

Airports and environmental sustainability: a review

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Abstract. This paper examines the energy and environmental context of the design and operation of airports and air transport in general in the direction of achieving sustainability and cooperation with modern sustainable trends. At the same time, the importance of this design is highlighted, and all the latest developments on individual issues (e.g., impact management, policies, benchmarking, modeling) are recorded. In parallel, apart from the theoretical approach, an analysis of the main environmental and energy achievements of different airports in Greece and abroad is made, which highlights, among others, the dynamics and the priority of these issues in the field of aviation. The need for a more extensive study of this sector is dictated by the reduction of energy reserves, increased energy costs, climate change, new energy regulations, and fines, increased passenger numbers, increased flights and airports, and the need for new airports. Therefore, knowing the benefits and impacts of a transition from simple economic growth to sustainable growth in the economy and the environment is essential. The circle is about society, the economy, and the environment and is repeated.

1 Introduction

An airport is a designated area on land (including any buildings, facilities, and equipment) intended to be used in whole or in part for aircraft arrival, departure, and surface movement. Today, airports can also meet other commercial, industrial, business, and entertainment service needs. Airport design has been widely discussed in various technical publications and papers and is related to the technical field of airport engineering. Similarly, due to the need to regulate and standardize air traffic rules and airport planning, the International Civil Aviation Organization (ICAO) was created in 1947. Its aviation and airport standards and recommendations are required by global aviation authorities.

On the other hand, the concept of sustainable development was defined, in 1987, by the Brundtland Commission Report, as “the type of development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainable development shapes a different way of thinking about the future, according to which society, the economy, and the environment are taken into account and are in harmony, aiming to achieve a high level of quality of life [1].

This paper summarizes the current state of the behavior and evolution of airport energy uses, focusing on their sustainable development.

The review is divided into six (6) sections.

The next section refers to the methodology followed.

The third section refers to the literature review regarding energy and airports.

The fourth section includes the results of the review and discussion on airports’ environmental and energy management.

The fifth section includes proposals for the environmental and energy management of airports.

Finally, the sixth section includes the conclusions of the present paper.

Useful information is presented, such as a review with the description of the main energy sources and consumers, the implementation of energy-saving and energy-efficiency measures in airports, and the establishment of energy indicators and benchmarking between airports, as well as energy modeling and simulation.

2 Methodology

In this paper, there will be a presentation of the types of energy that exist and are used, of alternative forms of energy, and examples of airports that use such forms of energy and how they respond.

Airport facilities will also be compared in terms of their categories, sizes, energy consumption, carbon dioxide (CO₂) emissions, number of services, and passenger comfort. We will try to quote quantitative data and figures to make an assessment of the importance of sustainable development, both in a theoretical and a research context, in order to show the importance of sustainable development in general, but also, in particular, in the case of airports.

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The main research questions investigated are the following:

- the types and categories of sustainable and energy planning models of airports,
- airport profiles,
- airport sizes,
- passenger services,
- number of aircraft movements,
- energy consumption and CO₂ emissions, and
- types of alternative energy forms and their application in airports.

The main part of the research was conducted by the first author [2] under the supervision of the other authors, with further elaboration of the findings based on literature [3-11]. This is a review paper; therefore, the methodological approach was based on a comprehensive literature review.

3 Energy and airports

Renewable Energy Sources (RES) are energy sources that are considered practically inexhaustible and exist in abundance in the natural environment. It is the first form of energy that man used before turning to the use of fossil fuels. Their use does not pollute the environment; however, their exploitation is limited by developing economically acceptable and reliable technologies to capture their potential [2].

The interest in developing RES technologies first appeared after the first oil crisis in 1974 and was consolidated after the awareness of the serious environmental problems observed worldwide in recent years [2].

For many countries, RES are domestic energy sources with positive prospects of contributing to their energy balance, reducing dependence on imported oil, and strengthening the security of their energy supply. In addition, they contribute to improving the quality of the environment since it has now been established that the energy sector is primarily responsible for environmental pollution. It is indicative that the only possible way for the European Union (EU) to meet the ambitious goal set in 1992 at the Rio Conference on Environment and Development, namely, to limit CO₂ emissions in the world by the year 2000 at the levels of 1993, is to accelerate the development of RES. The main forms of renewable energy are solar, wind, hydro, geothermal, biomass or chemical, and wave energy [2].

The development of aviation has a huge effect on the economy and development of a country. Some sectors positively impacted by aviation are land transportation, tourism, accommodation and catering, entertainment, financial services, Information Technology (IT) services, and retail. At the same time, however, the construction and operation of an airport burden the environment in many ways. Some of the problems they cause are noise pollution, air pollution, the change in climatic conditions in the area, etc. [2].

A wide range of aviation operations and services burdens or impacts the environment, such as:

- the operation of aircraft,

- the operation of airport vehicles and passenger vehicles,
- the operation of airport Ground Service Equipment (GSE),
- the cleaning and maintenance of aircraft, GSEs, and vehicles,
- the de-icing and anti-icing procedures of aircraft and runways,
- the fueling of aircraft and vehicles and the storage of fuel, and
- the maintenance and operation procedures of airport facilities and construction work are also harmful factors, which are combined with the construction of airports or their expansion [2].

Primary energy consumption and CO₂ emissions have increased by 50% worldwide in the last two decades. Currently, despite uncertainty about short- and medium-term economic growth prospects, forecasts show that global energy demand will surge by a third over the period 2015-2040. This rapid increase in energy consumption is likely to have significant environmental impacts in the near future and may even cause supply problems in some areas [3].

Regarding services, airports can resemble small towns due to their particular characteristics. They serve as hubs for local, national, and global transportation and facilitate the establishment of businesses and trade. In 2014, the Airports Council International (ACI) already had 400 airport members [3].

The ACI Europe facilitated the transport of 1,800 million people and 18.4 million tons of cargo, using 1.8 million air flights. Regarding economic impact, European airports directly employ over 12.3 million people, representing 4.1% of the European Gross Domestic Product (GDP). To operate, airports must consume large amounts of natural resources, the most important of which is electricity. A key factor in order to reduce energy consumption in airports is understanding energy consumption behavior due to the multiple parameters and specificities involved. Therefore, airports are excellent candidates for energy research [3].

From an operational point of view, it is common to divide an airport into two main areas of activity: the landscape and the airport [3].

In the landscape, the passenger is the main customer. This means that all activities carried out in this area are aimed at satisfying their needs; most importantly, the activities related to the circulation, processing, organization, and control of the flow of passengers, baggage, and cargo in the terminal buildings, the means to facilitate this flow and the various means of land transport to access the terminal. Within the area, several facilities are common to all airports, such as the terminal building, the cargo terminal, and the car parking [3].

At the airport, the aircraft, and everything related to it, is the main customer. Aircraft operations are among the main processes (landing and take-off of aircraft and guidance on the apron), together with the organization and control of all the facilities involved [3].

Inside the airport are some buildings and facilities common to all airports for air traffic operations, such as the control tower, airport lighting, radio navigation

systems, firefighting buildings, hangers, and weather assessing facilities [3].

4 Results and discussion

4.1 General results

The purpose of this paper is to identify and present the environmental problems from the operation of civil airports. Then, the presentation of solutions to address them is sought through the presentation of methods applied to standard airports.

The methodology followed includes the investigation of the historical development of environmental protection and airports, the analysis and research of concepts such as sustainability, development, environment, energy, and RES. Finally, a sample report of airport models and types, research, and study of airport models, and reporting on the importance of implementing new models for a sustainable future are made, and the most important conclusions are drawn at the end of the paper.

The need for more research in this sector is due to the reduction of energy reserves, the increase in energy costs, climate change, new energy regulations and fines, the increase in the passenger public, the increase in flights and airports, and the need for new airports. Therefore, knowing the benefits and impacts of a transition from simple economic development to sustainable development in the economy and the environment is essential. The cycle is around society, the economy, and the environment, and it repeats itself. The concept of sustainable development is found in daily human life. It concerns the quality of life, the environment they live in, the energy reserves and natural resources they consume, and respect for the environment. In this context, this paper contributes to knowledge and information in the field of environmental and energy management of airports, reflecting the current trends and perspectives.

In light of the current forecast for air traffic growth, airports need to increase their capacity and reduce their environmental impact – particularly by improving energy efficiency and implementing integrated energy and environmental management towards sustainable development.

To date, airports have managed their energy efficiency levels in several ways. For example, more than 100 airports have installed solar panels, invested in green building designs that save energy, and started using more efficient lighting, air conditioning systems, etc. The first step in addressing airports' energy efficiency level is determining their energy consumption [4].

The Airport Carbon Emissions Reporting Tool (ACERT), developed in 2009 by ACI in collaboration with Transport Canada, is free and helps airports to record their energy consumption and related carbon emissions. Once their emissions are reported, airports are better equipped to plan for reductions and alternative energy use and to document their energy efficiency

improvement. The ACERT tool can be used by both experts and non-experts [4].

Also, ACI's Airport Greenhouse Gas Manual helps airports address their emissions related to energy use [4].

Other indicative international airport initiatives related to energy conservation and management include the ACI Asia-Pacific Green Airports Recognition program, which had the issue of "energy management" as its 2017 theme and documented some significant advances and practices [4].

For example, Kuala Lumpur International Airport was recognized for implementing a solar PhotoVoltaic (PV) system as part of the airport's Carbon Management Plan (CMP), which reduced its reliance on the grid by 7% per year or 18,638 MWh, and 13,811 tons of CO₂ per year. Darwin International Airport was also recognized for the development of the world's largest solar PV plant, a 5.5 MWh installation [4].

In North America, many airports have implemented renewable energy projects, and Miami International Airport recently won the ACI-North America (ACI-NA) Environmental Management Award for a project that will save the airport over 35 million KW of electricity per year and \$40 million in utility costs over the next 14 years [4].

Other inspiring landmark projects include the "Galapagos Ecological Airport" and Cochin International Airport, which has become the world's first fully solar-powered airport and expects to save 300,000 tons of CO₂ over the next 25 years - the equivalent of planting three (3) million trees [4].

Other initiatives to reduce energy consumption have also been successfully implemented. For example, those recognized by Leadership in Energy and Environmental Design (LEED) certification for improving the efficiency of buildings and businesses have certified airports such as San Francisco International (Terminal 2), Boston Logan (Terminal A), and the Hartsfield-Jackson Atlanta (International Terminal) [4].

Airports also participate in renewable energy projects that reduce CO₂ emissions from the aircraft to the gate. In this regard, ICAO is working with selected airports to implement the "solar-to-gate" project that uses solar energy to power the aircraft at the gate, replacing the use of the auxiliary power unit [4].

4.2 Environmental management discussion

Airports, with the facilities and services they provide, are considered one of the most important infrastructures required for the regular operation of aviation. Airports contribute significantly to the local economy and employment.

However, along with the socio-economic benefits they offer, environmental costs and impacts are integral results of their operation. With increasing passenger (Fig. 1) and cargo (Fig. 2) air transport demand, the aviation industry is expected to grow further, and this means more incentives and driving forces to build new airports or expand existing ones, and this will intensify

the importance and complexity of environmental and sustainable development [5].

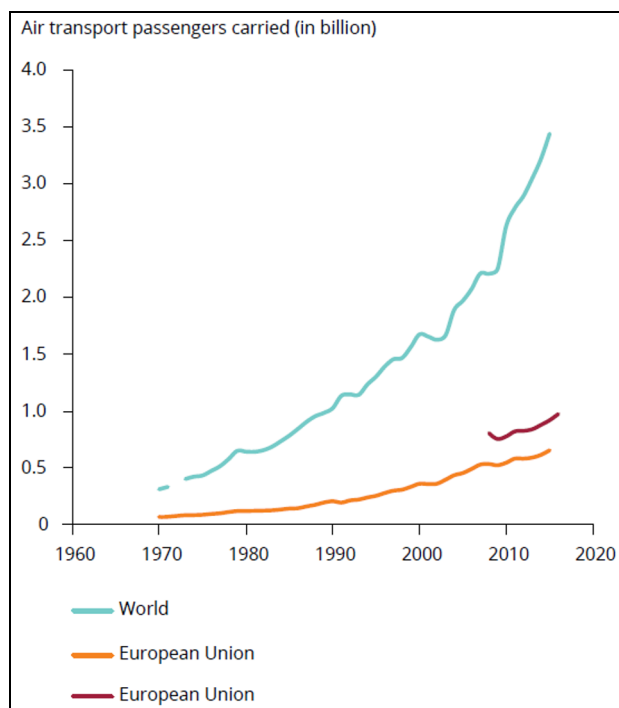


Fig. 1. Air transport passengers carried (in billion) [5].

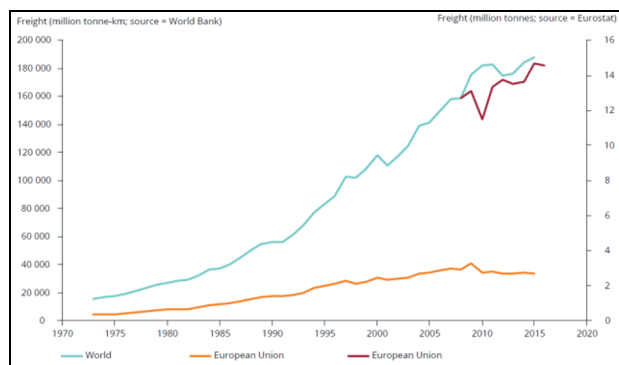


Fig. 2. Air transport freight (in million tonne-km [left] and million tonnes [right]) [5].

In Europe, the need to encourage a more sustainable policy is now well-documented and recognized. The High Level Group report on Networks for Peace and Development devotes only three paragraphs to the “environmental dimension,” which is treated in the most general terms. The Group emphasizes “The need to pay particular attention to environmental sustainability at the project definition and analysis stage, as well as when implementing the horizontal priorities” [2].

Recently, ACI Europe has committed to a landmark environmental resolution to indicate further how they wish to mitigate the effects of climate change. Also, the sustainability of air transport in tourist destinations is discussed by many researchers, where the role of Strategic Environmental Assessment (SEA) in the future development of airports is recognized as critical [5].

On a global scale, GreenHouse Gases (GHG) (CO₂, NO_x, and water vapor) are emitted from aircraft engines

into the atmosphere and also from various airport activities and contribute significantly to global warming and climate change (Fig. 3) [5].

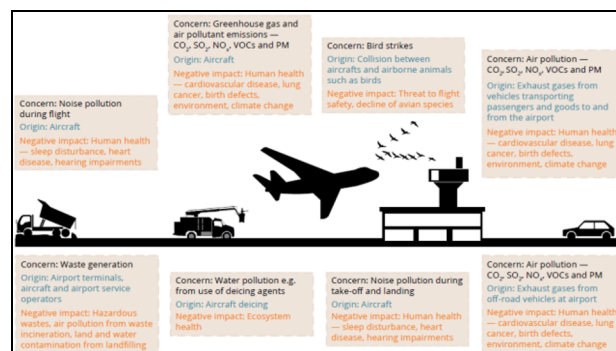


Fig. 3. Examples of environmental pressures from aviation activities [5].

Globally, aviation appears to be one of the fastest-growing sources of CO₂ emissions, and recent studies have shown that its overall impact on the climate is greater than suggested, amounting to around 4.7% of total anthropogenic climate change[5].

At a local level, the noise level at airports is the main limit to their expansion, particularly at regional airports. Noise appears to be one of the major causes of community backlash regarding airport operations. It has been recognized that the aviation industry will grow sustainably if it can meet increasing demand while at the same time limiting or reducing the number of people exposed to high levels of aircraft noise nuisance. It is worth noting that a recent survey of European airports showed that around two-thirds have restrictions on emitted noise and that this figure could increase to 80% in the next 5-10 years [4].

In addition, airports disrupt the environment in many other ways, such as the consumption of natural resources, land use, and impacts on biodiversity, microclimates, and nearby natural ecosystems, which may experience significant changes due to their operations [4].

Air transport moves more people and produces less pollution per passenger compared to other modes of transportation. Furthermore, considering the distances that aircraft travel to transport a large number of passengers within a short period of time, then the efficiency of air transport is relatively high [2].

Air transport has made significant efforts for several decades to minimize its environmental impact, and achieving high efficiency is essentially the only goal. Air transport has notably set targets for a neutral increase in CO₂ emissions from 2020 and a 50% reduction by 2050. Modern aircraft are considered to be 70% more fuel efficient than some 40 years ago, while research projects aimed to achieve a further fuel saving of 50% by 2020. In addition, proper air traffic management and other operational improvements, such as landside traffic management, have the potential to reduce fuel consumption from 8% to 18% [2].

The use of modern communication, navigation, surveillance, and air traffic management systems and

improved infrastructure will allow companies to travel safer, quieter, and shorter distances and thus reduce fuel consumption [2].

Many international airports have succeeded in their environmental efforts by organizing an environmental strategy, strict environmental controls, and strong awareness programs. By having a new and modern fleet, implementing all required maintenance procedures, systematically training their crews, and implementing effective operational practices, they can and do play an important role in the overall effort to reduce human environmental impacts [2].

4.3 Energy management discussion

Airports, in general, have high energy consumption. Influenced by many factors, the characteristics of airport energy consumption are stochastic, non-linear, and dynamic. In scientific research, energy consumption is mainly focused on terminal buildings, although they are only part of the airport as a whole, so a greater depth into all the aspects that affect the energy efficiency of airports is promising in the field of research.

The main energy consumers at airports can be divided between the airport and the airport area (Fig. 44). Airport energy consumers are primarily airport lighting and radio navigation systems. The consumers of energy savings are the airport building due to its function as a passenger and cargo processing hub and the large number of facilities required to operate it. Heating, Ventilation, and Air Conditioning (HVAC), lighting, and Information and Communication Technology (ICT) systems are usually the major energy consumers of airports, so it is important to research new methods to achieve a reduction in energy consumption in this type of facility [3].



Fig. 4. Scheme of main airport areas [3].

Electricity is the dominant energy source because it is necessary to supply the airport's energy consumption and to ensure the safety of air traffic operations. This electricity usually comes from the commercial, public grid and is supplied by an electricity company. However, it has been possible to find other types of energy sources in scientific literature and airports, such as Combined Heat and Power (CHP) plants or renewable energy technologies in recent years [3].

Nevertheless, due to their particular characteristics and the effect on air traffic safety, it is necessary to set rules that will make airports compatible with these types

of energy sources. Reducing energy consumption is a priority for airport managers today [3].

More importantly, the measures can be classified into the following categories:

- improvements in management systems and energy facilities,
- improvements in HVAC and lighting systems and new operational management, and
- systems that contribute to improving and optimizing the energy efficiency of airports [3].

Likewise, modeling and simulating airport energy consumption can be an important factor in reducing consumption. Therefore, the development of more accurate methods for the airport environment must focus on airports holistically and not only on the terminal building [3].

Finally, the use of Environmental Performance Index (EPI) indicators provides energy managers with information about energy but does not provide information about the reasons for good or poor energy consumption, and they cannot be used directly for benchmarking with other airports due to the different conditions and factors involved. It is necessary to develop new specific benchmarking methods for airports, which will take into account their characteristics and make them comparable to each other [3].

A considerable effort is being made to reduce the airport's energy consumption and carbon footprint. The analysis of the data showed different ways of achieving this, depending on location, climate, and organizational parameters. The main lesson learned is that airports are a whole world by themselves, but at the same time, they need to benefit from their environment as well as influence it.

5 Proposals

5.1 Environmental management proposals

Airport operations are usually accompanied by economic and social benefits for airport operators as well as for the local community and society. With the development of airports, these benefits increase. However, the increase in the environmental burden of airport development remains an issue that needs to be addressed. On the other hand, limiting airport development through environmental caps and quotas can lead to fewer benefits for the communities and society. When such conflicting interests arise, the decision to build or expand airports is a trade-off between the positive and negative effects of such a decision on local communities and society as a whole.

In this scenario, the role of government and its initiatives to adequately address sustainability issues is highlighted. When discussing the concept of sustainability, all three factors should be considered: economic, social, and environmental sustainability. Aviation-related issues are no exception.

The critical role of a particular airport in a nation's economy is extremely important and must be considered

when deciding on airport operations and expansion plans.

Along with efforts to minimize the adverse impacts that airport operations can have on development, it is also important that airports develop strategies that seek to maximize social and economic benefits. Airport development is encouraged for its economic and social benefits, but such development must be green and sustainable, in which increasing airport operational capacity will not increase the cost of environmental burdens.

Airport sustainability means considering all social, economic, and environmental factors and developing an efficient and sustainable approach. Achieving a desirable balance is possible through careful studies that help decide how to define airport environmental capabilities and constraints, while all environmental, as well as social, and economic parameters must be considered.

The active participation of local communities must be part of the process of creating and maintaining a sustainable air transport system, of which the airport is an important part. This is achieved by involving citizens in all stages of the development and implementation of plans required for the effective environmental management of airports. In other words, communities, especially local communities, must be heard [5].

Finally, public policy initiatives by policymakers should be taken in such a way as to encourage airport operators to actively seek sustainable practices. At the same time, airport regulators and operators need to design and select operational processes and support advanced technologies to achieve sustainability objectives based on the specific characteristics of a given airport in order to ensure the socio-economic feasibility and effectiveness of these processes. By proactively examining airport sustainability issues, ICAO can provide national and local authorities with practical, effective, and comprehensive guidance for establishing appropriate regulations [5].

The environmental actions of the airports presented in this paper are a typical case of the efforts of the airports to integrate their operation into the environmental and urban fabric harmoniously. Therefore, with appropriate programs and policies, the airports can become environmentally sustainable and accepted by the local, mainly, society. In this frame, the airports could learn a lot from other passenger and freight transportation terminals, especially seaports, which have a vast experience in environmental management and sustainable development issues [7-8].

5.2 Energy management proposals

Energy efficiency in airports is an issue that has evolved with the increase in the use of RES and new technologies that present both opportunities and challenges, especially considering the increasing demand for more capacity and transport efficiency.

New airport infrastructure, intended for long-term use, should be planned well in advance and include energy efficiency concepts. Similarly, airport energy

efficiency should also be addressed through better use of existing terminals and runways [9-10].

Increased engagement with third parties, such as airlines and ground transport, is the natural next step for airport operators seeking to reduce their own energy consumption and influence their partners to reduce theirs [11].

6 Conclusions and proposals for further research

The expanding demand for air transport services, especially with the rapid growth of low-budget airlines, underlines the necessity of sustainable design of airports.

In this paper, an attempt has been made to review the existing practices towards sustainable development of airports, contributing, thus, to this goal.

The focus of the research was on energy sustainability as well as the environmental sustainability of airports. Many good practices have been identified worldwide, and proposals have been formulated. The exchange of good practices among airports worldwide, as well as from other passenger and freight transportation terminals, e.g., ports, will have a leveraging effect towards integrated energy and environmental management of airports.

As air transportation increases rapidly, a trend that will not decrease in the foreseen future, integrated energy and environmental management of airports in order to achieve sustainable development is essential nowadays and further research should take place.

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