Overall, the action of removing heat requires an external energy input to transfer thermal energy and it occurs against the second law of thermodynamics [8]. Moreover, it is important to state that the current study excludes “refrigeration” applications in the transportation sector since its primary function is to store perishable materials at certain temperatures [9]. In contrast, this study is focused on space cooling for human comfort purposes.

Furthermore, it is worth mentioning that in the current work, the terms “cabin cooling”, and “human comfort cooling” are referred to as space cooling.

A significant increase in demand for SC compared to space heating (SH) is expected in the upcoming year [4]. A constant increment over the past thirty years has been observed for SC in terms of final energy consumption (FEC), as well as in terms of sales volume of SC equipment [9,10]. Overall, the SC needs throughout all sectors are expected to increase significantly by 2030 and 2050 [11,12]. Several reasons drive this SC trend, including global warming, population growth, welfare increase, urbanization (which leads towards hotter building surfaces), larger glazing areas (especially in the tertiary sector), and data centers that require significant cooling [2,12–14].

In terms of SC equipment, almost the entire SC technologies market (99%) is comprised of vapour-compression technology (VC), which is driven by electricity [7–13]. The remaining part of the market is composed of Thermally Driven Heat Pumps (TDHPs) technology [15]. Vapour compression technologies can be found in the residential as well as the service and process sectors both for SC and PC applications.

It is important to state that the SC sector has not been investigated much in scientific research compared with the SH sector [11]. Poor information and data can be found on SC with regard to residential, service, and industrial parts, and even fewer data and information are available on SC in the transportation sector, which is the focus of this study.

The present study aims to assess the European final energy consumption (FEC) for SC related to human comfort in the vehicle's cabin in the private and public transportation sectors. Numerous vehicles have been selected as subjects of this research, such as cars, trucks, tractors, buses, aircraft, ships, and trains. It is worth noting that the term FEC significantly differs from useful energy demand (UED) [16]. Notably, the latter is considered as the net heat which needs to be removed from the vehicle's cabin to be cooled while the FEC is related to the energy input of the cooling system installed in transports.

Once again, it is important to state that limited data can be found in the scientific literature on this topic and there have been significant difficulties in data and information collection due to the lack of resources and restrictions. A certain reference year has not been settled on for this study regarding the high-quality dataset creation; however, 2019 has been selected as the most adequate baseline since most of the collected data and information came from this year.

One of the most essential parts of this research is to generate a dataset on the transportation sector to assess the FEC for SC in the EU27+UK. To accomplish this, three main aspects were considered to ensure the accuracy, completeness, and reliability of the present work.

- Data inventory;
- Data reliability;
- Data definition and comparability.

1.1. Data Inventory

The work presented in the current section includes the scouting and listing of all existing data and information on the topic. Since the research was carried out at the European level, it offers advantages in terms of quantity of data and information thanks to the extension of the territory. A concise literature review methodology has been applied by scouting online through Google Scholar only scientific sources such as databases, peer-reviewed scientific journal papers, and reports. Different online datasets (e.g., ECMWF [17], EUROSTAT [18], UNECE [19], IATA [20], ENERGY PLUS [21]) were consulted. Notably, from the above-mentioned sources, historical meteorological data have been scouted, essential for the estimation of the air-conditioning usage behavior of the population, as well as the European road traffic data divided by vehicle types, and energy consumption simulation to possibly compare the space cooling usage in buildings with the transportation sector. Moreover, reports (e.g., ACEA 2019 [22], ICCT 2019 [23], European Commission 2018 [24]), and articles (CEMA 2019 [25]) were examined to understand the composition of the European transportation sector in detail, in terms of numbers of vehicles, shares of different fuel types, yearly driven distance, and different years of registrations for each vehicle category.

Additionally, several journal papers (e.g., Johnson et al., 2002 [26], Farrington et al., 2000 [27], Vaghela et al., 2014 [28], Paffumi et al., 2018 [29], Weng et al., 2019 [30], Ozkan et al., 2006 [31], Zulkifli et al., 2015 [32], Jong et al., 2016 [33], Mebarki et al., 2013 [34], Achaichia et al., 2011 [35], Santos et al., 2014 [36]) were fundamental in the source-by-source scouting phase. Vaghela et al., 2014 investigated the load calculation of automobile air-conditioning systems with mathematical models for space cooling transfer phenomena of the vehicle cabin [28]. Although the latter has been significant for understanding the light and medium vehicle sector's space cooling system capacities and efficiencies, no results at EU27+UK have been presented. In addition, Weng et al., 2019 studied the design and implementation of a low-energy-consumption air-conditioning control system for smart vehicles proposing a better energy-efficient cabin architecture [30]. Lastly, Zulkifli et al. in 2015 pointed out that, in their study, the electric compressor resulted in lower fuel consumption and better coefficient of performance compared to the conventional compressor [32]. Notably, throughout the literature review of scientific journals, topics such as the investigation of loads of the electric compressor on the automotive air-conditioning system, as well as on trucks, airplanes, buses, and trains, were scouted and marked as essential to understand air-conditioning systems efficiency and peak capacities. Moreover, several sources mentioned above include research on space cooling in buildings, important for data comparison. In addition, in 2002, the National Renewable Energy Laboratory (NREL), conducted a study on assessing the fuel consumption for the whole U.S. vehicle market by considering a thermal comfort-based approach founded on laboratory simulations [27]. The abovementioned work has been evaluated in the first phase of this study in which the most suitable approach could have been taken into consideration. Eventually, after the evaluation, a top-down approach seemed the best route for the present work without involving laboratory simulations, and by constructing a solid and reliable database for the calculation phase.

Furthermore, concerning the several sources mentioned above, it was necessary to properly provide the author/s, access, title, time references, and terms of usage to access, comprehend, and utilize the scouted data and information. The main intention was to appropriately represent the collected data and information in a comprehensible method. As already mentioned in Section 1, the SC sector entirely lacks any type of energy data, and therefore contextual information and a representation of the collected material for the current study are beneficial for any further in-depth research of this sector.

1.2. Data Reliability

Once the data inventory was created as presented in Section 1.1. Data inventory, a deeper analysis of the collected sources was conducted to assess their related reliability. It is important to state that several gaps were identified throughout the scouting phase, some of which were filled through assumptions and estimations (e.g., million vehicles kilometer per year-MWKm/y, threshold temperature for air-conditioning-AC). The remaining uncertainties have been excluded since they could have led to large-scale computational errors. It is important to state that although some data and information were initially investigated at the very first embryonal phase of the study (e.g., million vehicles kilometer per year-MWKm/y), they have not been further processed due to a lack of data during the collection phase. Therefore, a different approach that eventually involved dissimilar types of information has been considered (please see Section 2.)

It is worth mentioning that all of the data and information collected for cooling in the transport sector (i.e., the quantity and the categories of vehicles per country, the installed capacities of the cooling technology per vehicle, category, and country, the equivalent full-load hours (EFLHs) of the SC systems, and the cooling degree days) have been statistically assessed (Section 2—Materials and Methods details the methodology) [37].

1.3. Data definition and Comparability

Since the collected data and information for this study were not entirely comparable, adjustments of gaps and discrepancies were required. Particularly, several differences in terms of methods, measurements, specifications, time references, and assumptions were identified from the sources [38].

Data were collected from the datasets mentioned in Section 1.1. Data inventory and the most recent records have been utilized by identifying 2019 as the reference year for the current research. In contrast, collected data that were older than 10 years have not been classified as significant and therefore excluded.

Overall, the current text concerns the country-by-country final energy consumption of cooling for human comfort in the EU27+UK transportation sector. The reference year of this study is 2019.

The text structure entails Section 2, which involves the detailed gathering of data and information which helped us to produce the material utilized in the study, and the methods which consist of the procedures created to compute the results. Section 3 presents the results with tables and figures. Section 4 discusses the computed results presented in the previous-mentioned sections. Section 5 points out the summary of the outcome of the study with potential further developments.

2. Materials and Methods

One of the most critical aspects of this study—the assessment of FEC of SC for human comfort in the EU27+UK transportation sector—consisted of a breakdown of the SC technology types which are applied in the transportation sector and their key parameters. Moreover, data and information concerning the weather forecast per EU27+UK country were necessary to assess the cooling season in which the SC systems are mainly switched on. A critical parameter, such as the European stock of vehicles, was required, as well.

Hence, the following data per cooling technology and EU27+UK country have been investigated:

- Number of vehicles
- Equivalent full load hours (EFLHs)
- Cooling system power capacity
- Energy efficiency level

Furthermore, it is important to state that, in the present work, the EU27+UK stock of vehicles has been divided into transport categories since different types of cooling equipment are present in different types of vehicles (i.e., the capacity installed of the SC system of a car is different from the one of a train).

Notably, vehicles are sorted into different categories based on a weight scale. Particularly, vehicles weighing less than 3500 kg have been considered light, while medium vehicles weighing more than 3500 kg were categorized medium. Lastly, aircrafts, ships, and trains were reported in the heavy category [22].

Overall, the main categories under which the EU27+UK has been grouped are:

- 1 Light vehicles (Passenger cars and vans-weight less than 3500 kg)
- 2 Medium vehicles (Buses, Coaches, Trucks, Tractors-weight more than 3500 kg)
- 3 Heavy vehicles (Ships, Trains, Aircrafts)

Several key sources have been scouted throughout the data collection phase in this research. Notably, the European Centre for Medium-Range Weather Forecasts (ECMFW), Eurostat (which produce European statistics in partnership with National Statistical Institutes in the EU MSs), Energy Plus Weather Data (funded by the U.S. Department of Energy's-DOE, the Building Technologies Office-BTO, and managed by the National Renewable Energy Laboratory-NREL) were essential providers of data on weather forecasts such as temperatures, humidity, and cooling degree days (CDDs) across the EU27+UK [15,16,19].

The abovementioned information was essential for the input of the EFLHs calculation of each SC technology installed in each vehicle that makes up the EU27+UK transports sector. Particularly, the term EFLHs describes the intended degree of utilization of a technical system. The term is largely used in the energy-production plants' field by referring to the time for which a system needs to operate at its nominal power (capacity-kW) to convert the same amount of electrical work in a certain period [39]. In this study, the term is referred to as the yearly number of hours in which the cooling system of a vehicle is running for human comfort.

Moreover, the thermal balance point of the vehicle, which has been assumed as the average outdoor temperature below which SC is not needed and above which heating is not required, was assumed as 20 °C [27]. The reference temperature was assessed by considering the reference temperature in Report 1 of the Renewable Cooling under the "Revised Renewable Energy Directive ENER/C1/2018-493" [27]. Although the latter is focused on the building sector, the space-cooling load is considered linearly dependent on the outdoor temperature as it has been assumed in the transportation sector in this study.

In addition, in the case of maximum temperature encountered throughout the year, the SC system of the vehicle has been assumed to be switched on at 100% capacity for the whole SC season. Lastly, since the study carried out included a top-down approach, no vehicle occupancy simulations have been conducted.

The following equation (Equation (1)) has been utilized to compute the yearly number of EFLHs in the EU27+UK transportation sector:

$$EFLHs = \sum_{i, \text{season}} \frac{T_i - 20}{T_{max} - 20}, T_i > 20 \quad (1)$$

where:

- T_i is a certain hourly outdoor temperature
- T_{max} is the maximum outdoor temperature reached in the whole cooling season

In addition, the Copernicus Global Land Service and the Meteonorm software were essential to retrieve weather files that contain key parameters such as T_{max} and T_i by climate zones and EU27+UK countries [38–41]. The CDDs at the NUTS2 level were retrieved from the public repositories of the H2020 HotMaps project [42]. The latter, defined as the number of days where the temperature is above 20 °C, were important in determining the cooling season length [43].

According to the main transport categories mentioned above, the ELHs calculation method presented mainly entails the light and medium vehicles groups while aircraft, grouped under heavy vehicles, have been subjected to a different EFLHs computation methodology.

The SC of the air transport sector has been subjected to certain considerations since, at high altitudes (e.g., 11,000 m for a typical commercial flight), the external temperatures drop to negative 51 °C [44]. Therefore, in this study, the time at which the SC system is turned on for human comfort in the aircraft cabin has been assumed as 1 h. This time includes preparation tasks (ordering, cleaning, baggage handling), which is about 30 min. After this phase, the pilots are permitted to open the gate, and it takes another 30 min to embark all passengers [45]. To calculate the EFLHs for the aircraft sector, the SC time of the aircraft cabin has been computed with the cooling season length, as well as the number of flights throughout the whole EU27+UK [20].

Following the transport categories mentioned above, the SC system power capacity, the energy efficiency levels, and the stock of vehicles have been investigated:

1. The light vehicles category was divided into subcategories by dividing cars and the light commercial categories. Particularly, the latter refers to motor vehicles of up to 3.5 tons mainly used for the carriage of goods. According to the European Automobile Manufacturer Association (ACEA), the number of vehicles in use in the EU27+UK, with 2019 as a baseline, has been collected [22]. Particularly the collected data entails light vehicles by different fuel types, such as petrol, diesel, hybrid electric, battery-electric, plug-in hybrid, and LPC + natural gas. An essential study, conducted by NREL, by Farrington et al., 2000 [27] on how the fuel economy impacts the APU (auxiliary power unit). In the current study, for simplicity reasons, the auxiliary power loads have been assumed as having 3 kW average capacity peak among the different vehicles fuel types.
2. The medium vehicles category has been partitioned into buses, trucks, and tractors. Concerning buses and trucks, the ACEA has been appointed as the most complete source to retrieve the stock in the EU27+UK in 2019 by fuel type [22]. Regarding the tractors sector, EUROSTAT provided the stock of vehicles at the NUTS2 level [46]. Data gaps have been filled in different EU27+UK countries by regressions according to CEMA information [25]. Moreover, regarding the medium vehicles SC system types, the Integrated air-conditioning (AC) and Rooftop AC systems have been identified as the most common throughout the sector [47]. Notably, the most recurrent SC peak power capacity lies in ranges between 3.5 and 8.5 kW for Rooftop AC and between 4 and 9.6 kW for Integrated AC in the buses and tractors category. Regarding trucks, the Rooftop AC with a peak capacity of 1.6 kW has been appointed [47].
3. The heavy vehicles category has been broken down into trains, ships, and aircrafts. The train sector was investigated in terms of several locomotives and railcars, by the source of power [48,49]. Regressions have been computed to fill the lack of data for different EU27+UK countries. In terms of ship's stock data collection, it is important to state that the number of vessels collected in the study involves the ownership EU27+UK MS and the operational flags are already counted [50]. The key sources have been the Department of Transport of GOV UK and IHS [45,46]. Regarding the aircraft sector, EUROSTAT provided the number of aircraft of each EU27+UK MS by age whose sum generate the stock [51]. Concerning the training sector, Rooftop AC systems with a range between 20 and 35 kW of capacity have been appointed as the most common cooling technology mounted on both locomotives and railcars [52]. Lugo-Villaba et al., 2017 broke down the ship's air-conditioning sector by investigating energy savings of the air handling unit (AHU) of which the maximum SC capacity has been assumed to be around 392 kW [53]. Lastly, regarding the aircraft sector, the air-cycle machine, which also pressurizes the cabin and is powered by the APU, has been appointed with a maximum SC capacity of 56 kW [50,51,54,55].

Regarding the SC system efficiency, it is important to state that a significant lack of information has been encountered. Almost no numerical data were retrieved during the scouting phase. Therefore, in this case, Dittman et al., 2017 has been an essential reference for this study [56]. Notably, the work proposed a breakdown of VC technologies which mainly entailed SC in the buildings sector. In addition, seasonal performance metrics have

been retrieved from Regulations (EU) 626/2011 [57], (EU) 206/2012 [58] for AC systems with peak capacities below 12 kW, and lastly from Regulation (EU) 2281/2016 [59] for larger AC systems. Furthermore, efficiency parameters, such as the seasonal energy efficiency ratio (SEER), have been collected from the previously mentioned sources and a comparative analysis has been carried out between the SC building and transport sectors (e.g., Small splits—2.5 kW with a SEER of 4.3 mainly applied in the building sector have been compared with the APU of cars in the light vehicle segment, addressed with 3 kW of cooling capacity). It is worth to mention that no different energy efficiency levels related to different vehicles productions years have been considered.

Following the wide data and information collection conducted above, meshes and numerical assessments have been made. Data outside the range of minus or plus one standard deviation were excluded from the study (according to Section 1.3). The remaining values have been numerically assessed to construct a solid mean.

Once more, it is worth stating that the information-gathering process strictly involved technical literature. As mentioned in Section 1, the FEC is related to the energy input of the cooling system installed on the vehicles, therefore a work input (W_{input}) has been computed by dividing the space cooling system power capacity to their respective energy efficiency levels per vehicle category and EU27+UK MS. Finally, the FEC of SC in the EU27+UK transportation sector has been assessed using Equation (2) below, which involved the quantity (number- $Nr_{vehicles}$) multiplied by their relative EFLHs (time- T) and its work input (W_{input}) per EU27+UK MS.

$$FEC_{space\ cooling} = Nr_{vehicles} * T_{equivalent\ full\ load\ hours} * W_{input} \quad (2)$$

where:

- $Nr_{vehicles}$ is the number of vehicles of a certain category
- $T_{equivalent\ full\ load\ hours}$ is the equivalent full load hours
- W_{input} is the work input of the space cooling system, intended as the fraction of the system power capacity and its respective energy efficiency level

The following Section 3 presents the outcomes of the above-mentioned calculation with facts and figures broken down into the three main vehicle categories.

3. Results

3.1. Light Vehicles

Concerning the light vehicle group, the two main transport types that were considered were cars and light commercial vehicles (up to 3.5 tonnes of weight).

Figure 1 below presents the outcome of the FEC for space cooling in the light vehicle category.

As is evident, the largest energy-consuming sub-category is of cars, with an overall FEC in the EU27+UK of about 90 TWh/y, while light commercial vehicles generate an FEC in EU27+UK of around 26 TWh/y. Regarding the car segment, the histograms show that Italy is the most energy-consuming MS, with about 24 TWh/y, followed by Spain with around 20 TWh/y, and France and Germany with more than 10 TWh/y, respectively. The remaining MSs have only minor values. Concerning the light commercial segment, Spain presented the highest values with more than 8 TWh/y, followed by Italy with more than 5 TWh/y, and France with 4 TWh/y. Lesser values are shown for the remaining MSs.

According to the ACEA database mentioned in Section 2 of the current study, the largest numbers in terms of cars are detained by MSs such as Germany, Italy, France, Spain, and Poland, while in terms of commercial light vehicles France, Italy, Spain, Germany, and Poland result to register the highest values [22]. Apart from Poland, in which its EFLHs resulted in lower values compared to the above-mentioned MSs, the light vehicle results are in line and related to the quantities of registered vehicles presented in the report of ACEA [22]. Further details are presented in Tables A1 and A2 in the Appendix A.

Figure 1. Final energy consumption for space cooling in the light vehicles category for the EU27+UK—the reference year 2019.

3.2. Medium Vehicles

The medium vehicle category was broken down into the following three main segments: trucks, tractors, and buses.

Figure 2 below highlights the main results of the FEC for space cooling in the medium vehicle category.

Figure 2. Final energy consumption for space cooling in the medium vehicles category for the EU27+UK—the reference year 2019.

By considering the obtained results, the most energy consuming vehicle sub-category for the whole EU27+UK is the trucks segment with more than 6 TWh/y, followed by the tractors, characterized with almost 4 TWh/y, and, lastly, the buses segment with more than 1 TWh/y.

Concerning the buses segment, the most energy-consuming MS was found to be Italy with almost 0.18 TWh/y, followed by Poland, France, Spain, and Germany with around 0.12 TWh/y each. The remaining MSs only show minor values. With regard to the tractor segment, France had the highest, with almost 1 TWh/y, followed by Italy, Spain, and Germany with 0.98, 0.75, and 0.48 TWh/y, respectively, while the remaining

states present minor values. Lastly, regarding the truck segment, the greatest energy-consuming MS resulted to be Greece with almost 2.5 TWh/y, followed by Portugal with more than 1 TWh/y, and France with 0.8 TWh/y. Lesser values are shown by the rest of the EU27+UK MSs.

The highest number of buses and trucks throughout the whole EU27+UK is held by Poland, followed by Italy, France, Germany, and Spain which similarly reflects the aforementioned FEC results [22]. Furthermore, the highest number of tractors are to find in France, Germany, Italy, Poland, and Spain. As already mentioned, the EFLHs, are connected to the CDDs and therefore different climate conditions of the EU27+UK MSs influenced the results. Still, the most influential variable of Equation (2) remains to be $Nr_{vehicles}$. More details are presented in Tables A3–A5 in the Appendix A.

3.3. Heavy Vehicles

Concerning the heavy vehicles category, the following three main segments are involved: trains, ships, and aircrafts. Figure 3 below presents the main outcomes of the FEC for space cooling in the heavy vehicle category.

Figure 3. Final energy consumption for space cooling in the heavy vehicles category for the EU27+UK—the reference year 2019.

It can be observed that the most energy-consuming vehicle sub-category for the whole EU27+UK was the ships segment with almost 0.5 TWh/y, followed by the train and the aircraft segments with more than 0.2 TWh/y and almost 0.2 TWh/y, respectively.

Greece results to be the FEC top-consumer throughout the whole EU27+UK for the ships sub-category with almost 1.5 TWh/y, followed by Germany, United Kingdom, Netherlands, with 0.8, 0.5, and 0.4 TWh/y, respectively, while the remaining MSs presented minor values. Moreover, regarding the trains segment, France came first with almost 0.04 TWh/y, followed by Germany, Italy, and Poland with almost 0.04, 0.03, and 0.02 TWh/y, respectively, and just minor results for the remaining EU27+UK MSs. Lastly, concerning the aircraft sub-category, major values are identified by Germany and United Kingdom (UK) both with 0.006 TWh/y each, while Spain comes with 0.002 TWh/y, and France with more than 0.001 TWh/y. The remaining EU27+UK MSs had minor values.

Notably, regarding the ship segment, as mentioned in Section 2, the most relevant source was Lugo-Villaba et al., 2017, which provided results such as the energy consumption of a vessel AHU running for space cooling [53]. In this case, regarding the EFLHs computation, most of the data sourced through the Meteonorm software were gathered from on-shore stations [39]. Therefore, in this case, the FEC weighting procedure was conducted by averaging the FEC provided by the outcomes of Lugo-Villaba et al., 2017 for the whole EU27+UK and by multiplying the result by each MS's number of vessels

to obtain the aforementioned results. Further information is available in Tables A6–A8 in the Appendix A.

3.4. Final Energy Consumption for Space Cooling in the European Transportation Sector

Lastly, the results for the FEC for space cooling in the whole EU27+UK transportation sector are presented. Figure 4 below differentiates the outcomes per vehicle category.

Figure 4. Final energy consumption for space cooling in the EU27+UK per vehicles category—the reference year 2019.

By inspecting the figure, it can be said that the total FEC for space cooling results in the whole EU27+UK transportation sector to be almost 125 TWh/y.

Moreover, by breaking down the different vehicle categories, the light vehicles section was found to be the most energy-consuming, with more than 115 TWh/y for the whole EU27+UK. Italy had the highest value at almost 30 TWh/y, immediately followed by Spain with more than 28 TWh/y and by France and Germany with around 14 and 13 TWh/y, respectively.

Concerning the medium vehicles category, the FEC for space cooling in the EU27+UK was more than 8 TWh/y. Greece was found to be the most energy-consuming MS with about 2.5 TWh/y, followed by Portugal and France around 1 TWh/y each. The remaining MSs showed minor values.

Ultimately, regarding the heavy vehicles category, the FEC for space cooling of the entire EU27+UK was nearly 1 TWh/y. Greece, Germany, France, the United Kingdom, and Italy were found to be the most energy-consuming, with values of 0.15, 0.1, 0.07, 0.06, and 0.04 TWh/y, respectively. Concerning the remaining MSs, lesser values are presented.

As can be observed from the information presented in Section 2 concerning the vehicle space cooling system power peak capacity, high values are reported in categories such as aircrafts, ships, and trains, which can even surpass 300 kW, while the light and medium category is mainly dominated by values in the range of 3 to 10 kW. According to the results presented in Figure 4, it can be clearly stated that the greatest influence in Equation (2) is given by the number of vehicles ($N_{vehicles}$) in all the vehicle categories. Although heavy vehicles are mainly characterized by higher space cooling system power peak capacities, they little contributed to the overall EU27+UK FEC compared to the light vehicle sector which dominates in terms of the number of vehicles.

4. Discussion

According to the main findings of the current study, in 2019, the FEC for space cooling (SC) in the transportation sector for the whole EU27+UK accounted for almost 125 TWh/y.

Although the topic of SC in vehicles is almost unexplored in scientific literature, Farrington et al., 2000 published by NREL considered a bottom-up approach to determine the amount of fuel used in the United States of America (U.S.) for light vehicles AC by involving the occupant thermal comfort. The assessment estimated around 27 billion liters of gasoline [27]. The aforementioned study has been essential for the current work on which approach could have been considered at the beginning of the research. Eventually, although the current study embraced a top-down approach by collecting, analysing, and processing big data at the EU27+UK, Farrington et al., 2000 has been cited as a reference for which type of information was required at the beginning of the research. Although no relevant information at the EU27+UK level has been retrieved from the above-mentioned studies, their findings contribute to the future research perspectives presented in Section 5.

Nevertheless, the results of Report 1 of the Renewable Cooling under the “Revised Renewable Energy Directive ENER/C1/2018-493” have been considered as the most relevant for the present study comparison, since similar time-reference, as well as units of measurements, are applied in both studies [60]. Particularly, the outputs of FEC for cooling of the latter, which involved SC in buildings of the residential and the service sectors, resulted to be slightly more than 105 TWh/y for the entire EU27+UK.

Overall, the FEC for SC in the transportation sector (almost 125 TWh/y) accounts for more of the FEC for SC in the buildings sector (more than 105 TWh/y) in the EU27+UK.

According to the results presented in Section 3, the greatest energy-consuming segment has been identified as the light vehicles section with more than 115 TWh/y, followed by the medium vehicles section with more than 8 TWh/y, and, finally, by the heavy vehicles section with around 1 TWh/y.

The light vehicles segment is the largest portion of the transportation sector of the entire EU27+UK in terms of numbers of vehicles. Moreover, the cars sub-section was identified as being more energy-consuming than the light commercial section since the number of vehicles is significantly higher, although both the peak capacity of the SC generators and the EFLHs is equal for both sub-sections. It has been observed that, in Equation (2), the number of vehicles ($N_{vehicles}$) parameter proportionally influenced the most FEC results, followed by the EFLHs member. The latter was directly influenced by meteorological parameters of a certain MS. In the case of Poland, although the latter was characterized by a high number of vehicles in MSs such as Italy, France, Germany, and Spain, its EFLHs resulted in lower values compared to the aforementioned MSs by eventually resulting in FEC minor values.

With regard to the medium vehicles section, trucks comprise the largest number of vehicles, followed by tractors and buses. Therefore, although the peak capacity of the Rooftop AC systems applied in the trucks sub-section is significantly less compared with buses or tractors, trucks are responsible for the greatest energy consumption since it has the largest number of vehicles. As mentioned above, the number of vehicles greatly influence the current sector FEC. In this case, although France retained the highest number of trucks in the whole EU27+UK, Greece resulted to be the most energy-consuming for space cooling, since its EFLHs resulted to be higher compared to France.

Regarding the heavy vehicles element, ships, although not having the largest number in terms of vehicles, presented the highest SC peak capacity compared to the trains and aircraft systems. It is important to underline that significant data retrieving issues have been encountered in the vessels category. As previously mentioned, meteorological data obtained by the scouted datasets (please see—Section 2), were collected by on-shore stations, and therefore assumptions and simplifications have been made to retrieve FEC for the ship segment (please see—Section 3.3). Moreover, as already mentioned, the aircraft segment FEC computation method was differentiated from the other parts because the “SC” of the cabin has been assumed to occur only in a specific period— which was the “preparation-to-fly” time expended in the airports (please see—Section 2). Therefore, the results came to be significantly smaller compared to the other segments mainly due to the small time spent

on the ground by the aircraft. Further data and details, which are related to the discussion, can be found in the Appendix A.

Regarding the FEC shares, the most energy-consuming MSs across the whole EU27+UK are Italy and Spain, accounting for 24 and 23% of the whole EU27+UK FEC, respectively. France follows with 12% and Germany with 10%. Moreover, Greece accounts for 6%, Portugal for 4%, and Poland, the United Kingdom, and Romania for 3%, respectively. The remaining EU27+UK MSs had minor values of close to or of less than 1%. The outcomes are influenced by different parameters, of which the greatest combination was the EFLHs and the number of vehicles that eventually led Italy and Spain to become the most energy-consuming MSs throughout the whole EU27+UK. Although Germany resulted to have the largest number of vehicles in the light segment (most cars), Cyprus presented the highest ELHSs number of the entire EU27+UK (mainly due to its warm Mediterranean climate) despite it having a significantly lower number of vehicles compared to other MSs.

Once again, it is important to underline that the current study aims to be the first research on the assessment of the final energy consumption of space cooling for human comfort in the transportation sector of the EU27+UK market. The SC sector is not heavily investigated in scientific literature, and even less so for SC in the transportation sector.

Significant data and information difficulties during the collection phase were met during the literature review phase. In addition, significant retrieving data and information tribulations have been experienced concerning lacks and gaps in the scouted databases. Notably, regarding the wheeled vehicles (cars, light commercials, tractors, trucks, and buses) market, information accessibility issues were faced, mainly related to non-disclosure policies adopted by private companies which operate in the sector. Nonetheless, research and development (R&D) activities should be better supported by the operational sector [38].

5. Conclusions

The present work assessed the final energy consumption of space cooling for human comfort in the European transportation sector with 2019 as the baseline. Overall, the final energy consumption findings details of the work are summarized as follows:

- The total final energy consumption for space cooling in the European transportation sector in 2019 resulted to be more than 125 TWh/y. Italy was found to be the most energy-consuming member state with 30 TWh/y, followed by Spain with more than 28 TWh/y, then by France with more than 15 TWh/y, and Germany with 13 TWh/y. These countries account for 80% of the total final energy consumption of the whole European zone. The remaining 20% is accounted for by the remaining countries. The whole transportation sector was classified into the following three main categories: light, medium, and heavy vehicles.
- The light vehicle category was divided into cars and light commercials. The total final energy consumption for space cooling in the European light vehicle segment accounted for around 116 TWh/y. Italy came out to be the most energy-consuming member state with almost 30 TWh/y, followed by Spain with almost 28 TWh/y, then by France with 14 TWh/y, and Germany with almost 12 TWh/y. These countries account for 82% of the total final energy consumption of the whole European zone. The remaining 18% was accounted for by the rest of the European countries.
- The medium vehicle category was categorised into buses, tractors, and trucks. The total final energy consumption for space cooling in the European medium vehicle category accounted for about 11 TWh/y. Greece resulted to be the greatest energy-consuming member state with about 2.7 TWh/y, followed by France with almost 2 TWh/y, followed by Italy with almost 1.3 TWh/y, and Portugal with more than 1.2 TWh/y. These four countries account for more than 60% of the total final energy consumption of the whole European zone. The remaining 40% is accounted for by the rest of the European member states.
- The heavy vehicle category was classified into trains, ships, and aircrafts. The total final energy consumption for space cooling in the European heavy vehicle category resulted

to be almost 0.7 TWh/y. Greece presented the highest values with around 1.5 TWh/y, followed by Germany with around 0.11 TWh/y, then followed by France with almost 0.07 TWh/y, then the United Kingdom with almost 0.06 TWh/y, followed by Italy and Netherlands with 0.04 TWh/y, respectively. Taken together, these five countries account for 70% of the entire European final energy consumption in the heavy vehicles segment. Therefore, the remaining 30% entails the rest of the European member states.

Overall, the main finding of the present study has been that the European final space cooling consumption in the transportation sector accounted for more than the final space cooling consumption in the buildings sector, including both the residential and service portions. Given this work, it can be considered as a point of discussion for further research on the topic. Nowadays, great attention by the scientific literature is mainly focused on space heating in buildings regarding energy efficiency, savings, and developing new technologies.

Moreover, it has been observed that the light vehicles category is the largest part of the total final energy consumption of the European transportation sector. Notably, the cars segment is the most energy-demanding and the largest in terms of the number of operating transports (which is principally driven by private companies). Given the fact that, currently, great attention is given to the electric automotive sector, potential further research could be focused on the space cooling energy consumption for human comfort in the electric vehicles which could lead to different results compared to this study due to the different space cooling system capacities.

During the literature review, which involved the scouting of numerous sources, the authors faced relevant data and information-collection issues since knowledge from certain European member states, as well as from certain vehicles categories and cooling technologies, are inconsistent, fragmented, unavailable, or even outdated. Therefore, better accessibility, as well as reliability of data and information and major involvement of the private sector, is necessary for research and development purposes.

According to what has been stated above, it can be said that the current study is the first outlook and a potential reference on a highly unexplored field in the European scientific literature.

In conclusion, space cooling in the transportation sector is expected to grow in the future according to different drivers such as climate change, which increases space cooling demand, driven by soaring temperatures and humidity during summers, as well as the increase in the number of vehicles due to the expected growth in population and welfare throughout the member states of the European Union.

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Appendix A

Table A1. Light vehicles segment-Final space cooling energy consumption of cars in the EU27+UK, the reference year 2019.

Country	n° of Cars	Cooling System Capacity [kW]	EFLHs [h]	Energy Efficiency	Work Input [kW]	FEC [TWh]
Austria	4,978,852	3	368	3.42	0.877192982	1.40726815
Belgium	5,782,685	3	276	3.57	0.840336134	0.448605678
Bulgaria	2829964	3	276	3.51	0.854700855	0.625701722
Croatia	1,665,391	3	552	3.66	0.819672131	0.722723942
Cyprus	572,501	3	552	3.4	0.882352941	0.614926321
Czechia	5,802,520	3	276	3.25	0.923076923	0.950594355
Denmark	2,593,568	3	184	4.02	0.746268657	0.199331375
Estonia	746,464	3	184	4.04	0.742574257	0.078514739
Finland	2,696,334	3	184	3.25	0.923076923	0.310101985
France	33,020,132	3	460	3.38	0.887573964	10.20529244
Germany	47,095,784	3	460	3.32	0.903614458	10.52729641
Greece	5,164,183	3	552	3.29	0.911854103	3.527751136
Hungary	3,638,374	3	276	3.28	0.914634146	1.146928637
Ireland	2,104,060	3	184	3.66	0.819672131	0.081260881
Italy	39,018,170	3	552	3.23	0.928792571	24.2693347
Latvia	636,671	3	184	4.04	0.742574257	0.031482682
Lithuania	1,430,520	3	184	4.06	0.738916256	0.114531905
Luxembourg	415,128	3	184	3.75	0.816298091	0.034924181
Malta	307,130	3	552	3.4	0.882352941	0.227737384
Netherlands	8,787,283	3	184	3.37	0.890207715	0.763538686
Poland	23,429,016	3	184	3.45	0.869565217	3.207479231
Portugal	5,015,057	3	552	3.21	0.934579439	2.985544189
Romania	6,450,750	3	276	3.35	0.895522388	2.543396091
Slovakia	2,326,787	3	368	3.86	0.777202073	0.484176646
Slovenia	1,203,774	3	368	3.66	0.819672131	0.29091479
Spain	24,074,216	3	552	3.21	0.934579439	20.04833209
Sweden	4,870,783	3	184	3.41	0.879765396	0.629297496
United Kingdom	34,887,915	3	368	3.39	0.884955752	2.736965813

Table A2. Light vehicles segment-Final space cooling energy consumption of light commercials in the EU27+UK, the reference year 2019.

Country	n° of Light-Commercials	Cooling System Capacity [kW]	EFLHs [h]	Energy Efficiency	Work Input [kW]	FEC [TWh]
Austria	422,745	6.4	322.22	3.42	1.871345029	0.254908807
Belgium	769,386	6.4	92.31710824	3.57	1.792717087	0.127332196
Bulgaria	558,037	6.4	258.6856283	3.51	1.823361823	0.263213496
Croatia	135,800	6.4	529.4391585	3.66	1.74863388	0.125722995
Cyprus	130,941	6.4	1217.319266	3.4	1.882352941	0.300041416
Czechia	574,722	6.4	177.4764328	3.25	1.969230769	0.200860771
Denmark	389,350	6.4	102.9870981	4.02	1.592039801	0.063837654
Estonia	83,307	6.4	141.6453873	4.04	1.584158416	0.018693152
Finland	325,656	6.4	124.5928052	3.25	1.969230769	0.079900346
France	6,233,473	6.4	348.2106861	3.38	1.893491124	4.109939712
Germany	2,724,783	6.4	247.3726315	3.32	1.927710843	1.299347935
Greece	889,638	6.4	749.1537536	3.29	1.945288754	1.296487581
Hungary	446,647	6.4	344.6526691	3.28	1.951219512	0.300366987
Ireland	380,883	6.4	47.11760842	3.66	1.74863388	0.031381501
Italy	4,146,206	6.4	669.6875761	3.23	1.981424149	5.50174642
Latvia	50,835	6.4	66.59118884	4.04	1.584158416	0.005362635
Lithuania	49,576	6.4	108.3520986	4.06	1.57635468	0.008467647

Table A2. Cont.

Country	n° of Light-Commercials	Cooling System Capacity [kW]	EFLHs [h]	Energy Efficiency	Work Input [kW]	FEC [TWh]
Luxembourg	36,603	6.4	105.1608813	3.75	1.706666667	0.006569308
Malta	4472	6.4	840.3684724	3.4	1.882352941	0.007074123
Netherlands	995,796	6.4	97.60792473	3.37	1.899109792	0.184588878
Poland	2,649,198	6.4	157.4373041	3.45	1.855072464	0.77371843
Portugal	1,120,270	6.4	636.9882301	3.21	1.99376947	1.422751511
Romania	758,037	6.4	440.2783607	3.35	1.910447761	0.637606759
Slovakia	259,629	6.4	267.74	3.86	1.658031088	0.115254829
Slovenia	105,360	6.4	294.8361107	3.66	1.74863388	0.054319445
Spain	4,640,154	6.4	891.0659992	3.21	1.99376947	8.243605653
Sweden	572,075	6.4	146.855544	3.41	1.876832845	0.157677204
United Kingdom	4,407,561	6.4	88.64878766	3.39	1.887905605	0.737651803

Table A3. Medium vehicles segment-Final space cooling energy consumption of buses in the EU27+UK, the reference year 2019.

Country	n° of Buses	Rooftop AC System Capacity [kW]	Integrated AC System Capacity [kW]	EFLHs [h]	Energy Efficiency	Work Input [kW]	FEC [TWh]
Austria	10,148	3.5–8.5	4–9.6	617.4051352	3.42	1.871345029	0.011724776
Belgium	16,486	3.5–8.5	4–9.6	525.6602203	3.57	1.792717087	0.015535748
Bulgaria	20,687	3.5–8.5	4–9.6	258.6856283	3.51	1.823361823	0.009757592
Croatia	5141	3.5–8.5	4–9.6	796.1426387	3.66	1.74863388	0.007157105
Cyprus	22,337	3.5–8.5	4–9.6	1045.413774	3.4	1.882352941	0.043955591
Czechia	21,443	3.5–8.5	4–9.6	543.2958441	3.25	1.969230769	0.022941327
Denmark	8982	3.5–8.5	4–9.6	490.5720542	4.02	1.592039801	0.007015034
Estonia	4973	3.5–8.5	4–9.6	489.4154688	4.04	1.584158416	0.003855625
Finland	12,481	3.5–8.5	4–9.6	524.9178456	3.25	1.969230769	0.012901415
France	92,498	3.5–8.5	4–9.6	709.7051699	3.38	1.893491124	0.124300703
Germany	106,024	3.5–8.5	4–9.6	555.7838302	3.32	1.927710843	0.113593108
Greece	27,970	3.5–8.5	4–9.6	940.184941	3.29	1.945288754	0.051155205
Hungary	19,454	3.5–8.5	4–9.6	667.4978107	3.28	1.951219512	0.025337566
Ireland	10,944	3.5–8.5	4–9.6	477.0265284	3.66	1.74863388	0.00912888
Italy	100,042	3.5–8.5	4–9.6	889.8351614	3.23	1.981424149	0.17638814
Latvia	4035	3.5–8.5	4–9.6	516.6464251	4.04	1.584158416	0.003302445
Lithuania	7517	3.5–8.5	4–9.6	505.4210506	4.06	1.57635468	0.005988966
Luxembourg	1963	3.5–8.5	4–9.6	543.6704544	3.75	1.706666667	0.001821398
Malta	876	3.5–8.5	4–9.6	973.2379443	3.4	1.882352941	0.001604812
Netherlands	10,055	3.5–8.5	4–9.6	524.0419209	3.37	1.899109792	0.010006868
Poland	119,471	3.5–8.5	4–9.6	561.5596548	3.45	1.855072464	0.124456985
Portugal	16,200	3.5–8.5	4–9.6	741.2477614	3.21	1.99376947	0.02394161
Romania	23,935	3.5–8.5	4–9.6	741.2920198	3.35	1.910447761	0.033896739
Slovakia	9078	3.5–8.5	4–9.6	651.4207554	3.86	1.658031088	0.009804929
Slovenia	2850	3.5–8.5	4–9.6	616.7809655	3.66	1.74863388	0.003073794
Spain	64,915	3.5–8.5	4–9.6	923.533643	3.21	1.99376947	0.119528845
Sweden	14,378	3.5–8.5	4–9.6	510.9332798	3.41	1.876832845	0.013787587
United Kingdom	84,391	3.5–8.5	4–9.6	533.8931404	3.39	1.887905605	0.085061052

Table A4. Medium vehicles segment-Final space cooling energy consumption of trucks in the EU27+UK, the reference year 2019.

Country	n° of Trucks	Cooling System Capacity [kW]	EFLHs [h]	Energy Efficiency	Work Input [kW]	FEC [TWh]
Austria	494,585	1.6	617.4051352	3.42	0.467836257	0.074556809
Belgium	885,487	1.6	525.6602203	3.57	0.448179272	0.036636683
Bulgaria	401,823	1.6	258.6856283	3.51	0.455840456	0.047382717
Croatia	112,468	1.6	796.1426387	3.66	0.43715847	0.026030585
Cyprus	719,687	1.6	1045.413774	3.4	0.470588235	0.412277106
Czechia	3,149,263	1.6	543.2958441	3.25	0.492307692	0.275160597
Denmark	408,094	1.6	490.5720542	4.02	0.39800995	0.016727728

Table A4. Cont.

Country	n° of Trucks	Cooling System Capacity [kW]	EFLHs [h]	Energy Efficiency	Work Input [kW]	FEC [TWh]
Estonia	118,125	1.6	489.4154688	4.04	0.396039604	0.00662648
Finland	1,304,839	1.6	524.9178456	3.25	0.492307692	0.08003621
France	5,015,973	1.6	709.7051699	3.38	0.473372781	0.826800189
Germany	646,483	1.6	555.7838302	3.32	0.481927711	0.07707094
Greece	6,784,661	1.6	940.184941	3.29	0.486322188	2.471856173
Hungary	180,674	1.6	667.4978107	3.28	0.487804878	0.030375501
Ireland	519,231	1.6	477.0265284	3.66	0.43715847	0.010695048
Italy	351,588	1.6	889.8351614	3.23	0.495356037	0.116633618
Latvia	4,175,689	1.6	516.6464251	4.04	0.396039604	0.110124394
Lithuania	95,464	1.6	505.4210506	4.06	0.39408867	0.004076345
Luxembourg	42,017	1.6	543.6704544	3.75	0.426666667	0.001885246
Malta	76,425	1.6	973.2379443	3.4	0.470588235	0.030223605
Netherlands	49,491	1.6	524.0419209	3.37	0.474777448	0.002293514
Poland	1,002,882	1.6	561.5596548	3.45	0.463768116	0.073224829
Portugal	3,436,184	1.6	741.2477614	3.21	0.498442368	1.090995023
Romania	60,797	1.6	741.2920198	3.35	0.47761194	0.012784527
Slovakia	943,062	1.6	651.4207554	3.86	0.414507772	0.104661314
Slovenia	653,879	1.6	616.7809655	3.66	0.43715847	0.084278532
Spain	99,231	1.6	923.533643	3.21	0.498442368	0.044072957
Sweden	296,952	1.6	510.9332798	3.41	0.469208211	0.020461723
United Kingdom	919,231	1.6	533.8931404	3.39	0.471976401	0.126236426

Table A5. Medium vehicles segment-Final space cooling energy consumption of tractors in the EU27+UK, the reference year 2019.

Country	n° of Tractors	Rooftop AC System Capacity [kW]	Integrated AC System Capacity [kW]	EFLHs [h]	Energy Efficiency	Work Input [kW]	FEC [TWh]
Austria	58,651	3.5–8.5	4–9.6	322.22	3.42	1.871345029	0.035365829
Belgium	8970	3.5–8.5	4–9.6	92.31710824	3.57	1.792717087	0.001484452
Bulgaria	68,698	3.5–8.5	4–9.6	258.6856283	3.51	1.823361823	0.032403116
Croatia	4620	3.5–8.5	4–9.6	529.4391585	3.66	1.74863388	0.004276955
Cyprus	4543	3.5–8.5	4–9.6	1217.319266	3.4	1.882352941	0.010409942
Czechia	9842	3.5–8.5	4–9.6	177.4764328	3.25	1.969230769	0.003439626
Denmark	102,275	3.5–8.5	4–9.6	102.9870981	4.02	1.592039801	0.016768885
Estonia	14,762	3.5–8.5	4–9.6	141.6453873	4.04	1.584158416	0.003312536
Finland	26,121	3.5–8.5	4–9.6	124.5928052	3.25	1.969230769	0.006408851
France	1,506,502	3.5–8.5	4–9.6	348.2106861	3.38	1.893491124	0.993287754
Germany	1,007,340	3.5–8.5	4–9.6	247.3726315	3.32	1.927710843	0.480363059
Greece	122,837	3.5–8.5	4–9.6	749.1537536	3.29	1.945288754	0.179013389
Hungary	40,059	3.5–8.5	4–9.6	344.6526691	3.28	1.951219512	0.026939089
Ireland	56,782	3.5–8.5	4–9.6	47.11760842	3.66	1.74863388	0.004678375
Italy	742,146	3.5–8.5	4–9.6	669.6875761	3.23	1.981424149	0.984779992
Latvia	6164	3.5–8.5	4–9.6	66.59118884	4.04	1.584158416	0.00065028
Lithuania	43,874	3.5–8.5	4–9.6	108.3520986	4.06	1.57635468	0.00749371
Luxembourg	6186	3.5–8.5	4–9.6	105.1608813	3.75	1.706666667	0.001110234
Malta	383	3.5–8.5	4–9.6	840.3684724	3.4	1.882352941	0.000605856
Netherlands	19,853	3.5–8.5	4–9.6	97.60792473	3.37	1.899109792	0.003680148
Poland	704,918	3.5–8.5	4–9.6	157.4373041	3.45	1.855072464	0.205876736
Portugal	89,363	3.5–8.5	4–9.6	636.9882301	3.21	1.99376947	0.113491093
Romania	55,587	3.5–8.5	4–9.6	440.2783607	3.35	1.910447761	0.046755827
Slovakia	18,305	3.5–8.5	4–9.6	267.74	3.86	1.658031088	0.008126064
Slovenia	23,007	3.5–8.5	4–9.6	294.8361107	3.66	1.74863388	0.011861609
Spain	421,714	3.5–8.5	4–9.6	891.0659992	3.21	1.99376947	0.749208108
Sweden	167,297	3.5–8.5	4–9.6	146.855544	3.41	1.876832845	0.046111086
United Kingdom	72,959	3.5–8.5	4–9.6	88.64878766	3.39	1.887905605	0.012210426

Table A6. Heavy vehicles segment-Final space cooling energy consumption of aircrafts in the EU27+UK, the reference year 2019.

Country	n° of Aircrafts	n° of Yearly Flights	ACM System Capacity [kW]	EFLHs [h]	Energy Efficiency	Work Input [kW]	FEC [TWh]
Austria	459	234	56	58.5	4	15.12228261	0.000406056
Belgium	176	208	56	52	3.84	14.4921875	0.000132633
Bulgaria	61	52	56	13	3.86	14.41709845	1.14328 × 10 ⁵
Croatia	36	38	56	9.5	3.86	14.41709845	4.93065 × 10 ⁶
Cyprus	15	76	56	19	3.82	14.56806283	4.1519 × 10 ⁶
Czechia	73	139	56	34.75	3.73	14.91957105	3.78472 × 10 ⁵
Denmark	149	254	56	63.5	3.82	14.56806283	0.000137836
Estonia	45	40	56	10	3.83	14.53002611	6.53851 × 10 ⁶
Finland	93	181	56	45.25	3.81	14.60629921	6.1467 × 10 ⁵
France	553	680	56	170	3.81	14.60629921	0.001373138
Germany	1134	1405	56	351.25	3.61	15.41551247	0.006140268
Greece	118	205	56	51.25	3.85	14.45454545	8.74139 × 10 ⁵
Hungary	120	102	56	25.5	3.7	15.04054054	4.60241 × 10 ⁵
Ireland	666	218	56	54.5	3.85	14.45454545	0.000524657
Italy	274	486	56	121.5	3.7	15.04054054	0.000500715
Latvia	57	78	56	19.5	3.81	14.60629921	1.62349 × 10 ⁵
Lithuania	44	52	56	13	3.81	14.60629921	8.3548 × 10 ⁶
Luxembourg	127	55	56	13.75	3.84	14.4921875	2.5307 × 10 ⁵
Malta	202	22	56	5.5	3.82	14.56806283	1.61851 × 10 ⁵
Netherlands	260	487	56	121.75	3.76	14.80053191	0.000468511
Poland	160	172	56	43	3.88	14.34278351	9.86784 × 10 ⁵
Portugal	239	216	56	54	3.8	14.64473684	0.000189005
Romania	63	114	56	28.5	3.82	14.56806283	2.6157 × 10 ⁵
Slovakia	19	29	56	7.25	3.84	14.4921875	1.9963 × 10 ⁶
Slovenia	38	25	56	6.25	3.85	14.45454545	3.43295 × 10 ⁶
Spain	528	1035	56	258.75	3.77	14.76127321	0.002016685
Sweden	272	231	56	57.75	3.77	14.76127321	0.00023187
United Kingdom	1300	1235	56	308.75	3.66	15.20491803	0.006102874

Table A7. Heavy vehicles segment-Final space cooling energy consumption of trains in the EU27+UK, the reference year 2019.

Country	n° of Locomotives and Railcars	Rooftop Mounted Units System Capacity [kW]	EFLHs [h]	Energy Efficiency	Work Input [kW]	FEC [TWh]
Austria	1849	20–35	617.4051352	3.96	6.944444444	0.007927653
Belgium	1277	20–35	525.6602203	3.86	7.124352332	0.004781165
Bulgaria	452	20–35	258.6856283	3.83	7.180156658	0.000839082
Croatia	433	20–35	796.1426387	3.75	7.333333333	0.002528018
Cyprus	0	20–35	1045.413774	0	0	0
Czechia	3139	20–35	543.2958441	3.82	7.19895288	0.012277135
Denmark	741	20–35	490.5720542	3.56	7.724719101	0.002808043
Estonia	266	20–35	489.4154688	3.55	7.746478873	0.001008472
Finland	570	20–35	524.9178456	3.83	7.180156658	0.002148326
France	7566	20–35	709.7051699	3.91	7.033248082	0.037765935
Germany	8533	20–35	555.7838302	3.92	7.015306122	0.033270967
Greece	217	20–35	940.184941	3.79	7.255936675	0.001480357
Hungary	1706	20–35	667.4978107	3.91	7.033248082	0.00800912
Ireland	482	20–35	477.0265284	3.83	7.180156658	0.00165091
Italy	3728	20–35	889.8351614	3.93	6.997455471	0.023213128
Latvia	325	20–35	516.6464251	3.77	7.294429708	0.001224808
Lithuania	268	20–35	505.4210506	3.77	7.294429708	0.000988051
Luxembourg	126	20–35	543.6704544	3.8	7.236842105	0.000495742
Malta	0	20–35	973.2379443	0	0	0
Netherlands	810	20–35	524.0419209	3.87	7.105943152	0.003016288
Poland	5197	20–35	561.5596548	3.96	6.944444444	0.020266844
Portugal	377	20–35	741.2477614	3.77	7.294429708	0.002038431
Romania	2995	20–35	741.2920198	3.89	7.06940874	0.015695286
Slovakia	132	20–35	651.4207554	3.8	7.236842105	0.000622278

Table A7. Cont.

Country	n° of Locomotives and Railcars	Rooftop Mounted Units System Capacity [kW]	EFLHs [h]	Energy Efficiency	Work Input [kW]	FEC [TWh]
Slovenia	252	20–35	616.7809655	3.82	7.19895288	0.001118925
Spain	1716	20–35	923.533643	3.78	7.275132275	0.011529511
Sweden	2771	20–35	510.9332798	3.97	6.926952141	0.009807152
United Kingdom	1804	20–35	533.8931404	3.85	7.142857143	0.006879594

Table A8. Heavy vehicles segment-Final space cooling energy consumption of ships in the EU27+UK, the reference year 2019.

Country	n° of Ships by Operational Flags	AHU Units System Capacity [kW]	FEC [TWh]
Austria	13	392	0.00041392
Belgium	357	392	0.01136688
Bulgaria	73	392	0.00232432
Croatia	87	392	0.00277008
Cyprus	311	392	0.00990224
Czechia	NA	392	NA
Denmark	928	392	0.02954752
Estonia	87	392	0.00277008
Finland	151	392	0.00480784
France	903	392	0.02875152
Germany	2395	392	0.0762568
Greece	4705	392	0.1498072
Hungary	NA	392	NA
Ireland	114	392	0.00362976
Italy	651	392	0.02072784
Latvia	77	392	0.00245168
Lithuania	53	392	0.00168752
Luxembourg	19	392	0.00060496
Malta	71	392	0.00226064
Netherlands	1207	392	0.03843088
Poland	130	392	0.0041392
Portugal	57	392	0.00181488
Romania	111	392	0.00353424
Slovakia	NA	392	NA
Slovenia	2	392	0.00006368
Spain	224	392	0.00713216
Sweden	298	392	0.00948832
United Kingdom	1348	392	0.04292032

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