Developing a Sustainable Rating System for Airports Airsides

MSc Thesis

November 2023

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NACO a company of Royal HaskoningDHV

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Master of Science

in Transport, Infrastructure and Logistics

at Delft University of Technology

by

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Graduation period: April 2023 – November 2023

An electronic version of this thesis is available at http://repository.tudelft.nl/

PREFACE

My interest in aviation has been present since my earliest memories, greatly influenced by my uncle who is a pilot for Aerolíneas Argentinas. As soon as I turned 16 years old, I ask permission to my parents to begin the course for the private pilot's license, which I finished even before finishing high school at the age of 17. Since then, I continued flying as a hobby while simultaneously commencing my career in Civil Engineering in Córdoba, Argentina. I had the opportunity to participate in a double-degree program with the Politecnico di Torino, in Italy, where I obtained my first Master of Science (MSc) in Civil Engineering with a specialization in Transport and Infrastructures. It was during this program that I realized that I discovered my field within Civil Engineering, and I decided to develop myself further in this field in a renowned university as it is Delft University of Technology, where I enrolled in the MSc program in Transport, Infrastructures and Logistics. Once here, during a guest lecture in the Airport Operations course, I got to know Netherlands Airports Consultants (NACO). I found this company to be the perfect intersection of my career and hobby. Hence, without hesitation I applied for a part-time position, where I am currently employed. This job significantly contributed to my general knowledge on different aspects of airports during my thesis. This report is the final product of my master's thesis research, which I completed as the final evaluation of my academic program.

Several people provided me great support during the entire research, and I would like to express my gratitude to them. First, I would like to thank all the interviewees who generously shared their time and knowledge, making significant contributions to this research. Then, I would like to thank my committee. Starting with Paul Roling; I would like to thank him for sharing his extensive knowledge on airports and aviation industry with me. Then, John Baggen, I am grateful for his supervision during the entire thesis with bi-weekly meetings, keeping me focused and motivated. My gratitude also goes to Bert van Wee, chair of the committee, for his thorough review and critical perspective on my thesis.

Also, I am thankful to Melissa Powys, who provided me the opportunity to join the Civil Engineering team at NACO as a part-timer and graduating on this topic. Moreover, I would like to express my gratitude to all my colleagues at NACO who made me feel like a part of the team. Special thanks go to Peter Vorage, my supervisor at NACO, for sharing his extensive knowledge on airports and civil engineering, as well as for his valuable contributions to this thesis with critical thoughts, which significantly improved the research outcome.

Of course, I want to thank my friends, who were always supporting me and keeping me motivated. I would also like to thank my football team and friends from the Monday league, with whom I always enjoyed fun games and beers. Furthermore, my heartfelt thanks go out to my mom, dad, brothers, and all my family who have always trusted in me, with the utmost confidence. Finally, the most special thanks to Manuela for her love and unwavering support throughout my entire master's program and during the completion of this thesis.

Tomás Erich Tisberger Ibañez

Delft, November 2023

SUMMARY

Introduction

This research is about sustainable rating systems on airports, more specifically, on airport's airsides. This thesis is a response to the need and lack of guidance on how to make the airport's airsides more sustainable, given that the existing rating systems are mostly focused on buildings, which translated to airports means the terminal building. The need for them, is to make the aviation industry more sustainable to be able to tackle climate change, given that the sector is responsible for a 3.5% of climate change (Kiest, 2020), and for a 2% of global carbon dioxide (**CO_2**) emissions, and if no change is made, this share is predicted to increase to 20% in 2050 (NACO Aviation Academy, 2023a; Pachauri et al., 2015). Although **CO_2** emissions are a great contributor to greenhouse gas (**GHG**) emissions, these are not the only environmental impact from the aviation industry on climate change. Other important ones that can be mentioned are the conservation of biodiversity, water consumption, waste management, the treatment of water effluents, and health effects to workers in airsides, such as nitrogen oxides (**NOx**) emissions and particulate matter (**PM**) (among others), mainly due to jet engine and Ground Support Equipment (**GSE**) emissions (Bendtsen et al., 2021; NACO Aviation Academy, 2023a). Therefore, a sustainable rating system can help tackling these environmental impacts by triggering and guiding project teams using this tool through different indicators, to find more sustainable measures to their airsides. Hence, this master thesis studies the development of a specific sustainable rating system for airport airsides, where the main focus is the environmental pillar from sustainability, and the whole system is developed from an infrastructural perspective. Therefore, the main research question of this research is:

How should a rating system be given form in such a way that it can be used for assessing the environmental impacts of airports airsides from an infrastructural perspective?

Methodology - Structure

This master thesis is divided into six phases (phase zero, plus five phases). The aim of phase zero is to collect and provide background information of environmental concerns in airports and sustainable rating systems, to understand and use these studies as guides. In Phase I, the goal is to understand and analyze the stakeholders that would be involved in a sustainable rating system for airsides. Then, in Phase II, the goal is to define the boundaries (spatial, component and functional) that the rating system developed in this thesis will evaluate. In Phase III, is where the main design stage of this thesis begins, and its goals is defining the indicators, with their weights and levels of certification, that this rating system will encompass to tackle the different environmental impacts defined from the component and functional boundaries. In Phase IV, the goal is to define the metrics of each credit, meaning how each credit is assessed against a project and recommending best practices. Finally, in Phase V, the aim is to validate the developed rating system in this thesis with the feedback from experts within Netherlands Airport Consultants (**NACO**) (company where this thesis is developed).

Phase zero. Literature Review.

In this phase, an extensive literature review was performed. The main output of this phase was understanding the main environmental impacts globally and within the aviation industry, exploring the

currently tools used in the world of airports to tackle these impacts and, more specifically, studying and understanding the tool called sustainable rating systems, which is the objective of this thesis. The main environmental concern globally nowadays is climate change (European Parliament, 2023), and the aviation industry has a contribution to this effect (2% of global **CO_2** emissions) (NACO Aviation Academy, 2023a). Not only the **CO_2** emissions play a role on climate change from the aviation industry, but also other impacts as those already mentioned in the introduction of this current summary. Sustainability is thus, a word that gained focus in the last decades (Hubbard & Hubbard, 2019). Different tools are being developed specifically for airports to tackle these environmental impacts and sustainability in general (with its three pillars, namely environmental, social and economic), and the most important for this thesis, are those state-of-the-art methodologies called sustainable rating systems. With these tools is possible to identify, quantify and minimize operation and constructional environmental impacts which are not yet covered by other standards (Gómez Comendador et al., 2019; Greer et al., 2020), via different indicators. A theory on the impact of design characteristics of a rating system on these indicators was also further studied and provided, where the indicators of the rating systems are influenced directly or indirectly by different parameters as the type of product, problem owner, region, time, scope and data. The rating systems most known nowadays are the ones called **LEED** - Leadership in Energy and Environmental Design and **BREEAM** - Building Research Establishment´s Environmental Assessment Method (mainly focused in buildings) (Bocchini et al., 2014), and therefore were further analyzed for the use as a guide for this thesis. Moreover, a third important rating system was added to the analysis, which is called Envision, because this tool is on early phases but is more focused in infrastructures rather than in buildings as the other two. The structure and point allocation from their indicators were described.

Phase I. Context Analysis

Since there are several stakeholders related to the development of a sustainable rating system for airports airsides, an analysis of them was performed. The output of this phase was recognizing main and secondary stakeholders, and then arranging them in a power-interest grid. It was noted that those stakeholders with more interest are those more related to the airports infrastructures in their day-to-day task, as Airport Operators (**AO**s), Airport Council International (**ACI**), staff on airside, airlines, governmental bodies, service providers (airport consultants and **GSE** providers) and local communities. However, each of them defends different interests. Also, it was noted that the stakeholders with more power are those more related to policy involvement as aviation regulators, governmental bodies, **AO**s and **ACI**.

Phase II. Boundaries.

Before going to the development of the rating system itself is first important to define the boundaries that this system will evaluate. Therefore, in this phase three types of boundaries were defined for this thesis, namely spatial boundaries, component boundaries and functional boundaries.

- Spatial Boundaries: with this type of boundaries the objective was to define the physical space within which the rating system developed in this thesis operates. In this case, is the airside of airports, which according to OTA (1984) is the area where an aircraft operates. This mainly englobes the runways (**RWY**s), taxiways (**TWY**s), the apron and gate areas.

- Component Boundaries: with this type of boundaries the objective was to define those elements from the airside that are considered part of the rating system. These elements were defined based on their relationship to infrastructures and contribution to environmental impacts. The elements in this thesis are part of different disciplines and activities. Those disciplines and activities (with its elements) that were found relevant to consider in this thesis are: pavements structures (**RWY**s, **TWY**s, aprons and service roads), drainage systems (pipes, culverts, channels, ditches, Oil-Water Separators (**OWS**s), drains, ponds and storage of water), visual aids (Airfield Ground Lighting (**AGL**)), miscellaneous elements (infrastructure for alternative power sources), aircraft movements (taxiing) and different **GSE**.

- Functional boundaries: with this type of boundaries the objective was to define those functions or processes that this rating system encompasses for each element, from a planning and design perspective. The functions or processes to be considered were defined based on the environmental impact of the life cycle of each element. Therefore, for pavements and drainage system, the whole life cycle is included in this rating system. For all the rest of elements (**AGL**, infrastructure for alternative power sources, taxiing movements and **GSE**), just the operation phase is included.

Phase III. Structuring & Weighting.

This phase is the main phase where the design of the specific rating system happens. In this, indicators were defined (called credit categories and credits) to provide the structure of the rating system. Moreover, the weight allocation and possible levels of certification were provided in this phase.

The credit categories and credits were defined in a process which involved mainly desk research. First, the credit categories were defined based on the Sustainable Development Goals (**SDG**s) that were defined in the Agenda 2030 (United Nations, 2015), and the link between them and airports, considering the boundaries of this thesis and the environmental pillar of sustainability. Those relevant goals that provided categories for this thesis are number 6 (clean water and sanitation), 7 (affordable and clean energy), 12 (responsible consumption and production), 13 (climate action), 14 (life below water) and 15 (life on land). These were then transformed into categories accordingly, while two more categories were added to consider the managerial and innovative perspective from an airport's airside. The eight categories obtained can be seen in Figure 0-1 under number 1 – Credit Categories.

Then, credits were defined for each credit category based also on an intensive desk research, using as a guide different existing rating systems for buildings, airports and infrastructures. Those studies used were the ones described in Phase zero and other relevant ones found when executing extra research. A total of ten studies were used. From them, the relevant credits according to the boundaries of this thesis were extracted from the literature and grouped to form the credits of this thesis. A total of twenty-two credits were created. The defined credits together with their categories, depicting the structure of the rating system can be seen in Figure 0-1, under number 2 – Credits per category and Weights (W).

After defining credit categories and credits, the weight for them was defined. For this, also desk research was executed, where the studies used were the same as those for defining the credits, except for two studies that were not providing any information in weights. Hence, a total of eight studies were used to define the weights. With them, values from each of the relevant credits per author were extracted, and an average was used to allocate the corresponding weight to those credits developed for this thesis. To see the final weight allocation please see Figure 0-1, under number 2 – Credits per category and Weights (W).

Finally, after defining the weights, the possible levels of certification that can be obtained with the developed rating system were set. For this, a similar process as that one done for weight allocation was conducted, where different authors were reviewed, and the mainstream was followed. In this case the rating systems used were four. It was discovered that a common ground for levels of certification was followed in those studies and thus, this thesis followed the same path, with approval from the rating system expert (ninth expert in Table C-1). To see the different levels of certification please refer to Figure 0-1, under number 4 – Levels of Certification.

At this point is also important to highlight that the developed rating system was given the name of ''Airport Rating System'' (**ARS**), with the slogan of *''Airports of Tomorrow''.* This slogan was defined to reflect the intent of this master thesis on contributing to the future of the aviation industry from a sustainability point of view.

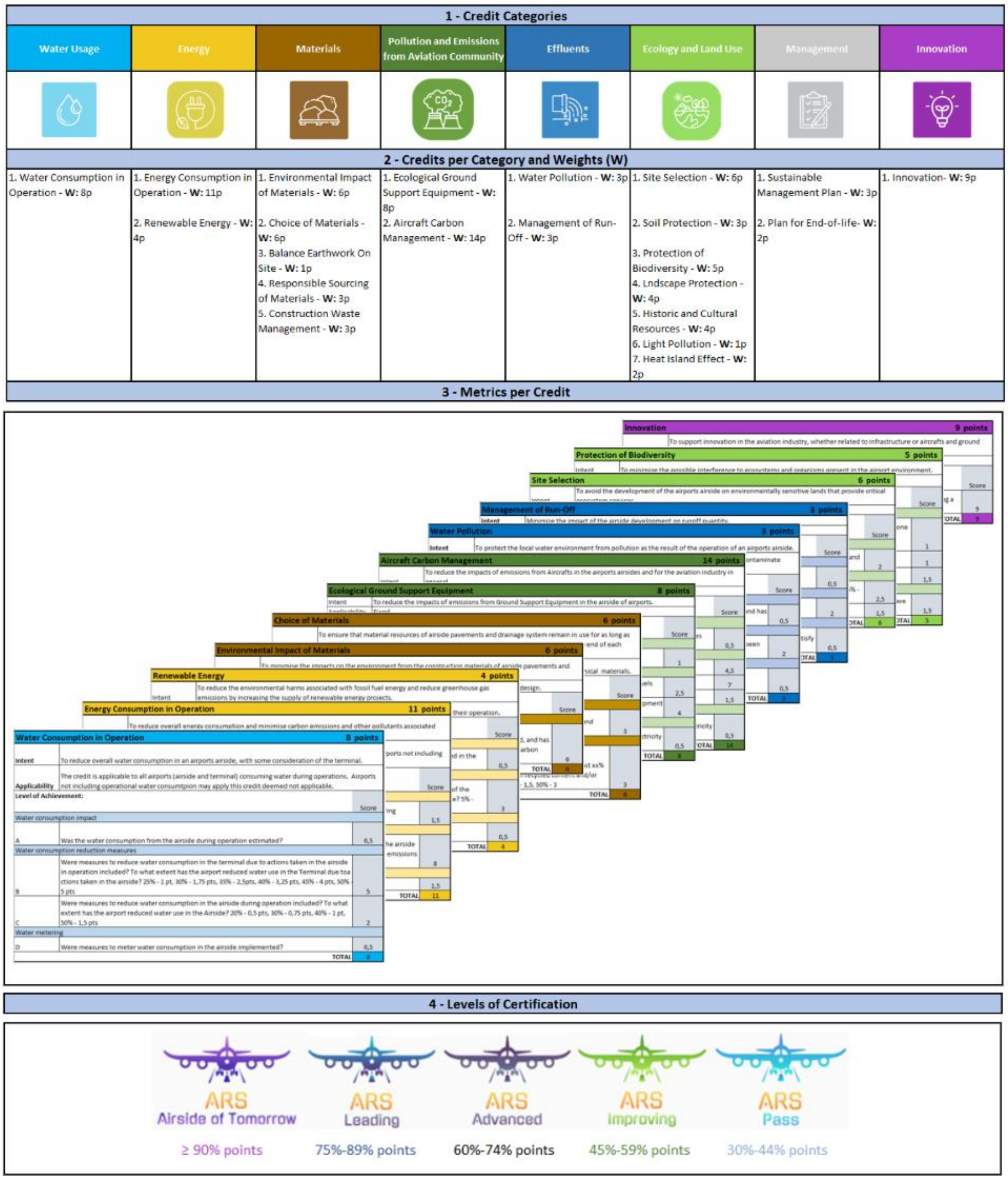

Figure 0-1. Summary of the developed rating system in this master thesis.

Phase IV. Metrics & Best Practices.

In phase V is where the metrics and best practices for the different credits are defined. But first, it's important to mention that this was done for those assigned as ''main credits'', which were decided according to a process based on their weights. Those credits referred to as main credits are the ones called: ''Water Consumption in Operation'', ''Energy Consumption in Operation'', ''Environmental Impact of Materials'', ''Choice of Materials'', ''Ecological Ground Support Equipment'', ''Aircraft Carbon Management'', ''Site Selection'', ''Protection of Biodiversity'' and ''Innovation''. Added to these credits, also three more credits were considered relevant to be analyzed for the objective of this thesis which are the ones called: ''Renewable Energy'', ''Water Pollution'' and ''Management of Run-Off''. In this way, a total of twelve credits were assigned metrics. This means that 55% of the credits are given metrics in this thesis.

The metrics of the main credits were assigned based on desk research where different existing rating systems for buildings, infrastructures and airports were used as a guide and source of point allocation. The studies used were the same as those for weight allocation, which are a total of eight studies. To start with the assignment of metrics, from the twelve credits, six of them were defined as ''continuous'', five of them as ''fixed'', and the last one (the Innovation credit) does not belong to any of the two categories. For all of them, the ''intent'', ''applicability'' and ''level of achievement'' was defined. The ''Intent'' refers to the objective of the credit, the ''Applicability'' refers to the condition of when to apply each credit, and the ''Level of Achievement'' is the set of questions defined to assess the projects against the credits. For those credits defined as ''continuous'' (meaning the ones that their effect considered in the design phase of the airside can vary after the airport airside is already in operation), three types of assessment questions were prepared: one question related to the current situation that they are designing for, one question related to what can be done to improve the current situation that they are designing for, and a last question related to the monitoring of their designs. On the other hand, for those credits defined as ''fixed'' (meaning that are a one-time decision that will not vary after the airport airside is in operation), different type of questions were defined depending on the credit, without any special logic, but more related to their impact. In order to come up with the questions, it was highly relevant to consider the impacts for each element defined in the component and functional boundaries. Finally, the ''Innovation'' credit was not given metrics given that this credit aims to incentivize teams to think of solutions that were not considered in any other credit and that can help sustainability in airports airsides. All the credits in a summarized way (due to space restrictions for this summary) can be seen in Figure 0-1, under number 3 – Metrics per Credit. For a more in-depth detail of the metrics please refer to section 7.2.1.

On the other hand, to recommend best practices for the different credits of the rating system developed in this thesis, literature research was conducted on current practices in different airports in the world. Moreover, experts at **NACO** were consulted for recommendations in each of the disciplines. To see the best practices for each credit in detail please refer to section 7.3 (due to space restrictions these cannot be included here).

Phase V. Validation.

In this last phase is where the validation of **ARS** was executed. To do this, a workshop was organized in **NACO** with the corresponding experts from each of the fields touched upon on this thesis (this means pavements, **AGL**, drainage, layout and design in general). In this workshop, a case study was applied followed by a round of feedback from the experts. The case study was the ''Aeropuerto Internacional Del Pacífico'', in La Unión, El Salvador, which was designed by **NACO** during the years

2022 and 2023. This airport was selected given that contains a simple and small airside, which is thought as a good approach for the validation of the rating system developed in this thesis. In the workshop, first a presentation of the objective of the thesis was given to familiarize the participants, and then, every main credit was analyzed one by one, answering to the assigned metrics, and finally obtaining a level of certification for its airside. The points obtained by El Salvador airport was equal to 25.5 out of 74 (34%), hence, a ''Pass'' level of certification was obtained. The experts sustained that the level achieved by El Salvador was as expected, recognizing a considerable space for improvement, and therefore, it can be said that the tool performed correctly.

Also, the experts defined the tool as a useful guidance framework that can be further developed, and definitely a good way to improve the environmental friendliness of their projects and airsides in general. Furthermore, one important comment was that **ARS** could make that sustainability as a word becomes tangible when designing airsides, applying it on a systematic way on every project.

Finally, also the experts were critics towards the ''Ecological Ground Support Equipment'' and ''Aircraft Carbon Management'' credits, where one question in each of them was defined as a binary choice while actually it should be studied further to give a percentage to scale it. This is something relevant and for further research. However, overall, the tool was well received and recognized as a useful tool with a real opportunity to continue developing it inside **NACO**.

Conclusion

The outcome from this thesis answers the main research question, by developing a rating system that can tackle environmental impacts from airports airsides from an infrastructural point of view. **ARS** was structured with credit categories and credits, while also assigning them weights, metrics, possible levels of certification and best practices. Therefore, it can be concluded that **ARS** can be seen as a state-of-the-art methodology that could help the aviation industry tackling environmental issues with solutions applied on airsides. This is due to the structure that it contains, which is sort of a checklist that can be used in a systematic way. With **ARS** is possible to trigger different stakeholders on thinking in a more sustainable airside and aviation industry in general.

Discussion

This study provided an outcome with academic and practical relevance. Academically, this thesis was able to bridge the gap given that there is no specific rating system for airports' airside in existence yet, and this thesis achieved one. Moreover, this thesis contributes to the academy given that it can be seen as a model to follow to create analog sustainable rating systems in different industries as a first step.

From a practical point of view, **ARS** could be useful for main stakeholders (as **ICAO**) to learn from it, and maybe push to make sustainable rating system mandatories always than an airport has to be designed. Also, **ARS** could be a useful way to make the aviation industry more environmentally friendly, where **AO**s could decide to use them in collaboration with different stakeholders, while communities around airports could get benefits from it. Last important point from practicalities, is that the image from airports could substantially change, attracting more passengers due to the provision of a more sustainable mode of transport/industry.

Finally, the outcome of this thesis can be linked to the course denominated AE4446 Airport Operations from the Aerospace Engineering Faculty, conducted by Ir. Paul Roling. Important topics from airports were studied on that course, where lectures for environment, runway design and airside were given, among others. That course was useful to get a general knowledge from the world of airports, and the civil engineering part could be further exploded in this thesis. Also, this thesis can be linked to the course denominated as SEN1741 - Innovations in Transport and Logistics from the Transport, Policy and Management Faculty, conducted by Dr. Baiba Pudane. This course is related given that the outcome of this thesis can be seen as an innovation within the aviation and construction industry, and also because one conceptual model was used to analyze the design characteristics of rating systems on indicators, which was done following the instructions from this course. Lastly this thesis can be also related to the course TIL4030-20 - TIL Research and Design Methods from the Civil Engineering Faculty, conducted by Dr. ir. Arjan van Binsbergen. The outcome of this thesis is related to this course given that some of the design methodologies studied on that course were used for this research (as the scorecard), and also a final product was designed, and in that course the objective was to design a certain product, so some steps followed are linked.

Recommendations

For this thesis two types of recommendations can be given, namely for the data and for further research. For the data, the main recommendation is that weight allocations to credits and to the questions in the metrics were based on mainstream data from different building, infrastructure and studies from airports rating systems, where a whole procedure calculating average values was followed. However, this is a limitation given that this is an expedited approach to develop a whole rating system, but due to the time constraints, it was considered adequate. These kinds of systems are created by entire associations, where they develop and update continuously the versions of their rating systems, which takes years. Nevertheless, it is highly recommended to involve all the stakeholders mentioned in this thesis for an iterative process, complementing them with a depth research per credit, conducted by a whole team of sustainability experts on airports, for a more precise allocation of weights to credits and assessment questions. By doing this, is expected that weights could slightly variate with respect to those defined in this thesis.

For recommendations of further research, several points can be mentioned but just the main ones are mentioned in this summary. The first recommendation is to study further including the social and economic pillars from sustainability when designing a sustainable rating system for airports airsides. In this thesis just the environmental pillar was considered, while topics such as noise and air quality are also relevant for airports (Janić, 2010). The second recommendation is to include solutions also from an operational and strategical point of view, and not just from the infrastructural perspectives. By considering them, airports can get relevant benefits (ACI EUROPE, 2021). Third recommendation is to define the metrics for all the credits developed in this thesis and not just the ''main'' ones, and to apply a case study to the whole package, to analyze the performance of the entire rating system. Last main recommendation is to study further the question related to ''Ecological Ground Support Equipment'' and ''Aircraft Carbon Management'' that was defined as a binary choice, where a more precise analysis should be done to define a scale and avoid the concept of ''green washing''.

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ACRONYMS

ACA	Airport Carbon Accreditation
ACI	Airport Council International
AGL	Airfield Ground Lighting
AHP	Analytical Hierarchy Process
ALS	Approach Lighting System
AO	Airport Operators
APU	Auxiliary Power Unit
ARFF	Airport Fire Fighting
ARS	Airports Rating System
ATCT	Air Traffic Control Tower
ATM	Air Traffic Management
AUA	Queen Beatrix International Airport
AWOS	Automated Weather Observing System
BRE	Building Research Establishment
BREEAM	Building Research Establishment's Environmental Assessment Method
CAA	Civil Aviation Authority
CEEQUAL	Civil Engineering Environmental Quality Assessment and Awards Scheme
CEM	Collaborative Environmental Management
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DME	Distance Measuring Equipment
DR	Direct Rating
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
GBRS	Green Building Rating Standards
GrADE	Green Airport Design Evaluation
GDP	Gross Domestic Power
GHG	Greenhouse Gas
GPS	Global Positioning System
GPU	Ground Power Unit
GSE	Ground Support Equipment
HFCs	Hydrofluorocarbon
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICE	Institution of Civil Engineers

ILS	Instrument Landing System
IS	Infrastructure Sustainability
ISI	Institute for Sustainable Infrastructure
IWDI	Illuminated Wind Direction Indicator
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
MDG	Millennium Development Goal
MET	Meteorological
NAA	National Aviation Authority
NACO	Netherlands Airport Consultants
NAVAIDS	Navigational Aids
N_2O	Nitrous Oxide
NOx	Nitrogen Oxides
OWS	Oil-Water Separator
PCA	Pre-Conditioned Air
PFCs	Perfluorocarbon
PM	Particulate Matter
RESA	Runway End Safety Area
RPK	Revenue Passengers Kilometers
RWY	Runway
SAF	Sustainable Aviation Fuels
SDG	Sustainable Development Goal
SF_6	Sulfur Hexafluoride
SQ	Sub Question
TBL	Triple Bottom Line
TWY	Taxiway
UK	United Kingdom
UN	United Nations
US	United States
USGBC	United States Green Building Council
VOCs	Volatile Organic Compounds
VOR	Very High Frequency Omnirange Radio
WSA	Western Sydney Airport

1 INTRODUCTION

The aviation sector has shown a significant growth during the last decades all over the world; the International Air Transport Association (**IATA**) in the year 2019 measured an average yearly growth of 5.5% in Revenue Passenger Kilometers (**RPK**) and expected this growth to continue (IATA, 2019). However, due to the recent COVID-19 pandemic the industry showed a contraction in air traffic in the year 2020. Nevertheless, the industry has proven to recover and it is now forecasted to grow from 1.5 billion passengers in 2020 to 8 billion passengers in 2040 (IATA, 2022). This is not the first time that the industry recovers, several crises such as oil crises in the seventies, terrorist attack in the United States (**US**) to the World Trade Center in 2001 and SARS epidemic in 2003 are other examples that impacted the aviation industry causing a contraction in air traffic volume but after a period of time (generally several months) the industry has proven to recover (Ferrulli, 2016).

While the aviation sector is expected to continue growing, the currently available infrastructure is not enough to cope with this increase by 2030 according to Hubbard & Hubbard (2019). Hence, more airport infrastructure is needed to be developed, but at the same time several problems have arisen in the last decades with the increasing focus in sustainability. In this line, current practices for airport´s infrastructure construction and operations are not enough to achieve a sustainable development and new practices or methods should be developed to achieve a more sustainable future in the aviation sector (Hubbard & Hubbard, 2019).

This chapter provides an introduction to this master thesis. First, section 1.1 a research context is provided to introduce the reader. Second, section 1.2 provides the problem statement for the research of this thesis. Third, section 1.3 defines the research objective and scope. Fourth, section 1.4 presents the Main Research Question and the corresponding Sub Questions. Fifth, section 1.5 states the relevance of this report. Sixth, section 1.6 elaborates on the approach to the research. Lastly, section 1.7 presents the outline of this master thesis report.

1.1 Research Context

During the last decades climate change and global warming have gained popularity within the population. The rise in temperatures is due to the increasing **GHG** emissions produced by human activity, and more especially due to **CO_2** emissions (which is one of the major **GHG**) and concentration in the atmosphere (NOAA, 2023).

The aviation sector is responsible for a 3.5% of climate change (Kiest, 2020), and for 2% of the global **CO_2** emissions according to NACO Aviation Academy (2023a). From that 2%, airlines take a 94%, airports are responsible for a 2%, while other sources accounts for a 4% (NACO Aviation Academy, 2023a). If no change is made, the 2% of the global **CO_2** emissions share from the aviation industry is predicted to increase to 20% in 2050 (NACO Aviation Academy, 2023a; Pachauri et al., 2015), hence, efforts in reducing these emissions should be made.

In this master thesis the focus is on contributing tackling part of the 2% from the aviation sector, plus other environmental impacts given in airports as conservation of biodiversity and the treatment of water effluents (NACO Aviation Academy, 2023a).

From an organizational perspective, also efforts are being carried out to help the aviation industry. Particularly, the International Civil Aviation Organization (**ICAO**) is seeking and pushing for a sustainable development in airports (Ramakrishnan et al., 2022). And for this, over the past few decades, numerous standards and tools have been developed which will be mentioned later in this section.

First, it's of great importance to briefly define what sustainable development means, and this concept is defined in Bocchini et al. (2014, p.6) and Kamalam (2017, p.43) as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs".* This concept is mainly focused on three "pillars", namely the Social, Economic and Environmental ones which are known as the Triple-Bottom-Line (**TBL**) (Alabi et al., 2021). So, the **TBL** is based on the notion of achieving financial stability, minimizing environmental impacts, and aligning with the expectations of communities, employees and consumers.

Based on the concept of sustainable development, several practices and methods are being developed in the aviation industry to pursue a greener future. Some of them that can be mentioned are the Airport Carbon Accreditation (**ACA**) developed by **ACI** in 2009, Green Building Rating Standards (**GBRS**) developed by private or governmental organizations and other methodologies mainly developed by privates.

In this thesis in particular the focus is on the methodologies known as **GBRS** or sustainable rating system. These guidance frameworks are chosen because they are state-of-the-art methodologies that are gaining popularity in different industries, and that are able to assess a product considering the whole sustainability spectrum (social, economic and environmental) (Diaz-Sarachaga et al., 2017b; Gómez Comendador et al., 2019). In the case of **GBRS**, these are frameworks specialized in buildings and infrastructures, and with them, stakeholders and users are guided and triggered through different indicators to make informed decisions to improve the sustainable performance of their projects (airports in this case) and, in consequence, improve the overall sustainability of the aviation industry. In section 3.2.1 a more in-depth description of sustainable rating systems is given, and in section 3.3 of this report, a description of main rating systems currently in use for buildings and infrastructures is provided.

1.2 Problem statement

In order to tackle climate change and seek for more sustainable airports, **GBRS** are considered to be state-of-the-art frameworks and guides (Gómez Comendador et al., 2019). Currently, in airports' terminal buildings such rating systems are already being applied, and two of the most known worldwide are **LEED** and **BREEAM** (Bocchini et al., 2014). These systems provide a guide to the airport operator, engineers, and contractor on how to make the terminal building more sustainable and finally, gives the corresponding certification depending on the level of sustainability achieved. <u>However, these are mostly focused on buildings and there is a lack of guidance on how to make the airport's airside more sustainable</u>. Although there are some new rating systems that are being developed for infrastructures itself, <u>these are not yet 100% aligned with the whole concept of airside in airports. This means there is a knowledge gap</u>. Therefore, this master thesis focuses on the development of a rating system specifically for airports airsides, where the main problem owner is the airport operator. However, it's important to highlight that these tools can be used by every stakeholder, as designers in collaboration with airport operators to achieve better results.

1.3 Research Objective and Scope

The objective of this research is to develop a rating system specifically for airport's airsides considering infrastructures and the influence of them to operations to close the gap. Where the reason behind rating is because in this way airports can apply a label to both, their terminal and airside, giving a better image to the world and every passenger using that airport. Hence, if these **GBRS**s are applied, more and more airports will seek for them to not lag behind and a competition for more sustainable airports will be generated, causing a greener future in the sector. Moreover, the purpose of developing this rating system is twofold, first, to provide guidance (a framework) to airport operators on how to go for more sustainable airsides and second, to push for the research and use of these state-of-the-art methodologies in the aviation industry to make it more sustainable.

The scope of this thesis should be defined in several points, and are the following:

- Just the airside of airports for green field projects and already existing projects that want to be certified are considered. Where the spatial, component, and functional boundaries of an airport to take into account for this research are defined later in chapter 5.
- The infrastructure and operations (from an infrastructural perspective) of an airport's airside are the focus of this thesis.
- The phases that are considered in the developed sustainable rating system are the planning and design phases. However, the sustainable approaches identified by the project teams using this framework (rating system) in the planning and design phases will be carried forward throughout the project's construction, operation, maintenance, and End-of-life phases. Hence, it can be said that decisions made in the planning and design phases are crucial because they can influence the whole life cycle of a product.
- The **TBL** is an important concept to be considered, and hence, from the three pillars (social, economic and environmental), this rating system aims to consider just the environmental one, which is the main focus and key factor in all the rating systems existing nowadays (Doan et al., 2017), leaving social and economic impacts for further research.

1.4 Research Questions

In order to reach the desired research objective, the following Main Research Question has been defined:

Main Research Question: How should a rating system be given form in such a way that it can be used for assessing the environmental impacts of airports airsides from an infrastructural perspective?

To answer the main research question, the following Sub Questions (**SQ**s) will be answered:

Sub-questions:

1. Who are the main stakeholders involved in a rating system for environmentally friendly airports airsides?
2. What are the boundaries that this rating system will evaluate at an airport?
3. What are the main rating criteria (credit categories and credits) to consider for this rating system? and how are they structured in the rating system?
4. What is the weight of each credit and what are the possible levels of certification?
5. What are the metrics of each credit? And what are possible practices to achieve the highest level of certification?
6. To what extent is the achieved rating system practical to use in airfield development projects?

By answering these six **SQ**s, the Main Research Question will be given an answer. Moreover, it is important to highlight that in **SQ**s 3,4 and 5 is where the design of the rating system itself happens. In these three questions the credit categories and credits are given, then the point allocation for each of them is done, and finally the metrics per credits are provided. In this way, a whole rating system is obtained.

1.5 Relevance

This project has societal, scientific and practical relevance (the latter one can be associated to **NACO** – where this thesis is performed, at the Civil Engineering team of the Airport Asset Design department). As mentioned earlier, **GBRS**s can improve the sustainability in airports. The following points indicate the relevance:

Societal relevance:

- The result of this master thesis could make the aviation industry become more environmentally friendly.
- Communities around the airports could have an improved environment.
- The image from airports could be improved and passengers could feel attracted to use air as a mode of transport.

Scientific relevance:

- There is no specific rating system for airports' airside in existence yet. Therefore, this thesis is one of the first studies that seeks to implement this.
- The steps and methodologies followed in this thesis (see chapter 2) can be used as an example for other researchers on how to pursue the development of a sustainable rating system for other industries.
- Main stakeholders as **ICAO** and knowledge centers could learn from the results and push to apply mandatorily sustainable rating systems in airports worldwide.

Practical relevance:

- The development of a sustainable rating system specifically for airports' airside could help airport consulting firms as **NACO** by providing guidance on how to design more sustainable airsides and improve their products.

- Using the sustainable rating system could increase the reputation of airport consulting firms as **NACO** from an environmental point of view, benchmarking the company as a consultancy that follows sustainable and green methodologies.

- The expertise of consulting firms in sustainable airports could increase.

1.6 Research Approach

As it is depicted in Figure 1-1, this research is setup in six phases (phase zero plus five phases). Each phase contains chapters, and each chapter answers to one or more **SQ**s, except for chapter 3 that does not answer any question and chapter 9 that answers the main research question. In **Phase zero** a Literature Review is done to collect background information of environmental concerns in airports and sustainable rating systems currently used in the construction sector.

In **Phase I**, an exploration of the context is done, where the main stakeholders involved in rating systems for airports are described. In this way **SQ** 1 is answered.

In **Phase II** the boundaries for this rating system are defined, namely the spatial, component, and functional boundaries, answering **SQ** 2. In **Phase III**, the rating criteria (credit categories and credits) are obtained and organized answering **SQ** 3, and then, weights (points) are assigned to each of them, taking into account their importance, answering **SQ** 4.

Then, in **Phase IV**, metrics per credit are defined, which means saying how each of the credits are measured. Moreover, in this Phase best practices to achieve the highest level of certification possible are recommended, and in this way answering **SQ** 5.

Next, in **Phase V** the validation of the developed rating system is done. This is an important and mandatory step that answers **SQ** 6. At the end of this master thesis, also conclusions and recommendations are given based on the developed rating system and its performance, achieving to answer the Main Research Question.

The framework shown in Figure 1-1 illustrates the process flow of the research. Please note that this flow is linear, but the data flow may not. To see a further discretization of the process together with the data flow please see chapter 2. Furthermore, methodologies used for each Phase and each **SQ** is given in chapter 2 as well.

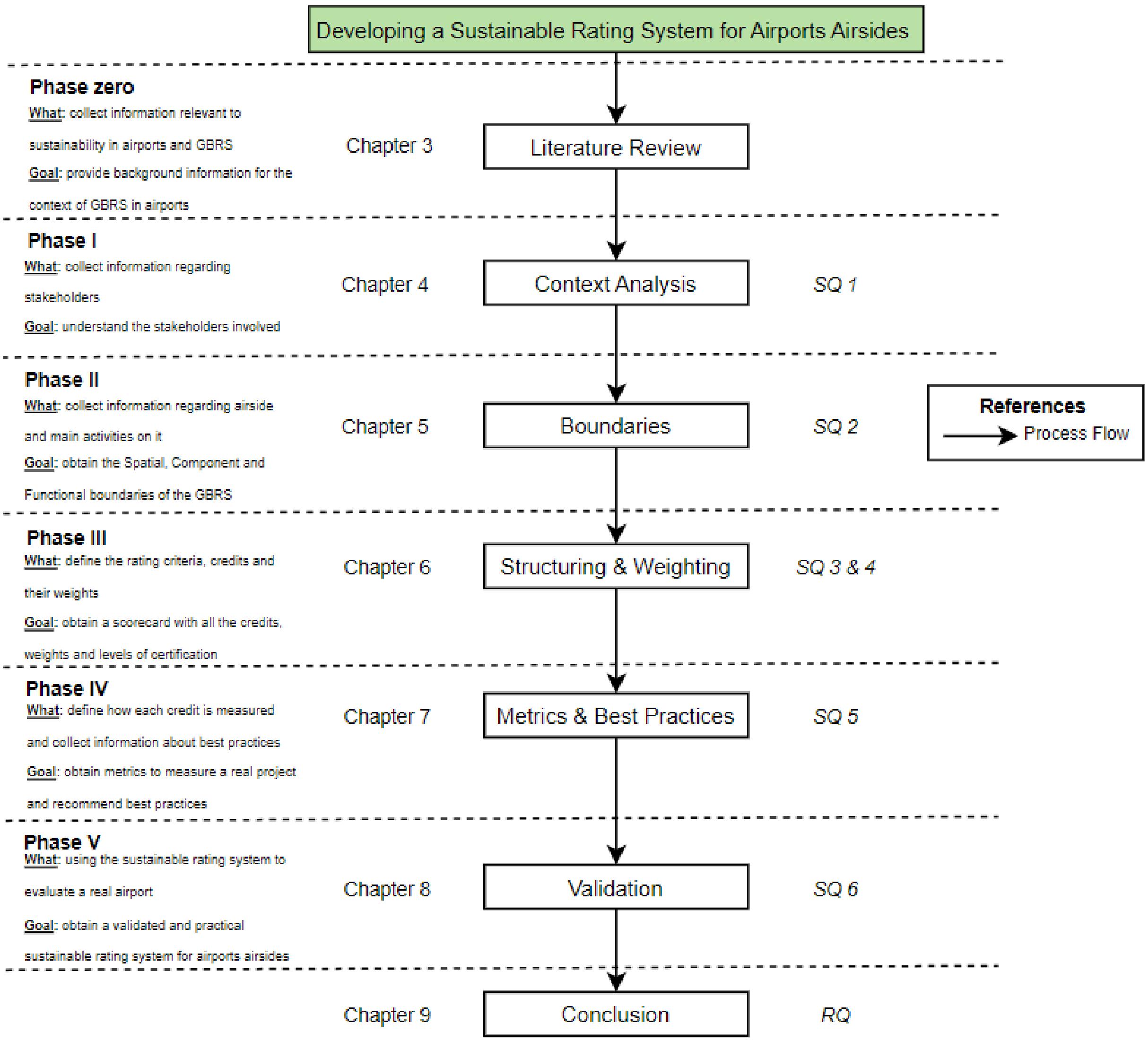


Figure 1-1. Research framework

1.7 Report Structure

The current master thesis is organized as follows: first, in chapter 2, the applied methodologies are elaborated. Then, the rest of the thesis is structured as depicted in Figure 1-1 following the different phases. Hence, in chapter 3, a literature review performed is presented. Then, in chapter 4 a context analysis for stakeholders of rating systems is defined. After that, in chapter 5 the spatial, component, and functional boundaries that are considered are given. Next, in chapter 6, the structuring and weighting of the rating system is defined. Following, in chapter 7 the metrics and best practices for each credit is detailed. In chapter 8, the validation of the rating system is executed and finally, in chapter 9 conclusions and recommendations of this thesis are constructed.

2 METHODOLOGY

This thesis uses a mix of methodologies to achieve the final output. This mix consists of several methodologies that fit to answer perfectly and in a complete way each sub-question or part of it, where some of them are qualitative and some quantitative. First, in section 2.1 a framework overview is provided to guide the reader through each phase. Then, in section 2.2, the methodologies used for this thesis are described one by one. Finally, in section 2.3 a table is presented with an overview of every methodology used per phase and **SQ**.

2.1 Framework Overview

For a better organization of chapter 2, the process flow diagram from Figure 1-1, is now further discretized, illustrating each step to follow within the chapters with their corresponding **SQ** and it's shown in Figure 2-1. This illustration shows the key steps of the thesis as an overview, and it is shown to provide a better guidance to the reader through chapter 2 (the whole chapter is referred to it).

In the following, a description of each phase from Figure 2-1 is given to link each phase with the different methodologies used in this thesis. However, a more in detail description of each methodology is given in section 2.2.

Phase zero: Literature Review

Methods used: Literature Review

In this first phase, a literature review is performed to collect background information of environmental concerns in airports and sustainable rating systems currently used in the construction sector. This methodology is important in this phase because knowledge of the most widely used rating systems of buildings and infrastructures can be obtained. This knowledge is important to develop a new rating system because the already existing rating systems are used as guides.

Phase I: Context Analysis

Methods used: Literature Review and Stakeholder Analysis

Then, it is important to understand the context. To do so, literature review and stakeholder analysis are performed. The former one it's important because with it, it is possible to collect information for main and secondary stakeholders. While the latter one is relevant to perform the analysis of stakeholders to know their roles, interest, and power that they have considering the development of a sustainable rating system. To make this clear, stakeholders come arranged in a Power-Interest Grid.

Phase II: Boundaries

Methods used: Literature Review, Desk Research, Expert Consulting and Interviews

As the outcome of this thesis is a Sustainable Rating System for airports' airsides, it is necessary to define the boundaries that the system considers. In this case, three types of boundaries are defined, namely spatial, component, and functional boundaries. With the spatial boundaries is intended to define the geographical demarcation that the rating system considers (mainly airside), which will be done with literature review, because with this methodology is possible to give a description of the airside. With the component boundaries is intended to define specifically which activities and disciplines from the airside are considered for this rating system, based on which of those activities are related to infrastructure and pollute the most, this is done with literature review and Interviews. Literature review in this case is important to give the description of the different activities and disciplines on airside, while also providing their contribution to pollution. In the case of Interviews, these are important because they help providing information on impacts from the different disciplines and activities which complement the literature review. Then, the functional boundaries are defined based on these main polluting activities. This means recognizing and defining the specific processes of each activity that pollutes the most and specifically naming per activity which environmental impact is considered. This is done with desk research and expert consulting. Desk research is used because with this methodology it's possible to define the most important processes to consider per activity based on what it was found in research. While expert consulting is used because with this methodology it's possible to consult with experts from the industry, if the defined boundaries are correct. In this way, the boundaries are already clear, and it is possible to proceed with the next phase.

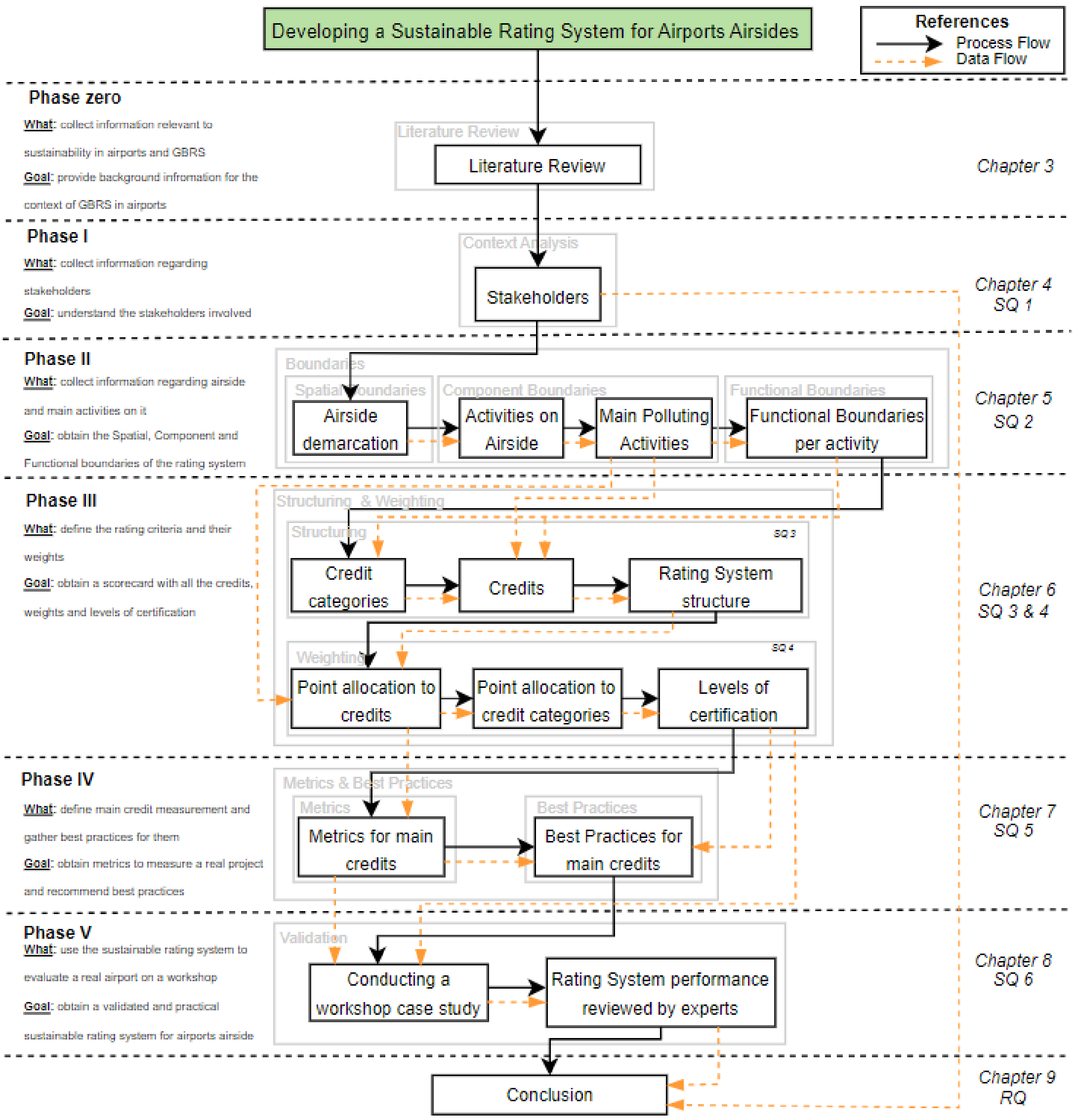


Figure 2-1. Framework overview, decomposition from Figure 1-1.

Phase III: Structuring & Weighting

Methods used: Desk Research, Expert Consulting, Direct Rating, Literature Review and Scorecard

Once the boundaries are defined, in this phase the structuring and weighting of the rating system happens. For the structuring, the rating criteria is needed to be defined, meaning credit categories and credits. These ones are defined based on the knowledge from already existing rating systems for buildings and infrastructures described in Phase zero, while also considering the functional boundaries and main polluting sources from Phase II. Therefore, for this it's important to use the desk research methodology, which is used to define the structure of the rating system developed in this thesis, based on research from other rating systems. Then, the weighting takes place, mainly allocating points (weights) to credit categories and credits. This is done via direct rating methodology, because with this methodology its possible to allocate weights based on the studied rating systems from Phase zero. After this, all the points are accommodated in a scorecard, with an expert consulting check. The scorecard is used because it's a simple way to illustrate the structure of the rating system with its credits and credit categories with their corresponding weights. Also, the expert consulting check is used in this phase, to have an expert opinion over the obtained weights, to see if they make sense. After this, the possible levels of certification that can be achieved are defined, and this is based on the points arranged in the scorecard, where breakpoint points are decided according to literature review from other systems and experts from rating systems within Royal HaskoningDHV (mother company of **NACO**). The literature review methodology in this case is used to gather information from the existing rating systems, to analyze how it is done on them. And finally, the expert consulting is used in this case to validate the defined breakpoints and levels of certifications.

Phase IV: Metrics & Best Practices

Methods used: Literature Review, Desk Research, Expert Consulting, Direct Rating and Interviews

Until this phase everything is arranged in a tidy way, but an important step is missing, and comes to place in this phase. This step is giving metrics to each credit, meaning how each credit is measured according to different practices. So basically, this step is saying how many points out of the total amount of points possible per credit, is a certain measure obtaining. To do this, also direct rating will be used based on desk research from the different rating systems studied. Desk research is important because with it, it's possible to come up with different metrics for the different credits, while the direct rating it's important to allocate weights to them, based on the different studies used to come up with the metrics. The metrics established are checked with experts within **NACO** so as to validate the results. After giving the metrics, also best practices for those considered "main credits" (having the most weight) are given. This is done so as to recommend the users on how to achieve high levels of certification in an airside. To find the best practices, literature review is executed, complemented with interviews to experts within **NACO**. Literature review its important because with this methodology is possible to find what are common practices used nowadays in airports around the world, while with the interviews to experts, its possible to have more information on state-of-the-art methodologies that are not found in literature review.

Phase V: Validation

Methods used: Case Study and Expert Consulting

Finally, to validate the developed rating system in this thesis, a case study with experts from **NACO** in an existing airport is applied in sort of a workshop. Then, the performance of the system is reviewed by the experts. In this phase, the main goal is to have a practical and validated rating system, and in this way this is obtainable. A case study is chosen in this phase, because in this way it's possible to apply the developed rating system to an existing airport, analyzing the real performance of the tool. While the expert review its of utmost importance to check this performance of the tool, and they can recommend what is missing or which are possible aspects to improve. The airport chosen for this phase is the ''Aeropuerto Internacional Del Pacífico'' in El Salvador, designed by **NACO** where all the data is provided by **NACO**, and more details are given in section 2.2.7.

2.2 Methodologies

In this section every methodology applied in this research is further described. Explaining what the methodology is about, and how it contributes to answer each **SQ**.

2.2.1 Literature review

The main goal of a literature review is to avoid wasting time "reinventing the wheel" as described by Djamba & Neuman (2014). Therefore, it is essential to read and investigate what other researchers have done in the field and build on that. In this research, the literature review has the goal to summarize what is already known in the corresponding area of study. Hence, with this methodology, insights in rating systems and how are them currently used can be extracted. By doing so, an integration of finding and perspectives from different sources is achieved (Snyder, 2019), that can be used to better answer to **SQ**s.

To perform an efficient literature study and a good collection of articles, first, online electronic databases were used, namely, ASCE (American Society of Civil Engineers) library, Scopus, SpringerLink, TU Delft Library and Google Scholar. Scopus and SpringerLink are databases that contain peer-reviewed literature such as scientific journals, books and conference papers. The special thing about ASCE library is that it's specifically for civil engineering literature. While Google Scholar and TU Delft library are search engines that gathers scholarly literature from different disciplines and sources in one place. The main advantage of TU Delft library is that while some papers or books in a certain search engine as Google Scholar must be paid, in this library they are provided freely due to the license of Delft University. To execute the research of articles and reports relevant to "sustainable rating systems" and "airport sustainability", the keywords used were "rating system", "airports" and variations of "sustainability". Some of these variations include "green rating systems", "green airports", "sustainable development" and "environmental sustainability". Moreover, the snowballing method (forward and backward) (Wohlin, 2014) was used in order to find more relevant literature.

The literature review methodology in the case of this thesis is used for chapter 3 and to answer **SQ** 1, part of **SQ** 2, part of **SQ** 4 and part of **SQ** 5 (please refer to Figure 2-1 to distinguish them). This is because these questions have more descriptive parts that can be answered by collecting and summarizing information from previous research. In this way, for chapter 3, this methodology is used to collect background information of environmental concerns in airports and sustainable rating systems currently used in the construction sector. In **SQ** 1 a good description of main stakeholders involved in rating systems can be given. Then, in **SQ** 2, when it comes to defining the spatial and component boundaries, this methodology is also useful for describing them. In the case of **SQ** 4, literature review is useful to define the different levels of certification, so as to correctly indicate the breakpoints according to how is it done in already existing systems. Finally, this methodology is also used for part of **SQ** 5 to provide the best practices to achieve the highest level of certification possible. Therefore, a collection of best practices that are being currently used in airports is necessary.

2.2.2 Stakeholder Analysis

The stakeholder analysis is done in order to recognize who are the main actors involved in a system. This analysis is helpful to understand what is the role of each stakeholder, what is their perspective and their relevance in the system (Brugha & Varvasovszky, 2000). In this research, the stakeholder analysis is performed for sustainable rating systems for airports airsides, and it is a methodology that helps answering **SQ** 1 (please refer to Figure 2-1).

Hence, first, from literature review a list of main stakeholders is extracted with their corresponding roles, goals and objectives for the sustainable rating system for airports airsides. Then, a power-interest grid is constructed, where it is visibly clear who are the main actors for this system.

2.2.2.1 Power-Interest grid

These type of grid was defined by Ackermann & Eden (2011), where four different quadrants were set. Each quadrant is a category for stakeholders, and the four categories exactly are: Players, Context Setters, Subjects and Crowds (see Figure 2-2) (Ackermann & Eden, 2011).

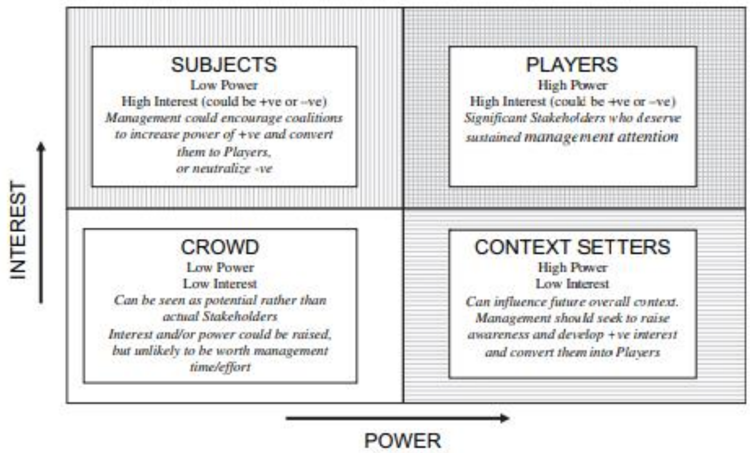


Figure 2-2. Outline stakeholder power-interest grid. (Ackermann & Eden, 2011)

As depicted in Figure 2-2, Players are the stakeholders that possess high power and high interest. Context Setters are the ones that still have high power but low interest. Subjects are those who have low power and high interest, and, finally, Crowds are the ones that have low power and low interest. So, Power is defined as the capability to influence in the organization of the system according to Murray-Webster & Simon (2007). While interest is defined as the state of a stakeholder, meaning whether this will be active or passive (Murray-Webster & Simon, 2007). In this type of grid, the different main and secondary stakeholders for a sustainable rating system for airports airsides will come arranged in chapter 4, to clearly depict their roles and positions.

2.2.3 Desk research

Desk research methodology is also called secondary research, which means using already existing data from previous research as a method, and hence, relying on this data to come up with new designs (Aela, 2022). It might sound similar to the literature review methodology, but the main difference is that a literature review is a summary of previous studies while desk research is using already existing data as a method (peachyessay, 2020).

This type of methodology is quite useful for this thesis given that the topic of sustainable rating systems is quite new and there is hardly information about it. Therefore, using already existing data from the currently used rating systems and different papers from the sector, to come up with a new one for airports airsides to achieve the goal of this thesis, is thought to be one of the most appropriate methodologies. The existing rating systems for transport infrastructures are studied and analyzed, then, relevant information is collected, and further utilized to contribute developing a rating system for airports airsides. Moreover, to contribute on the outcome of this thesis, also relevant papers are used. Some of these papers are the same as those used for the literature review methodology while others are new papers that were collected through the same methodology as explained in section 2.2.1.

This methodology is mainly used to answer part of **SQ** 2, **SQ** 3, part of **SQ** 4 and part of **SQ** 5 (please refer to Figure 2-1). More specifically, in **SQ** 2, desk research is key to define the functional boundaries that are considered for each activity depending in the contribution to pollution of each of them. This means, gathering information about the most pollutant activities in airside (part of component boundaries), analyzing their process, finding numbers on how they contribute to pollution and then based on all this, define the functional boundaries that the rating system will consider (only the most relevant sources of emissions are taken into account). For **SQ** 3, desk research is used to gather information from the different existing rating systems rating criteria, associate them with the component and functional boundaries from **SQ** 2 to come up with the different rating criteria of this thesis. Moreover, with this methodology, the information from different types of rating systems is useful to see how they arrange the credits categories and credits, and then come up with an own design for this thesis. Similarly, for **SQ** 4 the desk research methodology is used to gather information from different rating systems and come up with the point allocation for the different credit categories and credits defined in this thesis. Finally, in the case of assigning metrics to credits as part of **SQ** 5, this methodology is of much utility. In this case, different sources are investigated and studied to collect information about emissions of each defined credit. After that, based on all the emissions from each credit, a direct rating methodology (see section 2.2.6) is applied to further decide on reference levels that assigns points per credit depending on the practical measures carried out.

2.2.4 Expert Consulting

Expert consulting, as the word states, is basically requiring input from experts of a certain field to provide credibility, accuracy and added value to a project (Project Management Institute, 2016). In the case of this thesis, different experts are consulted to contribute answering different sub-questions. Experts from the aviation industry that are consulted are mainly professionals from **NACO**.

This methodology is used as a complement to answering part of **SQ** 2, part of **SQ** 4, part of **SQ** 5 and part of **SQ** 6 (please refer to Figure 2-1). The specific expert is consulted to come up with a more reliable rating system. In **SQ** 2, the professional is consulted to give more accuracy to the functional boundaries that are taken into account. In **SQ** 4, the expert consulted in the final weight allocation for each credit. In **SQ** 5, the contribution of an expert is useful to make sure that the metrics for each credit are measured with as much credibility as possible. Finally, in **SQ** 6, experts help validating the rating system by analyzing its performance in the case study applied (see section 2.2.7), assessing its practicability.

2.2.5 Scorecard

A Scorecard is a methodology that is used to assess different criteria from a project (van Binsbergen, 2021). They also indicate the efficiency and successfulness of the project based on different criteria (Praxie, 2018) (credits in the case of rating systems).

In this thesis, a scorecard is provided to organize the structure of the rating system. In this, the different credit categories and credits are found, together with their corresponding points allocation. The scorecard is a summary of all the credits from the rating system, which at the end it has the sum of all the points achieved by a certain project, which in consequence provides the level of certification achieved.

The scorecard is mainly used for **SQ** 4 (please refer to Figure 2-1), especially in giving the final structure to the created rating system, where a summary of all the credits, point allocation per credit and levels of certification are found.

2.2.6 Subjective method – Direct Rating Methodology

In order to test different criteria, an overall “score” has to be assessed. This is normally done by weighting the criteria, i.e. determining which criteria are more, and which criteria are less important (van Binsbergen, 2021). To this end, different approaches can be used.

According to Jahan & Edwards (2013), one of the methodologies that can be used are called the Subjective Methods. These determine the weights of attributes (or criteria) based on expert evaluation according to previous experience or constraints in the design. Additionally, these methodologies can be further divided in direct weighting procedure or pair-wise comparison. Each of them has different techniques available to apply (Jahan & Edwards, 2013). For this research a weighting procedure technique called Direct Rating (**DR**) is used to assign different weights (points) to the rating criteria (credit categories and credits).

Direct Rating is a methodology where the expert assign scores to different criteria in a numeric scale defined by him, and that is based on the importance of each criteria relative to the other ones (Doyle et al., 1997).

For this thesis, the **DR** is based on different experts from different rating systems that were found during the desk research, and an average between all the experts was calculated. This methodology is used mainly to answer part of **SQ** 4 and part of **SQ** 5 (please refer to Figure 2-1). More specifically, to answer part of **SQ** 4, it is used to give the point allocation to each credit, based on the weight of each credit compared to the whole system. This means that while a credit has more relevance in contributing to pollution (based on the desk research performed), more points will be allocated to it. This can be explained as a more environmentally friendly project (higher level of certification) whenever it solves or rate high in an important credit. In the case of answering part of **SQ** 5, this methodology is used when metrics have to be given to each credit. To be more specific, first in **SQ** 4 the point allocation to each credit is done as explained before, but then, when it comes to **SQ** 5, a project has to be measured against a credit and it is necessary to say how many points of an X credit a certain project will have. Therefore, it is necessary to use **DR** to say the amount of points that a project gain in certain credit, based on desk research and expert consulting (as explained in sections 2.2.3 and 2.2.4 respectively).

2.2.7 Case Study

In order to assess the practicability of the developed rating system, a workshop in **NACO** will be executed, where a case study is used to validate the tool. The rating system will be used to assess the environmental impacts from the airside design of ''Aeropuerto Internacional Del Pacífico'' in El Salvador, a project developed by **NACO**, in collaboration with a Mexican architectural firm during the years 2022 and 2023. Different experts involved in the project from different fields within **NACO** will contribute to the validation in the workshop. For more details of the workshop organization and case study please see chapter 8.

A case study in this context means applying the developed rating system to a real-world project and closely examining its performance, impact, and outcomes. This method allows for a comprehensive understanding of how the rating system functions and how it influences decision-making or outcomes in a specific context.

In the case of this research, this methodology is used to answer **SQ** 6 (please refer to Figure 2-1). The objective in this last **SQ** is to assess the practicability of the rating system, i.e., applicability, ease of use, efficiency and resources required. By applying a real-world project, the practicability of the rating system can be proven. Moreover, the expert consulting methodology is also applied in **SQ** 6 (see section 2.2.4), which together with the case study can validate the rating system.

2.2.8 Interviews

Interviews are qualitative research methodologies that are based on asking questions to collect data (George, 2022). This methodology involves an interviewer (who asks the questions) and one or more interviewees.

In this thesis, the interviews were conducted face to face with different experts from **NACO**, to be able to gather extra data in some different topics. These interviews were organized informally, where the interviewees were asked for brief conversations during working hours. The different experts chosen for the interviews were selected according to the different fields touched upon on this thesis. A total of nine interviews were executed and for more details on them please refer to Appendix C.

The interviews are mainly used to answer part of **SQ** 2 and part of **SQ** 5 (please refer to Figure 2-1). More specifically, to answer part of **SQ** 2, interviews are used to collect information from environmental impacts from different fields. In the case of answering part of **SQ** 5, this methodology is used when best practices have to be given to each credit. The input from experts is valuable to have best practices that can be applied nowadays in each relevant field.

2.3 Overview

A final overview of all the methodologies applied in this thesis can be seen in Table 2-1. In this table four columns can be seen, indicating the chapter/phase, sub-question, further subdivision of each sub-question and the methodology applied. To each of these subdivisions referred as "steps" in the third column (that are coincident with those already shown in Figure 2-1), the corresponding methodology is assigned.

Table 2-1. Sub-questions and methodologies.

Chapter and Phase	Sub-question	Steps (Figure 2-1)	Method
3. Literature Review *Phase zero*	Contribute to background information for this thesis	Literature Review	• Literature Review
4. Context Analysis *Phase I*	1. Who are the main stakeholders involved in a rating system for environmentally firendly airports airsides?	Stakeholders	• Literature Review • Stakeholder Analysis
5. Spatial, Component and Functional Boundaries *Phase II*	2. What are the boundaries that this rating system will evaluate at an airport	Airside demarcation and activities on airside (Spatial Boundaries)	• Literature Review
		Main polluting activities (Component Boundaries)	• Literature Review • Interviews
		Functional Boundaries per activity	• Desk Research • Expert Consulting
6. Structuring and Weighting *Phase III*	3. What are the main rating criteria (credit categories and credits) to consider for this rating system? And how are they structured in the rating system?	Credit categories and credits	• Desk Research
		Rating System structure	• Desk Research
	4. What is the weight of each credit and what are the possible levels of certification?	Point allocation to credit categories and credits	• Desk Research • Direct Rating • Scorecard • Expert Consulting
		Levels of certification	• Literature Review • Scorecard
7. Metrics and Best practices *Phase IV*	5. What are the metrics of each credit? And what are possible practices to achieve the highest level of certification?	Metric per credit	• Desk Research • Direct Rating • Expert Consulting
		Best practices for main credits	• Literature Review • Interviews
8. Validation of the Rating System *Phase V*	6. To what extent is the achieved rating system practical to use in airfield development projects?	Conducting a workshop case study	• Case study
		Rating System performance reviewed by experts	• Expert Consulting

Having finished explaining the methodology that will be used in this thesis, now in chapter 3, the literature review conducted to have background information for this thesis is given.

3 LITERATURE REVIEW

The purpose of this literature review is to collect background information of environmental concerns in airports and sustainable rating systems currently used in the construction sector. With this information is possible to understand the importance of the environmental concerns nowadays in the aviation industry and more specifically in airports. Moreover, it is possible to briefly analyze the most widely used rating systems in the construction sector and use their components and structure as a guide to develop the proposed rating system in this thesis. Lastly, this literature review sets the reader in the context of this research.

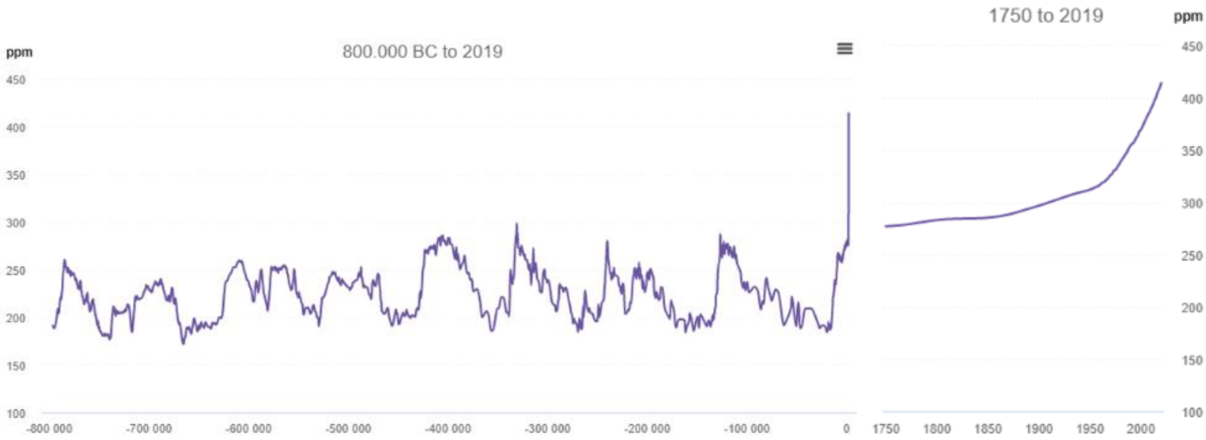
This chapter is organized as follows: in section 3.1 a description of the current environmental concerns at world level is given, followed by a more specific description of these concerns for the aviation sector and airports. Then, in section 3.2 an explanation of the current tools assessing sustainability on airports nowadays is given, with a more detailed description of those state-of-the-art methodologies called rating systems. Finally, in section 3.3 a more detailed description of the most used rating system in the constructions sector is provided.

3.1 Environmental concerns at a global scale

During the last decades, public known phenomenon named climate change and global warming have gained popularity within the population creating a sense of concern. Global temperatures have been significantly rising after the industrial revolution and even more in the last two decades (European Parliament, 2023). Average global temperature is nowadays 0.95 to 1.20 °C higher than at the end of the 19th century and 2 °C is considered a threshold with catastrophic consequences for the environment according to scientists (European Parliament, 2023). This rise in temperatures is due to the increasing **GHG** emissions produced by human activity, and more especially due to **CO_2** emissions (which is the major source of **GHG**, responsible for 80% of them according to US EPA (2015)) and concentration in the atmosphere (NOAA, 2023). In Figure 3-1 (a), a graph with the concentration of **CO_2** in ppm in the atmosphere over 800,000 years can be seen.

From Figure 3-1 (b) the tendency of an exponential increase in the concentration of **CO_2** in the atmosphere in the last 270 years is clear and something must be done from every sector in order to tackle climate change.

Although **CO_2** is the main source of **GHG** emissions, is not the only one. Other contributors are methane (**CH_4**) (responsible for a 11.5% of **GHG**), nitrous oxides (**N_2O**) (responsible for 6.2% of **GHG**), and less than 3% of **GHG** emissions come from fluorinated gases, such as hydrofluorocarbons (**HFCs**), perfluorocarbons (**PFCs**), and sulfur hexafluoride (**SF_6**) (US EPA, 2015). According to Hu (2021), methane is the second most important **GHG** and its potential for warming per unit of methane molecule is around 20 times that of **CO_2**. The main source of **CH_4** is the fermentation process of anaerobic bacteria and the leakage of natural gas and crude oil (Hu, 2021). The concentration of **CH_4** in 2008 reached 1797 ppbv globally, which is an increase of 157% compared to the year 1750 (Hu, 2021). On the other hand, in the case of nitrous oxide, Hu (2021) states that its potential for warming per unit of **N_2O** molecule is around 300 times that of **CO_2**. The main natural source of **N_2O** is the release of tropical and marine forests. While main anthropogenic sources are industrial production, agricultural production, and livestock emissions (Hu, 2021). The concentration of **N_2O** till the industrial revolution was around 270 ppbv, but after that this increased at a rate of 0.3% per year. By 2008, the concentration of **N_2O** reached 322 ppbv globally (Hu, 2021).



(a) **(b)**

Figure 3-1. Atmospheric Carbon Dioxide concentration. (a) Over 800,000 years (b) From the year 1750 to 2019 (NOAA, 2023).

In this thesis in particular, the focus is made on the transportation sector and yet more specific, on airports from the aviation sector. Therefore, in the following some environmental concerns within the sector are described.

3.1.1 Environmental concerns for the Aviation Industry

The transportation sector accounts for 23% of the global **CO_2** emissions (International Energy Agency, 2022b). From this percentage, a 2% corresponds to the aviation sector (International Energy Agency, 2022a). However, most importantly, the aviation sector is responsible for 3.5% of climate change (Kiest, 2020). This share on climate change accounts for factors as **CO_2** and **NOx** emissions, and the effect of condensation trails (a.k.a. contrails) (Kiest, 2020). These contrails have a significant impact on climate change according to Yin (2023). He stated that the effect of contrails in climate change is twice greater than that of **CO_2**, and that those that are considered significant are the ''persistent contrails'', which are those that remain suspended in the air for several hours and up to a day. While those contrails suspended for a few minutes or one hour have a negligible effect.

It is also interesting to see the distribution of **CO_2** emissions within the aviation sector to have a better illustration. So, from the 2% **CO_2** emissions of the aviation industry, airports are responsible for a 2% share of that percentage, while airlines take a 94% of responsibility and other sources accounts for a 4% (NACO Aviation Academy, 2023a). Please see Figure 3-2 for an illustration of the **CO_2** emissions distribution. According to NACO Aviation Academy (2023a), the ''Airlines'' 94% englobes emissions generated during flights, aircraft ground movements, Auxiliary Power Unit (**APU**) usage and **GSE** owned by airlines. Also, NACO Aviation Academy (2023a) states that the 4% emissions englobed in the "Other" category are those generated from **GSE** owned by third parties, construction & demolition waste, staff commute, passenger travel to the airport and off-site waste management. Finally, NACO Aviation Academy (2023a) says that the 2% from the ''Airports'' category are those emissions coming from the

GSE owned by airports, on-site waste management, on-site wastewater management, on-site power generation, firefighting exercises, and de-icing substances.

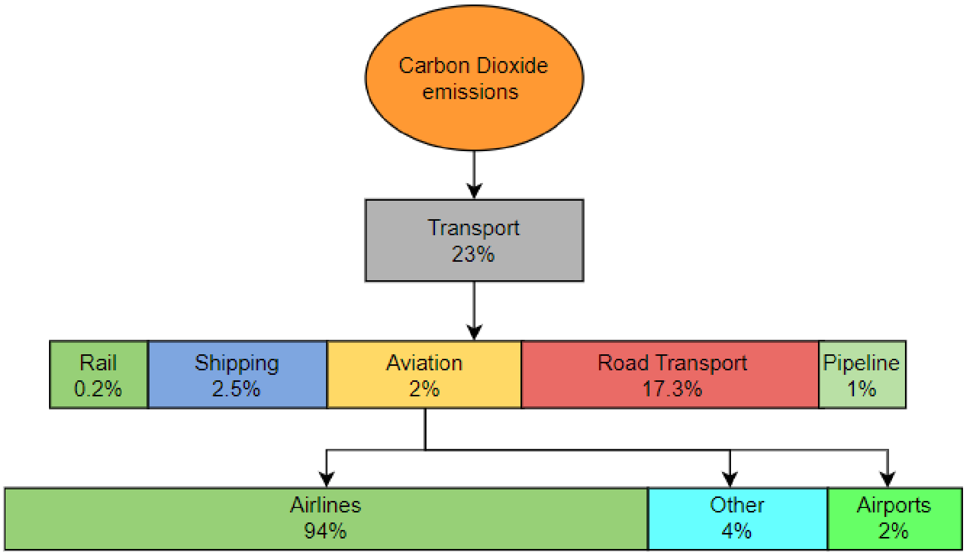


Figure 3-2. CO_2 emissions distribution within the transport sector.

The percentages presented in Figure 3-2 are of utmost importance to consider. Currently, the aviation industry accounts for 2% of the global **CO_2** emissions, however, this is predicted to increase to 20% in 2050 if no change is made (NACO Aviation Academy, 2023a; Pachauri et al., 2015), hence, efforts in reducing these emissions should be made. This master thesis contributes on tackling part of the 2% emissions from aviation.

Although **CO_2** emissions are the greatest contributor to **GHG** and climate change now, and main point of focus to every sector, all other sources of pollution can be mentioned. Especially in airports, some of them that can be mentioned are the conservation of biodiversity, water consumption, waste management, the treatment of water effluents, and health effects to workers in airsides, such as **NOx** emissions and **PM** (among others), mainly due to jet engine and **GSE** emissions (NACO Aviation Academy, 2023a). The last two (**NOx** and **PM**), are of great importance to workers in airsides because these kind of emissions are linked to carcinogenic effects, high risk of disease and lung problems (Bendtsen et al., 2021). Given all these sources of pollution, the **ICAO** is pushing for more sustainable development in airports to pursue an eco-friendly and carbon-neutral industry (Ramakrishnan et al., 2022). To this end, several standards and tools have been developed during the last decades which will be further described in section 3.2 with the focus on airports.

3.2 Tools Assessing Sustainability on Airports

Sustainable development was already defined in section 1.1 of this thesis but is important to repeat this definition given that is significant for this research, and according to Bocchini et al. (2014, p. 6) and Kamalam (2017, p. 43), this concept is defined as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*. With such a definition, the **ACI** defines airport sustainability as "*holistic approach to managing an airport so as to ensure the integrity of the economic viability, operational efficiency, natural resource conservation and social responsibility of the airport"* (Monsalud et al., 2015, p. 415). This definition is based on the three "pillars" of sustainability which are known as the **TBL**, and are namely the economic, environmental and social impacts of investments (Alabi et al., 2021).

The Triple-Bottom-Line concept is shown in Figure 3-3. and it is the new order of business. The concept relies on the idea of being financially secure, minimizing environmental impacts while conforming communities, employees and consumers (social expectations). This concept is expected to help the aviation industry and airports overcome the challenges that they are facing nowadays (Hubbard & Hubbard, 2019).

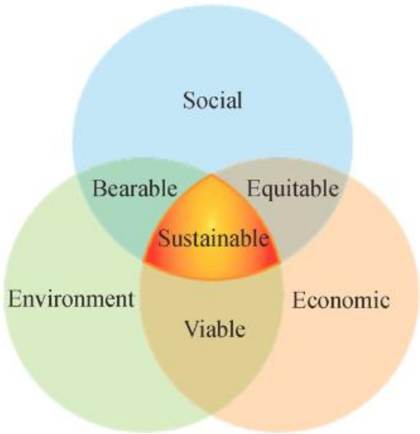


Figure 3-3. The Triple-Bottom-Line (Hubbard & Hubbard, 2019).

Several methods, practices, and standards are being developed or brought to the sector, seeking to control and minimize environmental, economic and social impacts. All these tools that can cope with emissions and help to achieve a greener future, are based in the concepts of airport sustainability and the Triple-Bottom-Line and are briefly described below.

To begin with, **ACA** was developed by **ACI** in 2009. This accreditation is the only global standard for airports to manage carbon emissions. Its main goal is to reduce and manage carbon emissions from operations that are completely under control of the airports, and as a final objective to make airports become carbon neutral. To account for carbon emissions, this standard is based on the international standard ISO 14064 and the **GHG** Protocol. In this way, **ACA** is compliant and consistent with international reporting of carbon emissions. It is clear that this standard, is very much focused in **GHG** emission sources and other impacts such as noise pollution, land use or air quality (among others) are not taken into account (Gómez Comendador et al., 2019; Hubbard & Hubbard, 2019).

The second standard that can be mentioned it is more a specification. It is called the Collaborative Environmental Management (**CEM**) promoted by the Eurocontrol. This is done to create more collaboration between the main stakeholders at airports (airport and aircraft operators, plus air navigation service providers) and together minimize the total environmental impacts of that specific airport by combining their disciplines. What it is done in this case, is establishing **CEM** arrangements in a contract that suits the local needs, based on setting requirements and best recommended practices (Gómez Comendador et al., 2019).

Thirdly and one of the most important topics nowadays regards to **GBRS** or sustainable rating systems. Many airports nowadays pursue the idea to have their terminals and other buildings certified according to different levels of the rating systems based on sustainability. These are state-of-the-art methodologies that have the potential to identify, quantify and minimize operation and constructional environmental impacts which are not yet covered by other standards, such as energy management, building occupant comfort, water quality, site and habitat, resilience, etc. (Gómez Comendador et al., 2019; Greer et al., 2020). These systems are mostly focused on buildings as their name states. Some of the most important **GBRS** nowadays are: **LEED** and **BREEAM** (Bocchini et al., 2014).

Other methods that can be mentioned in this review were developed by privates with the same objective of achieving sustainability in airports. One of them that can be mentioned was developed by Ferrulli (2016) and it is called Green Airport Design Evaluation (**GrADE**). It is mainly focused on how the design process and management of an infrastructure, technological and operational features, complies with the sustainability criteria. As the design process is complex regarding a considerable amount of decisions in a multidisciplinary field, this tool enables the sharing of information and evaluation to improve efficiency and effectiveness in the decision-making process (Ferrulli, 2016).

Another indicator that can be mentioned was developed by Milan Janić. The system is focused on monitoring, analyzing and assessing airport sustainability. The main focus of this indicator was based on the Triple-Bottom-Line, taking into account the airport economic, social and environmental dimension of performances. Focusing on environmental impacts, the main ones taken into account include: noise emission, air pollution, congestion and delays, land use and waste. From the social and economic point of view, this indicator focuses on contribution to local employment, regional economy and Gross Domestic Product (**GDP**) (Janić, 2010).

Finally, it is fair to mention some good practices and innovations that are applied in airports all over the world. For instance, Seymour Airport, which is mostly knows as Galapagos Ecological Airport runs only in wind and solar power. Moreover, 80% of its infrastructure has been built using recycled material from the previous building, and it contains mechanical shutters which works based on the level of carbon dioxide and heat of the building (Nagarajan et al., 2018). Other airport that can be mentioned is Chicago O´Hare International Airport, which uses rainwater for harvesting, it has solar panels and wind turbines for energy production, rooftop gardens and chargers for electric vehicles (Nagarajan et al., 2018). Furthermore, Vadodara Airport in India used fly ash bricks to construct their terminal which makes it an interesting and innovative green infrastructure (Nagarajan et al., 2018). In Europe, one clear example is Oslo Airport, scoring an excellent in the **BREEAM** certification. The terminal of this airport contains a wooden roof, which slope is designed to take the maximum advantage from the daylight to minimize solar heat gain or loss. In this way, also artificial lighting inside the building is minimized, favoring the natural light for more passenger comfort. Last but not least, this airport also contains a system of reservoirs where snowfall can be harvested and used for coolant during summer, and maximizes energy saving (Nagarajan et al., 2018).

As can be seen, several methodologies or standards are out there already for assessing sustainability in different ways. For this thesis, the focus is on the state-of-the-art methodologies known as **GBRS** or sustainable rating systems and will be further developed in section 3.2.1.

3.2.1 Sustainable Rating Systems

The sustainable rating systems are defined in Diaz-Sarachaga et al. (2017b) as a collection of best practices which assess sustainability by assigning scores to a series of specific indicators. These frameworks permit using different indicators measured in different units that are integrated with the objective to rate certain product (infrastructure projects in this case) (Diaz-Sarachaga et al., 2017b). For infrastructures and buildings, these frameworks provide guidance in the whole life-cycle or part of it, so they are decision-making tools (Institute for Sustainable Infrastructure, 2018). However, even if the focus of this thesis is on infrastructures, it is fair to mention that these rating systems or labels exist for different kind of industries as well. As an example, the labels for different home appliances can be mentioned. But, in line with the transportation and construction sector, these guides provide industry-wide sustainability metrics for all types of buildings and infrastructure to help users assess their projects from a sustainable point of view. In this way, they can measure to which extent the project contributes to the sustainability conditions defined in the **TBL** (social, economic and environmental indicators) (LEED, 2019). Therefore, with the sustainable rating systems, designers, owners and other stakeholders are able to make more informed decisions about the sustainability of buildings and infrastructure. These tools can be used for different phases during the development of a project depending on their scope. Different phases are planning, design, construction, operations, maintenance and end-of-life (Gómez Comendador et al., 2019).

So, to state it clearly, the purpose of these frameworks is to foster an improvement in the sustainable performance of buildings and infrastructure (in the case of the transportation and construction sector but it is analogous for the other sectors) (Dall'O' & Bruni, 2020). This is of great importance nowadays given the environmental concerns already mentioned in section 3.1, plus the social and economic concerns taken into account in the **TBL**. Some of the social concerns that can be mentioned are preservation of communities, employment, health & safety, and equality & diversity. While some economic concerns are corruption, inflation, and sustainable supply chains (ACI EUROPE, 2021). Hence, this is the reason of the need for these state-of-the-art decision-making tools, to help users and experts from different sectors from all over the world to tackle the environmental, social and economic issues to pursue a more sustainable future. From the perspective of the aviation sector users of these tools are contractors, experts from the aviation industry, airport operators, aviation consultancies, airlines and other stakeholders (a better and more in-depth description of them is provided in chapter 4 of this thesis).

The sustainable rating systems are based on different sustainability indicators (usually called credits) and are grouped in different categories which are basically several sustainability criteria (usually called credit categories). Each of the credits has different possible levels of achievement given in points, representing the performance goal of each of the credits, the more points the more sustainable the project is in that credit. By assessing the total achievement for all the credits (summing all points), a final score is given to the project with the corresponding certification, depending on the level of sustainability achieved by the project. Therefore, project teams should be aware of the whole range of possible credits and pursue for as many points as they can to make their project more sustainable.

Now, in sub-section 3.2.1.1 a brief description of the impact of design characteristics on the indicators of a sustainable rating systems is given.

3.2.1.1 Impact of design characteristics on indicators

The sustainable rating systems are based on rating criteria as said in the previous section, which are rating categories and indicators per category. The latter ones are key elements for rating systems, and in this section a brief theory on how the design characteristics influence them is explained. This is done via a conceptual model which was developed following the instructions from the course denominated as SEN1741 - Innovations in Transport and Logistics from the Transport, Policy and Management Faculty, conducted by Dr. Baiba Pudane.

The development of a proper sustainable rating system depends on several characteristics. These characteristics answer to the following questions: ''For whom is the rating system intended?'' which in this thesis is called the Problem Owner, ''Where is the rating system applied?'' referred to as Region, ''For which type of product is the rating system intended?'' referred to as Type of Product, ''When is the rating system issued?'' referred to as Time, ''What is it considered inside the rating system?'' referred to as Scope, and ''Where is the background data extracted from?'' referred to as Data in this thesis. All these characteristics influence on the sustainable indicators that are selected for the development of a rating system and the weight of each of them. Hence, they can impact from which pillar to focus on (Social, Economic or Environmental, or in all three of them), till which indicators per pillar to select and their weights, meaning how important an indicator is relatively to the others. The impact or influence that these characteristics have on the indicators and their importance it's not always direct, in several cases the impact is indirect, and this can be seen in the conceptual model illustrated in Figure 3-4.

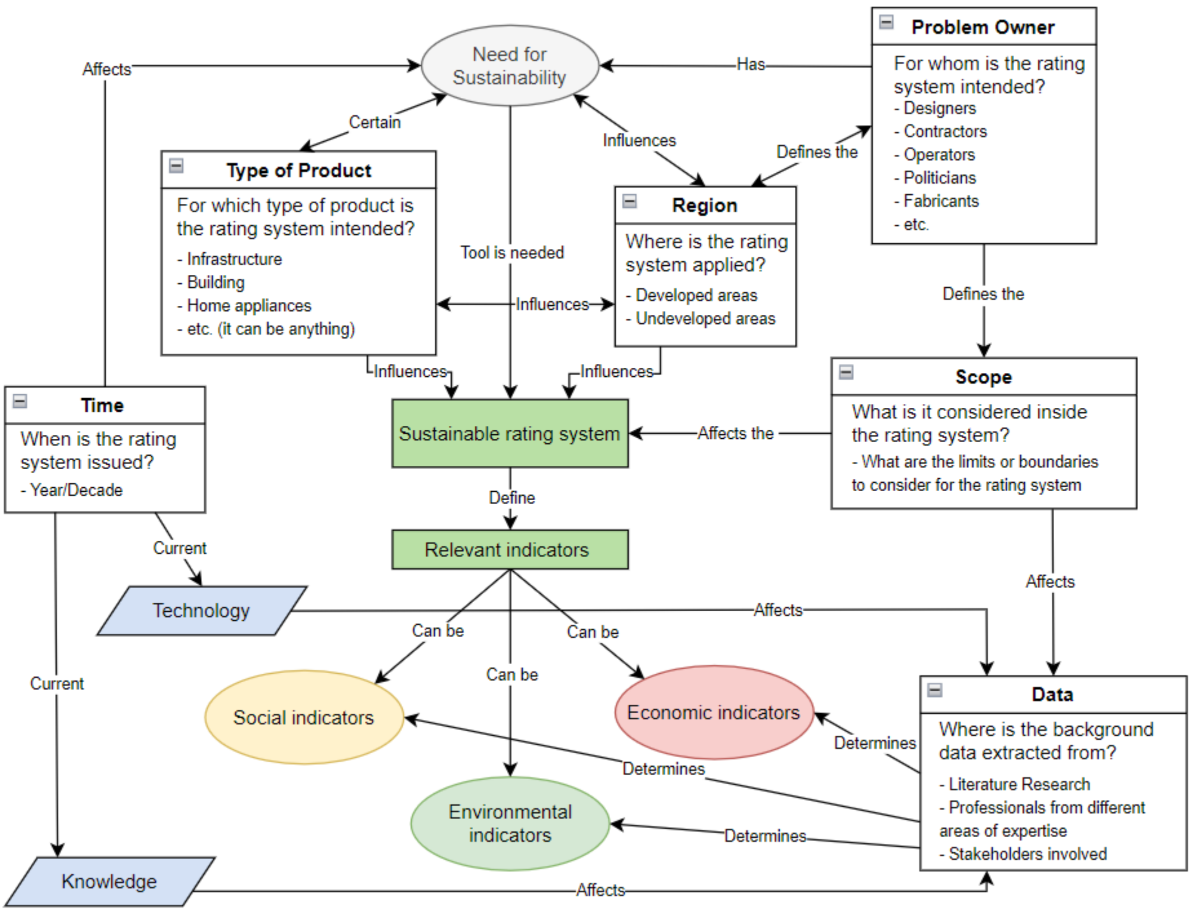


Figure 3-4. Conceptual model explaining the influence of design characteristics on indicators.

One important comment to mention related to the Time characteristic, is that this element clearly influences two other main elements: current technology and knowledge globally available, which in turns impacts directly on the Data. Therefore, the ''mainstream'' found in literature research, knowledge from professionals and stakeholders involved, are significantly influenced on when the rating system has been developed/issued.

In section 3.3 of this report, a description of main rating systems currently in use for buildings and infrastructure is given.

3.3 Existing Rating Systems for infrastructures and buildings

In this section a brief description of the most currently used sustainable rating systems for building and infrastructures is given. This is done in order to have a notion of what is there in existence right now and to analyze how are them organized. This information is useful to come up with a new rating system because they serve as a guide.

3.3.1 BREEAM

BREEAM was one of the first methods for the rating and certification for sustainability in the construction sector. This was developed by the Building Research Establishment (**BRE**) in 1990 in the United Kingdom (**UK**) and its main focus is on buildings (Hubbard & Hubbard, 2019). This system is widely used, and it has issued so far over 560,000 certifications, with an increase pattern in the last years (Doan et al., 2017). Also when talking about the number of countries where **BREEAM** was applied, it reaches over 75 countries according to Doan et al. (2017). This rating system is mainly used in Europe, where it has a share of 80% of the market for sustainable building certifications. Although **BREEAM** addresses the 3 sustainability pillars presented in the **TBL**, the environmental one is predominant (Doan et al., 2017).

Moreover, **BREEAM** is used for almost every stage of the lifecycle of a building, namely design, construction, operation, and maintenance. **BRE** provides manuals for New Construction, In-Use, Infrastructure, Refurbishment and Communities. The main categories that **BREEAM** evaluates are Management, Health & Wellbeing, Energy, Transport, Water, Material, Waste, Land Use & Ecology, Pollution, and Innovation. These are pre-weighted categories according to the relevance of each of them in the field of sustainability (Doan et al., 2017). For each category there are also different ''Assessment issues" (sub-categories) which are scored with credits according to different metrics (BRE Group, 2022). After that, once the project is completely assessed, **BREEAM** gives different rating levels which are as follows:

- Outstanding: if ≥ 85% of the credits are obtained
- Excellent: if ≥ 70% of the credits are obtained
- Very Good: if ≥ 55% of the credits are obtained
- Good: if ≥ 45% of the credits are obtained
- Pass: if ≥ 30% of the credits are obtained
- Unclassified: if < 30% of the credits are obtained

3.3.2 BREEAM infrastructure

BREEAM infrastructure is more relevant to this thesis due to the similarity of the objective of it. This was formerly called Civil Engineering Environmental Quality Assessment and Awards Scheme (**CEEQUAL**) and was developed in 2003 by the Institution of Civil Engineers (**ICE**) in the **UK**. In 2015, **CEEQUAL** was acquired by **BRE** and became part of **BREEAM** rating system (BRE Group, 2022). This rating system is used for the assessment of civil engineering, infrastructure, landscaping, and public realm projects and contracts. As an example, it is used for several projects like roads, bridges, tunnels, utilities and water projects (Hubbard & Hubbard, 2019).

The phases that this rating system assesses in infrastructure projects are strategy, design, and construction. It also contains eight rating categories, namely Management, Resilience, Communities and Stakeholders, Land Use and ecology, Landscape and historic environment, Pollution, Resources and Transport. Each of these categories at the same time contain several Assessment issues that can be seen in Figure 3-5 (BRE Group, 2022). At the same time, each category is given a weight and it has a maximum number of credits available depending on its assessment issues. For **BREEAM** infrastructure, the total amount of credits possible across all the categories is 5,000 plus 500 from a 9th category called Innovation. Then, different rating levels are possible according to the number of credits obtained and are described as follows:

- Outstanding: if ≥ 90% of the credits are obtained
- Excellent: if ≥ 75% of the credits are obtained
- Very Good: if ≥ 60% of the credits are obtained
- Good: if ≥ 45% of the credits are obtained
- Pass: if ≥ 30% of the credits are obtained
- Unclassified: if < 30% of the credits are obtained

The innovation category is to support innovative solutions within the construction industry and its supply chain. This is done by adding additional credits in a 9th category and rewarding developments that go beyond best practice in a particular aspect of sustainability. These extra credits are summed to the overall score helping teams to achieve better levels of sustainability. Moreover, **BREEAM** infrastructure contains some prerequisites at some assessment issues, which are basically minimum standards that must be complied in order to get credits in that assessment issue, otherwise no score is obtained in that sub-category (BRE Group, 2022).

Category	Assessment issues
1 Management	1.1 Sustainability leadership
	1.2 Environmental management
	1.3 Responsible construction management
	1.4 Staff and supply chain social governance
	1.5 Whole life costing
2 Resilience	2.1 Risk assessment and mitigation
	2.2 Flooding and surface water run-off
	2.3 Future needs
3 Communities and stakeholders	3.1 Consultation and engagement
	3.2 Wider social benefits
	3.3 Wider economic benefits
4 Land use and ecology	4.1 Land use and value
	4.2 Land contamination and remediation
	4.3 Protection of biodiversity
	4.4 Change and enhancement of biodiversity
	4.5 Long-term management of biodiversity
5 Landscape and historic environment	5.1 Landscape and visual impact
	5.2 Heritage assets
6 Pollution	6.1 Water pollution
	6.2 Air, noise and light pollution
7 Resources	7.1 Strategy for resource efficiency
	7.2 Reducing whole life carbon emissions
	7.3 Environmental impact of construction products
	7.4 Circular use of construction products
	7.5 Responsible sourcing of construction products
	7.6 Construction waste management
	7.7 Energy use
	7.8 Water use
8 Transport	8.1 Transport networks
	8.2 Construction logistics

Figure 3-5. Categories and assessment issues for BREEAM infrastructure (BRE Group, 2022).

3.3.3 LEED

Leadership in Energy and Environmental Design, mostly known for its abbreviation as **LEED**, it's a design framework and certification developed by **US** Green Building Council (**USGBC**) that was first launched in 1998 with a pilot version. It's mainly used for buildings, and it was released after **BREEAM** but still it is adopted in more countries, with over 160 countries. Nevertheless, the number of certified buildings is lower, a bit over 79,000. Additionally, from the three pillars of sustainability, **LEED** is mostly focused on the environmental one (Doan et al., 2017).

Moreover, **LEED** is used for the whole lifecycle of a building, this includes design, construction, operations, maintenance and end-of-life. There are four different rating systems developed by **LEED** which are called Building Design and Construction, Interior Design and Construction, Building Operations and Maintenance and Neighbourhood Development. The main categories evaluated at **LEED** are Integrative process, Indoor Environment, Quality, Energy & Atmosphere, Location & Transportation, Water Efficiency, Material & Resources, Sustainable Sites, Regional Priority and Innovation. These categories at the same time have credits (sub-categories), and each credit receives points according to their relative importance (like weights). Then, projects come assessed against the credits and points are allocated depending on the extent of complying to each of them, to be finally all summed (this approach is called ''additive credits''). The maximum number of points possible across all categories is 100 points plus 10 for innovation (same principle as in **BREEAM**, where methods that promote sustainability beyond what is expected in the credits, are rewarded with points) (Hubbard & Hubbard, 2019; LEED, 2019). With the points, **LEED** applies different rating levels and are:

- Platinum: if ≥ 80 points are obtained
- Gold: if ≥ 60 points are obtained
- Silver: if ≥ 50 points are obtained
- Certified: if ≥ 40 points are obtained

LEED categories and credits (with their points allocated) can be seen summarized in Figure 3-6. This is a typical project checklist for **LEED**, and please note that this is for the Building Design and Construction rating system, specifically for New Constructions, so every category and credit is related to it.

LEED v4.1 BD+C
Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	1
0	0	0		**Location and Transportation**	**16**
			Credit	LEED for Neighborhood Development Location	16
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site and Equitable Development	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	5
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Electric Vehicles	1
0	0	0		**Sustainable Sites**	**10**
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1
0	0	0		**Water Efficiency**	**11**
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Optimize Process Water Use	2
			Credit	Water Metering	1
0	0	0		**Energy and Atmosphere**	**33**
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Grid Harmonization	2
			Credit	Renewable Energy	5
			Credit	Enhanced Refrigerant Management	1
0	0	0		**Materials and Resources**	**13**
Y			Prereq	Storage and Collection of Recyclables	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Environmental Product Declarations	2
			Credit	Sourcing of Raw Materials	2
			Credit	Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2
0	0	0		**Indoor Environmental Quality**	**16**
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1
0	0	0		**Innovation**	**6**
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1
0	0	0		**Regional Priority**	**4**
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
0	0	0		**TOTALS** Possible Points:	**110**

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

Figure 3-6. LEED Project Checklist for Building Design and Construction, New Construction.

3.3.4 Envision

Envision is a rating system that is mainly focused on horizontal infrastructures. This rating system was developed in a cooperation between the Institute for Sustainable Infrastructure (**ISI**) and the Zofnass Programme for Sustainable Infrastructure at the Harvard University in the **US**. Envision was launched in 2012 and with it, is possible to design and build roads, railways, ports, airports, power lines, power plants, communication networks, etc (Dall'O' & Bruni, 2020). As it is a relatively new system, just over 140 projects have the Envision award and just a few of them are airports, bridges or roadways (Hubbard & Hubbard, 2019). Additionally, from the three pillars of sustainability, Envision is mostly focused on the environmental one, but is also fair to mention that this rating system assesses resilience of infrastructures (Institute for Sustainable Infrastructure, 2018).

Moreover, Envision is used for the whole lifecycle of an infrastructure, this includes planning, design, construction, operations, maintenance and end-of-life. The structure of Envision is divided in categories, sub-categories, and credits. The main categories assessed are Quality of life, Leadership, Resource Allocation, Natural World and Climate and Resilience (Institute for Sustainable Infrastructure, 2018). The credits are the ones which are given points according to their relevance and are the ones that projects are assessed against. These credits can be quantitative or qualitative assessment credits. At the end, the sum of all the points obtained across all the applicable credits to a certain project, are the ones that indicate the rating level of a project. The maximum number of points possible across all categories and credits is 1,000 points plus points for innovation (same principle as in **BREEAM**, where methods that promote sustainability beyond what is expected in the credits, are rewarded with points) (Dall'O' & Bruni, 2020). The rating levels that can be achieved with Envision are:

- Platinum: if ≥ 50 % of applicable points are obtained
- Gold: if ≥ 40 % of applicable points are obtained
- Silver: if ≥ 30 % of applicable points are obtained
- Verified: if ≥ 20 % of applicable points are obtained

Envision categories, sub-categories and credits (with their points allocated) can be seen summarized in Figure 3-7 (this is a points table for Envision).

ENVISION POINTS TABLE

			Improved	Enhanced	Superior	Conserving	Restorative	Maximum Points
Quality of Life	Wellbeing	QL1.1 Improve Community Quality of Life	2	5	10	20	26	200
		QL1.2 Enhance Public Health & Safety	2	7	12	16	20	
		QL1.3 Improve Construction Safety	2	5	10	14	—	
		QL1.4 Minimize Noise & Vibration	1	3	6	10	12	
		QL1.5 Minimize Light Pollution	1	3	6	10	12	
		QL1.6 Minimize Construction Impacts	1	2	4	8	—	
	Mobility	QL2.1 Improve Community Mobility	1	3	7	11	14	
		QL2.2 Encourage Sustainable Transportation	—	5	8	12	16	
		QL2.3 Improve Access & Wayfinding	1	5	9	14	—	
	Community	QL3.1 Advance Equity & Social Justice	3	6	10	14	18	
		QL3.2 Preserve Historic & Cultural Resources	—	2	7	12	18	
		QL3.3 Enhance Views & Local Character	1	3	7	11	14	
		QL3.4 Enhance Public Space & Amenities	1	3	7	11	14	
Leadership	Collaboration	LD1.1 Provide Effective Leadership & Commitment	2	5	12	18	—	182
		LD1.2 Foster Collaboration & Teamwork	2	5	12	18	—	
		LD1.3 Provide for Stakeholder Involvement	3	6	9	14	18	
		LD1.4 Pursue Byproduct Synergies	3	6	12	14	18	
	Planning	LD2.1 Establish a Sustainability Management Plan	4	7	12	18	—	
		LD2.2 Plan for Sustainable Communities	4	6	9	12	16	
		LD2.3 Plan for Long-Term Monitoring & Maintenance	2	5	8	12	—	
		LD2.4 Plan for End-of-Life	2	5	8	14	—	
	Economy	LD3.1 Stimulate Economic Prosperity & Development	3	6	12	20	—	
		LD3.2 Develop Local Skills & Capabilities	2	4	8	12	16	
		LD3.3 Conduct a Life-Cycle Economic Evaluation	5	7	10	12	14	
Resource Allocation	Materials	RA1.1 Support Sustainable Procurement Practices	3	6	9	12	—	196
		RA1.2 Use Recycled Materials	4	6	9	16	—	
		RA1.3 Reduce Operational Waste	4	7	10	14	—	
		RA1.4 Reduce Construction Waste	4	7	10	16	—	
		RA1.5 Balance Earthwork On Site	2	4	6	8	—	
	Energy	RA2.1 Reduce Operational Energy Consumption	6	12	18	26	—	
		RA2.2 Reduce Construction Energy Consumption	1	4	8	12	—	
		RA2.3 Use Renewable Energy	5	10	15	20	24	
		RA2.4 Commission & Monitor Energy Systems	3	6	12	14	—	
	Water	RA3.1 Preserve Water Resources	3	5	7	9	12	
		RA3.2 Reduce Operational Water Consumption	4	9	13	17	22	
		RA3.3 Reduce Construction Water Consumption	1	3	5	8	—	
		RA3.4 Monitor Water Systems	1	3	6	12	—	
Natural World	Siting	NW1.1 Preserve Sites of High Ecological Value	2	6	12	16	22	232
		NW1.2 Provide Wetland & Surface Water Buffers	2	5	10	16	20	
		NW1.3 Preserve Prime Farmland	—	2	8	12	16	
		NW1.4 Preserve Undeveloped Land	3	8	12	18	24	
	Conservation	NW2.1 Reclaim Brownfields	11	13	16	19	22	
		NW2.2 Manage Stormwater	2	4	9	17	24	
		NW2.3 Reduce Pesticide & Fertilizer Impacts	1	2	5	9	12	
		NW2.4 Protect Surface & Groundwater Quality	2	5	9	14	20	
	Ecology	NW3.1 Enhance Functional Habitats	2	5	9	15	18	
		NW3.2 Enhance Wetland & Surface Water Functions	3	7	12	18	20	
		NW3.3 Maintain Floodplain Functions	1	3	7	11	14	
		NW3.4 Control Invasive Species	1	2	6	9	12	
		NW3.5 Protect Soil Health	—	3	4	6	8	
Climate and Resilience	Emissions	CR1.1 Reduce Net Embodied Carbon	5	10	15	20	—	190
		CR1.2 Reduce Greenhouse Gas Emissions	8	13	18	22	26	
		CR1.3 Reduce Air Pollutant Emissions	2	4	9	14	18	
	Resilience	CR2.1 Avoid Unsuitable Development	3	6	8	12	16	
		CR2.2 Assess Climate Change Vulnerability	8	14	18	20	—	
		CR2.3 Evaluate Risk and Resilience	11	18	24	26	—	
		CR2.4 Establish Resilience Goals and Strategies	—	8	14	20	—	
		CR2.5 Maximize Resilience	11	15	20	26	—	
		CR2.6 Improve Infrastructure Integration	2	5	9	13	18	
							Maximum TOTAL Points	1,000

Figure 3-7. Envision Points Table (Institute for Sustainable Infrastructure, 2018).

An overview of the four systems described above can be found in Table 3-1.

Table 3-1. Overview of the most used rating systems in the construction sector.

	BREEAM	BREEAM Infrastructures	LEED	Envision
Country	UK	UK	US	US
Organizations	BRE	BRE	USGBC	ISI
Flexibility	77 countries	Mainly UK	160 countries	7 countries
First Version	1990	2003 (as CEEQUAL)	1998	2012
Main categories	Management	Management	Integrative process	Quality of Life
	Health & Wellbeing	Resilience	Indoor Environment	Leadership
	Energy	Communities & Stakeholders	Quality	Resource Allocation
	Transport	Land Use & Ecology	Energy & Atmosphere	Natural World
	Water	Landscape & Historic Environment	Location & Transportation	Climate & Resilience
	Material	Pollution	Water Efficiency	
	Waste	Transport	Material & Resources	
	Land Use & Ecology		Sustainable Sites	
	Pollution		Regional Priority	
	Innovation		Innovation	
Rating approach	Pre-weighted categories	Pre-weighted categories	Additive credits	Additive credits
Rating level	Outstanding ≥ 85	Outstanding ≥ 90	Platinum ≥ 80	Platinum ≥ 50
	Excellent ≥ 70	Excellent ≥ 75	Gold ≥ 60	Gold ≥ 40
	Very Good ≥ 55	Very Good ≥ 60	Silver ≥ 50	Silver ≥ 30
	Good ≥ 45	Good ≥ 45	Certified ≥ 40	Verified ≥ 20
	Pass ≥ 30	Pass ≥ 30		
	Unclassified < 30	Unclassified < 30		
Number of certified buildings	over 560,000	over 900	over 100,000	142

All in all, it can be said that the main aim of this literature review was achieved, which was to obtain background information of environmental concerns in airports and sustainable rating systems currently used in the construction sector.

With this review, it was possible to analyze the importance of the emissions and the role that the aviation industry has on climate change. Moreover, it was possible to identify tools to collaborate with sustainability from different perspectives in airports, and focus was made in the sustainable rating systems which are the main objective of this thesis, where one of them will be developed for airport airsides. As it was said before, these tools can help tackling environmental impacts through different indicators, guiding the users, and triggering them on which measures they should apply to be more sustainable. Hence, this literature review its relevant for this thesis because the information from the environmental impacts from the aviation industry is useful to see what are the issues that the rating system to be developed in this thesis should focus on. Also, the analysis of the different existing rating systems is of utmost importance, given that these are used as a guide to set the sustainable rating system in this thesis, mainly considering their structure in categories, indicators, and rating levels.

Now, chapter 4 starts with the development of a rating system for this master thesis, and it starts by analyzing who the main and secondary stakeholders of such a rating system are.

4 CONTEXT ANALYSIS

This chapter delves into a description of the context analysis for sustainable rating systems for airports airside, focusing on the stakeholders involved in the development of it. By examining the stakeholders engaged in these systems, this chapter aims to provide a comprehensive understanding of their roles, interests, and interactions. First, in section 4.1 a description of the main stakeholders is given. Then in section 4.2 a description of secondary stakeholders is given, and finally ins section 4.3 a power-interest grid for stakeholders is provided.

4.1 Main Stakeholders

The main stakeholders are those directly impacted by the implementation and outcomes of the sustainable rating system. They have a significant interest in its development, compliance, and adoption. These are mentioned in the following.

Airport Operators

Airport Operators are responsible for the management and operations of airports. This means that they are responsible for the infrastructure management, ensuring that the infrastructure meets safety standards and that is properly maintained to accommodate the needs of airlines, passengers and other stakeholders. Infrastructures include runways, taxiways, auxiliary streets, terminals, hangars, parking facilities and other related structure. Moreover, **AO** are responsible of airside operations, meaning managing the movement of aircraft on the ground, ensuring efficient aircraft flow in the runways, taxiways and apron to prevent accidents.

Additionally, **AO** are increasingly focused on environmental sustainability as stated in Sreenath et al. (2021), so they are striving for implementing measures that reduce the environmental impact of airport operations and infrastructure. Therefore, **AO** have a significant stake in a sustainable rating system for the airport airside, as it can impact their reputation, competitiveness, and relationships with airlines, passengers, and other stakeholders. They may actively participate in the rating system and strive to improve their sustainability performance. They can do this by following the rating system as a framework for guidance on how they should design and build the infrastructure. Nowadays, **AO** should consider more and more using these state-of-the-art methodologies to have a more sustainable (certified) airport and improve their image compared to other airports. Examples of airport operators are Royal Schiphol Group in the Netherlands and Aeropuertos Argentina 2000 in Argentina.

Airlines

Airlines are responsible for flight operations, transporting passenger and cargo. Hence, they must ensure safe and efficient operation of flights for passengers and crew, this is a paramount responsibility. Moreover, airlines focus on providing a positive customer experience via comfort, quality of service and convenience to passengers throughout their journey.

As airlines operate at airports, they depend on the management of these infrastructures provided by **AO** and the rules that they may apply. Hence, airlines have a vested interest in the sustainability of the airports they serve because they should comply with the airport regulations. In the case that the **AO** uses a sustainable rating system for airsides, this will have an impact on airlines. Moreover, a rating system it can help airlines assess the environmental impact of their operations and make informed decisions about choosing sustainable airports as hubs or destinations. Hence, airlines are considered to be interested in the system but with mid power over it, given that they depend on the **AO** decisions yet with possibility of feedback on it.

Airports Council International

ACI is a global association that represents airports and their interests around the world to promote excellence in the aviation sector (ACI, 2023). This association supports the development and sustainability of airports, being the ones that developed the **ACA** program. Hence, the rating system specifically for the aviation industry is of great relevance to them and they are also considered to have power given that they can push for the use of the tool among their members (712 members, 1,925 airports) (ACI, 2023).

Governmental bodies (ministries in some countries)

Governmental bodies are a crucial stakeholder in the development, regulation and management of transportation systems and infrastructures within a country. Some of their key roles and responsibilities related to a rating system for airports are policy development, infrastructure planning and development, regulation and legislation, and most importantly environmental sustainability. The latter one being of increasingly importance nowadays where these bodies focus on promoting sustainable transportation practices. They develop and implement policies to reduce greenhouse gas emissions and integrate environmental considerations into infrastructure planning and development. Therefore, a sustainable rating system for airport airsides is of much interest to them in order to push for a more sustainable future in the aviation industry, while their power is also considered to be high due to their influence on policies.

Aviation Regulators

The aviation regulators are national agencies and are often referred as National Aviation Authority (**NAA**) or Civil Aviation Authority (**CAA**). Their key responsibilities are to maintain an aircraft registry issuing registration certificates, ensuring a safe air travel, setting standards for environmental considerations within the aviation industry and also guidelines for airport operations and construction (TravelPerk, 2023). Therefore, they are key stakeholders for this master thesis because they have power when it comes to practices that make the aviation industry more sustainable given that they set the standards and regulations to be followed. However, their interest is not as high as their power, given that their main concern is safety, while sustainability is sometimes imposed to them via governmental bodies (ICAO, 2022). Some examples of these regulators are **ICAO** (specialized agency of the United Nations (**UN**)) , Federal Aviation Administration (**FAA**) in the United States and European Aviation Safety Agency (**EASA**) in Europe.

Suppliers and service providers

In this case, two different service providers related to airports are identified as main stakeholders. These are namely airport consultants' firms and **GSE** providers.

The former ones have a key role in the development of an airport, namely in the planning, designing and construction phases of the airport facilities. Some of the services offered are masterplan studies, structural design, environmental studies, construction supervision and, tendering and bidding (Rousset, 2021). One example of airport consultants is **NACO** where this thesis is currently being developed. For **NACO** (and other consultants), the development of such a framework as a sustainable rating system for airport airsides is of a mid-high interest, given that with these tools they can provide more environmentally friendly design of airports for their clients. Moreover, the use of these state-of-the-art methodologies also gives a better image and reputation to the company, by clearly demonstrating that they are eager to go green in the industry. On the other hand, their power is considered to be low because in the end, the client is who decides for what project to go for.

The latter ones, **GSE** providers (sometimes is the **AO** and sometimes third companies), are the ones in charge of supplying vehicles, machinery and equipment used at airports to support various ground operations related to aircraft handling, passenger services, cargo operations, and airport maintenance. Some of the common types of **GSE** are the pushback tractors, passenger boarding bridges, baggage tractors, ground handling equipment and de-icing equipment (NACO Aviation Academy, 2023d). For the **GSE** providers, the rating system for the airside is of importance because they will be influenced depending on the decisions taken by the **AO** on the infrastructural design. Maybe adapting their vehicles and equipment to the sustainable infrastructure is one of the consequences. Also, their power regarding a rating system for airports is mid-low, where they should follow orders but still can provide some feedback.

Staff on airside

The staff which is everyday working on airsides come from different companies and this depend on the airport administration. Commonly, the staff found on airsides are all of them who work for **GSE** companies, airlines and the **AO**. They are subjected to different sources of pollution like **PM**, noise, **NOx** and heat island effects (Møller et al., 2017). Hence, they are interested in the development of a rating system for airsides that can make their work environment healthier from some perspective. Moreover, they are considered to possess power giving that they are the ones who are present every day on airsides, and it is completely on their rights to ask or complaint for improved working conditions. In this way, the companies and, in consequence, the **AO** can listen to them and maybe opt for the use of a sustainable rating system in airsides.

Local communities

Residents of the surroundings of an airport are impacted by noise pollution, air quality, and land use. Their interest mainly lies in fewer noise emissions and better air quality from the airport (Sameh & Scavuzzi dos Santos, 2018). Therefore, they are in favor of the rating system developed in this thesis, in the case that this pushes for a change of technology in aircrafts and **GSE**. Additionally, they can provide feedback for the system on the environmental and social aspects of airport operations. They may also participate in public consultations and engage with airport operators to address community concerns. Hence, they have a big interest, but a low power given that their weight compared to the economy behind the aviation industry is quite low.

4.2 Secondary Stakeholders

The secondary stakeholders, while not directly affected by the rating system, still have a vested interest and contribute to its success. They provide expertise, influence, or support to the main stakeholders and may indirectly benefit from the implementation of sustainable practices in airports. These are mentioned in the following.

Environmental groups

Different environmental groups as Greenpeace or World Wildlife Fund, are known for their campaigns on climate change, pollution, and biodiversity conservation. One of the topics of interest for them is the aviation industry and call for a reduction in air travel and the adoption of cleaner technologies (WWF, 2023). New frameworks for guidance of **AO** on how to build more sustainable airports, it is for sure something that they support and has a positive impact on them. As their main focus it is not aviation, their interest is considered to be medium-low as well as their power.

Passengers

Passengers flying with different airlines are obviously obliged to go through an airport, given that they must board an airplane in a correct, safe, and organized way. Although they are not considered as main stakeholders for this thesis, still they can have some psychological influence from the application of a rating system in airsides. This is because nowadays more people is environmentally concerned, especially younger people, which have an influence in mode choice of passengers (Bouscasse et al., 2018), causing them to choose train over plane for instance, even if all other factors are similar (price, time, comfort, etc.). Hence, if an **AO** seeks to apply a sustainable rating system in their airsides and makes propaganda of it, passengers can feel more attracted to choose plane as a more environmentally friendly mode of transport. Nevertheless, passengers are considered to have low interest and low power for this thesis.

Local Governments (municipalities, city, or regional governments)

The local governments are responsible for issuing building permits. Therefore, they analyze the characteristics of an airport, with its influence in the surroundings and the methodologies carried out for an airport construction (Orvel, 2021). In the case that they do not agree with the characteristics of the project, they can block it completely. The rating system can be of much use to them because they can use it as a guide for them as well. In this case, **AO** and municipalities can use the framework to align objectives regarding environmentally friendly practices.

Suppliers and service providers (construction firms)

In this case, the service providers related to airports identified as secondary stakeholders are the construction firms. These companies should follow the design provided by the consultant firms, which at the same time was done following the sustainable rating system. Therefore, their power is considered to be low, but they rather have a mid-high interest in the rating system because they are the ones that should carry out the sustainable practices in their corresponding sector.

4.3 P/I Grid

A power-interest matrix is created taking into account all of the interests of the many parties involved in this project. The main objective is to indicate the position of the main stakeholders who can significantly influence the outcome of this project. The matrix also enables the inclusion of all the stakeholders who might not have a significant impact on the project but are nevertheless appropriate to mention. The created Power - Interest matrix for this project is given in Figure 4-1.

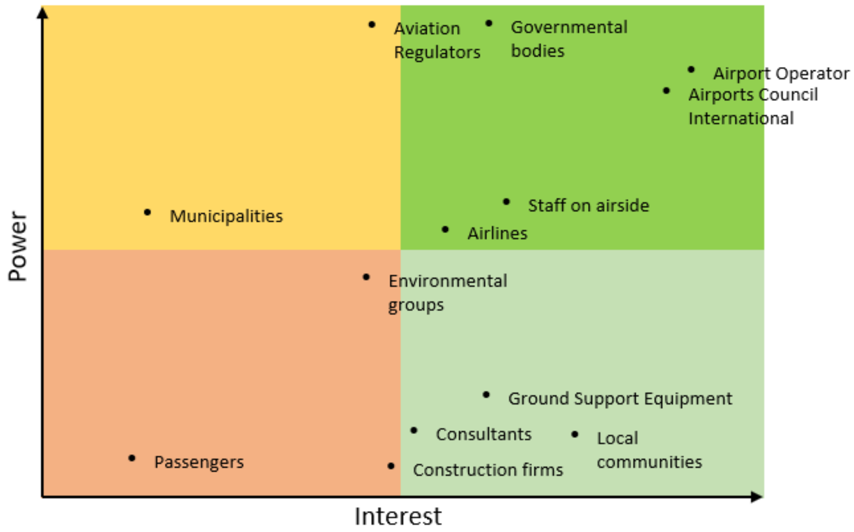


Figure 4-1. Stakeholder P/I grid.

Stakeholders are usually consulted when developing a sustainable rating system, they are usually involved in the weight of the different credits. This is done through questionnaires prepared for them comparing the different credits, where they have to assign a rating to them (AbdelAzim et al., 2017). Then, their ratings are transformed into points using different methodologies and techniques, as an Analytical Hierarchy Process (**AHP**) (AbdelAzim et al., 2017; Diaz-Sarachaga et al., 2017b; Yu et al., 2015). In this thesis, due to the objective and time reasons, this approach was not followed, but the weight its mainly done with desk research. Nevertheless, the stakeholders are used in the conclusion of this master thesis, to give an insight on what would change if the stakeholders were involved in the weight decision.

Having finished with the stakeholder analysis, now in chapter 5, the boundaries that this rating system considers are given.

5 BOUNDARIES OF RATING SYSTEM

The focus of this chapter is to define the boundaries of the rating system that is developed in this master thesis. This means defining the limits within which the rating system operates. In this way, elements, processes, and interactions to be included or excluded when designing the rating system are determined.

In the case of this thesis, three types of boundaries are defined, namely spatial boundaries (in section 5.1), component boundaries (in section 5.2) and functional boundaries (in section 5.3). The approach on defining the boundaries is a ''hierarchy'' approach, from broader to smaller, and an illustration can be seen in Figure 5-1. Where first the geographical area (spatial boundary) where the rating system acts is defined. Then, the activities inside this area (component boundaries) that are considered for the rating system are defined and, lastly, the specific parts/processes of the activities (functional boundaries) that are considered for the rating system are defined.

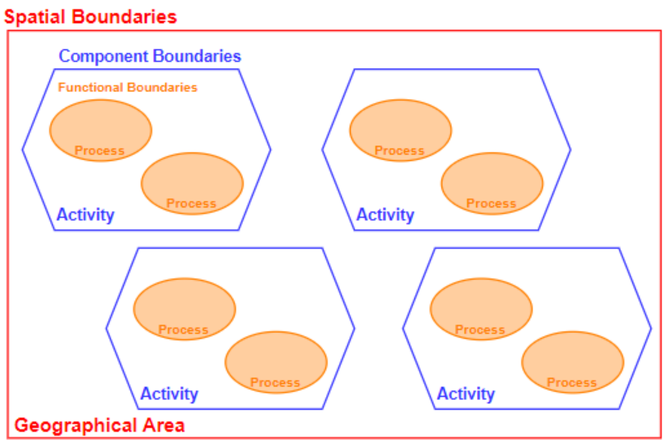


Figure 5-1. Boundaries scheme.

5.1 Spatial Boundaries

By spatial boundaries is intended to define the physical space within which the system operates. As already mentioned earlier in section 1.3, the scope of this rating system is the airside of an airport, hence, this section will define what exactly means the airside geographically speaking.

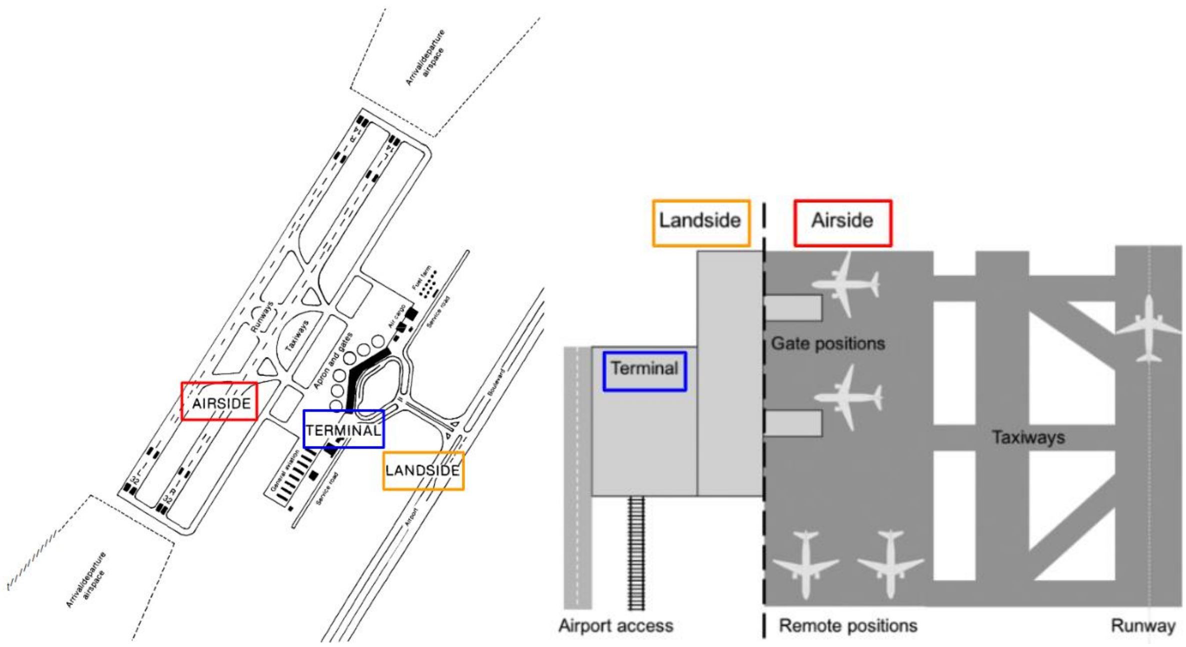
5.1.1 Geographical organization of an airport

Airports are fundamental for air transportation. They allow the take-off and landing of aircrafts while providing also essential facilities to serve the aircrafts (Schmidt, 2017). Hence, airports are complex transportation hubs which serves the aircraft, while also serving cargo, passengers, and surface vehicles (OTA, 1984). An airport has several components and it is common to classify them in two or three major categories, depending the source. OTA (1984) classifies them in three categories: landside facilities, terminal building, and airside facilities, and can be seen in Figure 5-2 (a). While Horonjeff (2010), gives a classification in two major categories: airside and landside, where the terminal is considered part of the landside, and can be seen in Figure 5-2 (b). For a purpose of discretization, the tripartite classification is described in the following.

The airside components are also called the airfield and are basically those where an aircraft operates. Mainly, this englobes the **RWY**s where an aircraft takes off and lands, the **TWY**s that connects and permits the movements of aircrafts between the runway and the terminal, and the apron and gate areas where aircrafts park and passengers embark and disembark (Please see Figure 5-2) (OTA, 1984).

The terminal is mainly the building that serves the passengers, and it contains passenger waiting and loading areas, ticket counters, facilities for baggage handling, security controls, shops, and car rental facilities. It is also important to mention that the air cargo facilities such as loading, handling and storage areas, are separately located but are considered part of the terminal complex (Please see Figure 5-2) (OTA, 1984).

The landside is the part of the airport that is dedicated to surface transportation. This means that begins at the curbside of the terminal building and englobes railway stations and lines that form part of an urban mass transit system, roadways that provides access to the airport and parking facilities. Habitually, just roadways and transportation facilities that are owned by the airport are considered part of the landside (Please see Figure 5-2) (OTA, 1984).



(a) **(b)**

Figure 5-2. Tripartite (a) (OTA, 1984), and bipartite (b) (Schmidt, 2017) classification of airports.

Irrespective of the tripartite or bipartite classification, this thesis defines as spatial boundary the airside of an airport. This means from the black dashed line to the right in Figure 5-2 (b). A description of the components of an airport system is given in Figure 5-3 and it summarizes all the components for a bipartite classification where the terminal is included in landside. Please note that from Figure 5-3, in this thesis the focus is done in all those components which are part from the airside. In section 5.2 a better description of the airside with its activities and components is given.

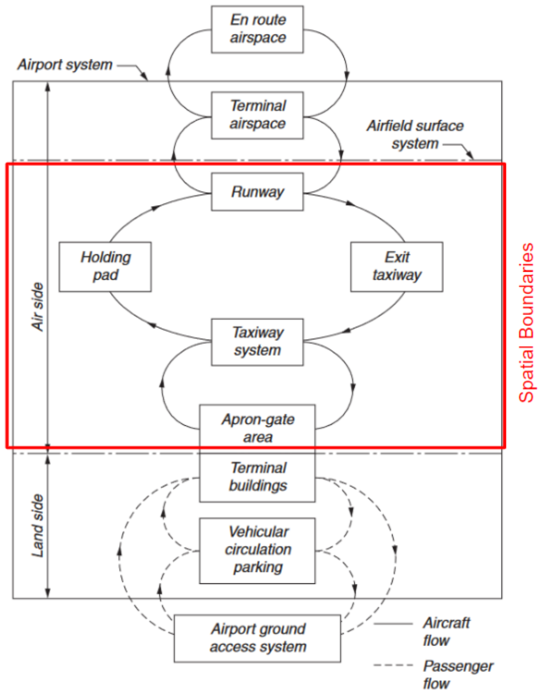


Figure 5-3. Components of the airport system (Horonjeff, 2010).

5.2 Component Boundaries

By component boundaries is intended to define the elements (subsystems or resources) that are part of the system. In the case of the airside of an airport, this means defining the different activities or disciplines carried out there, and specifically saying which of those are considered for this rating system. Hence, in section 5.2.1 all the activities and disciplines found in an airside are described. Then, in section 5.2.2 all those activities and disciplines that are related to an airside infrastructure are defined, in order to comply with the scope defined in section 1.3. Finally, in section 5.2.3, the most relevant disciplines and activities (from those of section 5.2.2) in terms of environmental impacts, to consider for this master thesis are provided.

5.2.1 Activities and Disciplines on Airside

It is important first to differentiate between disciplines and activities. On the one hand, by disciplines is intended to define all the different main sources of work that need to be carried out before an airport's airside is operational. On the other hand, by activities is intended to define the different tasks that are being executed every day in an operational airport's airside. In Figure 5-4 an illustration of all the activities and disciplines found on airside can be seen and are described further in this current section.

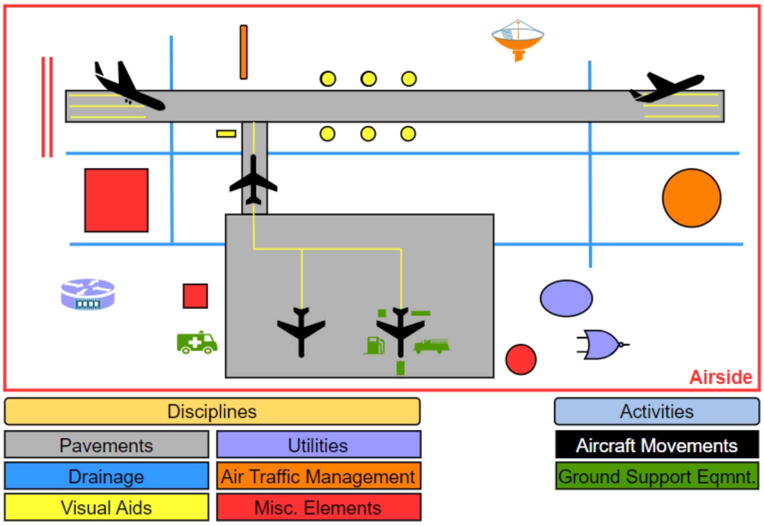


Figure 5-4. Disciplines and activities on airside.

To start with, the different main disciplines are defined in the following.

- Pavements

  This category englobes all the pavement structures in an airside, and these are the runways, taxiways, aprons (holding and terminal apron) and service roads.

  According to Horonjeff (2010), the runway is a rectangular surface which is prepared for the takeoff and landing of aircrafts. Moreover, an airport can have one or several, and these are located, oriented and constructed in such a way that provide safe and efficient use of them in several conditions. When talking about the runway system, this includes the structural pavement, the blast pad, the shoulders, the runway end safety area (**RESA**), the **RWY** protection zone and several surfaces free of obstructions (Horonjeff, 2010). The runway from Red Sea International Airport in Saudi Arabia, can be seen in Figure 5-5.

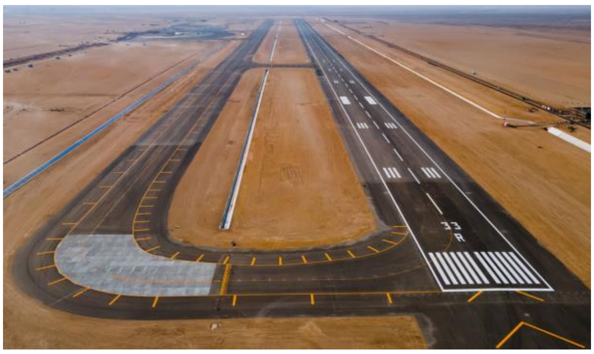


Figure 5-5. Red Sea International Airport runway (NACO Aviation Academy, 2023e).

  Then, Horonjeff (2010) defines the taxiways as paths on the airfield which are built for the aircrafts to move between one part of the airfield and another. The main movements are from the runway towards the apron. Apart from the regular taxiways, NACO Aviation Academy, (2023e) sustains that there are different types within the **TWY** system, and these are the aircraft stand taxilane, the apron taxiway, rapid exit taxiway, parallel taxiway, cross taxiway, entrance and exit taxiway and perimeter taxiway. To define some of them, the aircraft stand taxilane is the portion of the apron designated as taxiway that gives access to the aircraft stands only. Then, the apron taxiway is a portion of the **TWY** system that is located in the apron and provides through taxi-route across the apron (Horonjeff, 2010; NACO Aviation Academy, 2023e). Finally, the rapid exit taxiway is a **TWY** that is connected to a **RWY** at an acute angle and permits a fast clearing of the runway for landing aircrafts (NACO Aviation Academy, 2023e; Roling, 2022b). As in the case of the **RWY**, the **TWY**s also should have a safety margin in operating areas, this means that they should be sufficiently separated from each other and from other obstructions. To comply with this, minimum separations are stipulated in **ICAO** standards (Horonjeff, 2010). Part of the taxiway system from Red Sea International Airport can be seen in Figure 5-6.

Figure 5-6. Part of the taxiway system in Red Sea International Airport (NACO Aviation Academy, 2023e).

Now coming to the aprons, these are defined in Horonjeff (2010) as areas that are prepared for the parking or holding of aircrafts for a long period of time. NACO Aviation Academy, (2023e) sustains that there are different types of aprons such as terminal aprons, remote aprons (operational and non-operationals), general aviation aprons, helicopter apron, cargo apron, maintenance, repair and overhaul apron, de-icing apron, holding aprons, engine runup bays and isolated aircraft parking positions. Just to describe the most used of them, the terminal aprons are those that contain the aircraft stands or parking positions close to the terminal and permit the aircraft to be parked for a long period of time while passengers are boarding and deboarding and the aircraft is being served with different sources (Horonjeff, 2010; NACO Aviation Academy, 2023e). An important characteristic is that the aircraft stands are sized depending on the geometric properties of a given design aircraft, this includes wingspan, length of the fuselage, turning radii and also for the vehicles servicing the aircraft at the gates (NACO Aviation Academy, 2023e). To this end, minimum clearances between any part of two aircrafts, or between an aircraft and a structure, are recommended by **ICAO** (Horonjeff, 2010). The requirements of design for all the types of aprons are the same. The example of an apron under construction can be seen in Figure 5-7, from Red Sea International Airport. Also, an illustration showing the different types of pavements described so far can be seen in Figure 5-8.

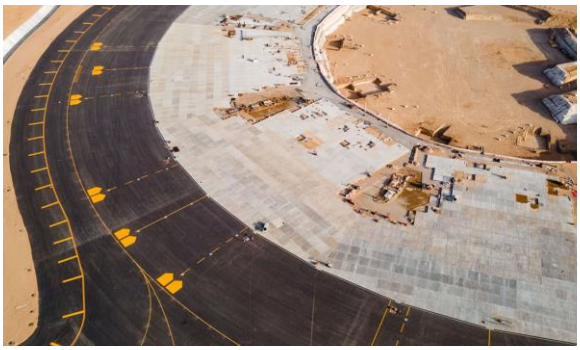


Figure 5-7. Apron of Red Sea International Airport under construction (NACO Aviation Academy, 2023e).

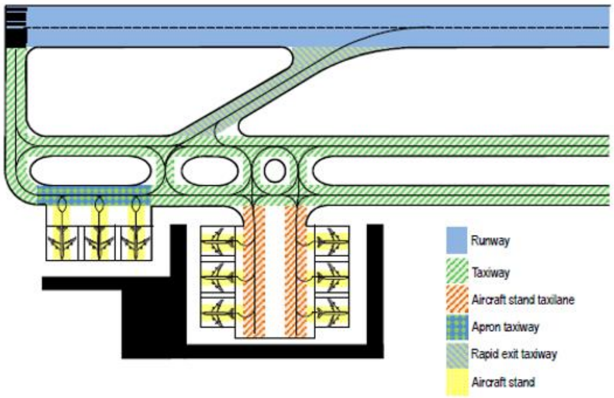


Figure 5-8. Different types of pavements on airside (NACO Aviation Academy, 2023e).

Finally, Horonjeff (2010) defines the service roads as internal roads within the airport and are pavement surfaces that provide access to different facilities in the airside of an airport. These are meant to be used by airport service vehicles as catering trucks, fire trucks, maintenance vehicles, baggage trolleys or different equipment necessary for airport operations (Horonjeff, 2010).

- <u>Drainage</u>
  This category englobes the drainage system and its structures in the airside.

  A drainage system is key to remove surface and subsurface water from pavements and keep them safe for aircraft operations. As mentioned in Horonjeff (2010), bad designs of drainage can lead to puddles in pavements, generating unsafe conditions for aircraft taking off and landing. Moreover, a bad drainage can also deteriorate pavements, which means that these will need to be maintained frequently or even replaced (Horonjeff, 2010).

  The goal of a drainage system at an airport is threefold, and is stated in Horonjeff (2010) as:
  1. To intercept and divert surface and groundwater flow which is originated from lands adjacent to the airport.
  2. To remove surface runoff water from the airport
  3. To remove subsurface flow from the airport

  To achieve this objective, several structures are often used at airports airsides. The main ones that can be distinguished are pipes, culverts, channels, ditches, grated drains, slotted drains, ponds and **OWS**s. It is fair to mention that although an **OWS** does not intercept and divert water, its main function is to separate oil and other hydrocarbons from water runoff (Gómez Comendador et al., 2019), and it is considered a structure within the drainage system for this master thesis.

- <u>Visual aids</u>
  This category englobes the **AGL**, marking and signage in the airside of an airport. All these aids are essential in an airport infrastructure and are there to assist pilots in the operations of landing, takeoff and navigating around the airfield.

  The lights are defined in Horonjeff (2010) as those in charge of guiding the pilots through the airfield and in takeoff and landing operations during the night. Lighting can be categorized in approach lighting or surface lighting. The approach lighting category englobes the Approach Lighting System (**ALS**) and the **RWY** approach slope indicators. While the surface lighting englobes the **RWY** threshold lighting, **RWY** edge lighting, **RWY** centerline and touchdown zone lights, the **TWY** edge lighting and the **TWY** edge lighting (Horonjeff, 2010; NACO Aviation Academy, 2023b). All these types of lights have different colors and can be seen in Figure 5-9.

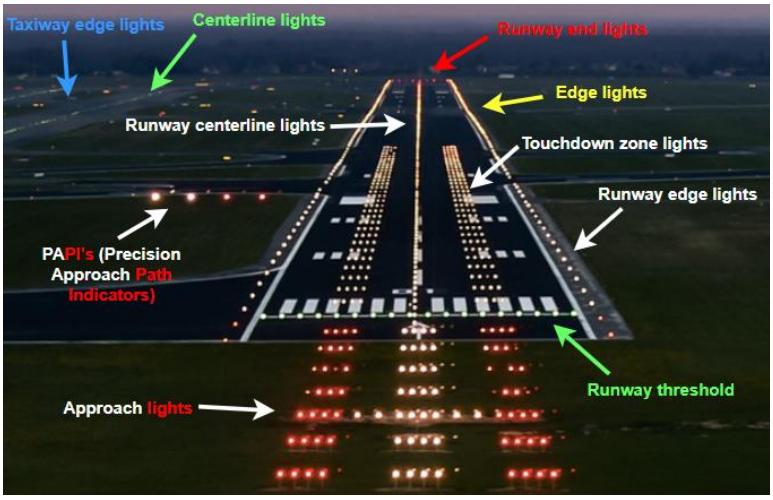
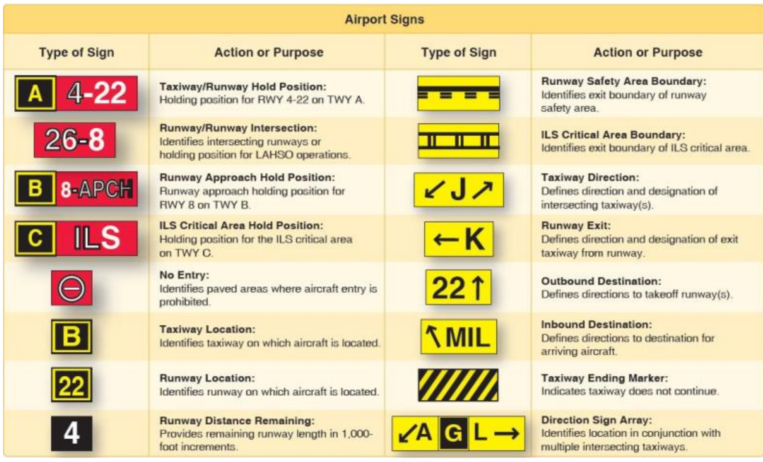


Figure 5-9. Different types of lights within the AGL system (NACO Aviation Academy, 2023b).

When it comes to marking, this is aimed to define the **RWY** and **TWY** pavement marking, which is done with lines and numbers. The objective of marking is to aid the pilots guiding the aircraft on **RWY**s and **TWY**s, and these are helpful during the day and dusk. In the night, the lighting is the main used system. White painting is used for the **RWY** (as those shown in Figure 5-5) while yellow painting is used for the **TWY** (as those shown in Figure 5-6) (Horonjeff, 2010; ICAO, 2018). The sizes of the different markings are already standardized as per different bodies as **ICAO** or **FAA**.

Signage is also there in the airside to guide pilots and ground vehicle operators to different locations in the airport. Moreover, some signage indicates other information such as remaining distance on a runway, location of key facilities or position on the airfield to pilots (Horonjeff, 2010). Part of the signage is mandatory as those indicating the entrance to a runway, a prohibited area, or critical areas. Please see Figure 5-10 to find different types of signage that can be found at an airfield.



Airport Signs			
Type of Sign	Action or Purpose	Type of Sign	Action or Purpose
A 4-22	**Taxiway/Runway Hold Position:** Holding position for RWY 4-22 on TWY A.		**Runway Safety Area Boundary:** Identifies exit boundary of runway safety area.
26-8	**Runway/Runway Intersection:** Identifies intersecting runways or holding position for LAHSO operations.		**ILS Critical Area Boundary:** Identifies exit boundary of ILS critical area.
B 8-APCH	**Runway Approach Hold Position:** Runway approach holding position for RWY 8 on TWY B.	↙J↗	**Taxiway Direction:** Defines direction and designation of intersecting taxiway(s).
C ILS	**ILS Critical Area Hold Position:** Holding position for the ILS critical area on TWY C.	←K	**Runway Exit:** Defines direction and designation of exit taxiway from runway.
⊖	**No Entry:** Identifies paved areas where aircraft entry is prohibited.	22↑	**Outbound Destination:** Defines directions to takeoff runway(s).
B	**Taxiway Location:** Identifies taxiway on which aircraft is located.	↖MIL	**Inbound Destination:** Defines directions to destination for arriving aircraft.
22	**Runway Location:** Identifies runway on which aircraft is located.		**Taxiway Ending Marker:** Indicates taxiway does not continue.
4	**Runway Distance Remaining:** Provides remaining runway length in 1,000-foot increments.	↙A G L→	**Direction Sign Array:** Identifies location in conjunction with multiple intersecting taxiways.

Figure 5-10. Airfield Signage (ASA, 2018).

- Utilities

  It is important first to mention that all the information related to utilities was extracted from NACO Aviation Academy (2023c).

  Utilities are public services such as electricity, telecommunications or water that are used by everyone. These are required at airports to ensure that its intended purpose can be carried out. If utilities were not there, the airport facilities would be unusable boxes. There are two categories of utilities, Dry utilities, and Wet utilities, but in this case also a third category is added, called aviation related utility activities and are explained at the end (NACO Aviation Academy, 2023c).

  Dry utilities are those that do not convey a liquid, and these can be electricity, natural gas, and telecommunications. At an airport the most common ones are power supply and telecommunications. The power supply at an airport comes from a distribution sub-station from an electrical power system, and travels in cables or cable ducts to medium and low voltage sub-stations to be finally used by the consumer (aircrafts at airports for instance). While telecommunications are the transmission of information by different types of technologies over wire, radio, optical or other electromagnetic systems. In an airport this have different uses for different stakeholders, and this can include passenger handling, baggage handling, air traffic control or video surveillance and access control.

  On the contrary Wet utilities are those that convey liquids, and these can be sewer, water, firewater, heating, and cooling. At an airport the most common ones are potable water, wastewater, firewater, heating, and cooling. The potable water source can be ground water or surface water from lakes, dams, or rivers, with prior treatment in plant. After the plant this is generally stored at an airport and is distributed via a pipe network. The wastewater is that waterborne waste coming from human activities and compounds from industries and commercial establishments (is also known as sewage water), which is then sent to a wastewater treatment plant. Then, firewater refers to the water that is used for firefighting. This type of water is stored on-site in a reservoir and is pumped via pressure to firefighting devices such as fire hydrants, hose, and sprinkler systems. The heating is done via district heating facilities that refers to the distribution of heat generated in a centralized location through a system of insulated pipes for space heating and water heating. The heat can be generated via fossil fuels, biomass, solar heat, or geothermal heat. Similarly, district cooling applies the same principle, where chilled water from a water plant travel to the building, cooling the space, and returns to the plant to be cooled again.

  The aviation related utilities are all those related directly to the operations of aircrafts. In this case, they are the Pre-Conditioned Air (**PCA**), the Ground Power Unit (**GPU**), potable water for the aircraft, trituration/blue water/aircraft wastewater disposal, fuel, de-icing, and aircraft washing. The **PCA** units provide outside air for heating or cooling the parked aircraft, and it is attached to it via one or more air hoses through a port typically located on the underbelly of the aircraft. These units can be mobile, fixed, or centralized, and are easy to spot because in most large airports around the world it contains bright yellow hoses. The **GPU** provides the 400 Hz power required by an aircraft electrical system, while this is parked in the stand position, allowing the aircraft to shut down the **APU** engines. The **GPU** units can also be mobile, fixed, or centralized. The potable water is filled into aircrafts with portable water trucks, portable water cabinets or tank on carts. Another utility is the wastewater from the aircraft, which is emptied into a tank of the lavatory service vehicle via a port, on the underbelly of the aircraft. Furthermore, the lavatory tanks are flushed and filled with diluted blue water (biocide) from a different storage tank from the same truck. Then, the wastewater is transported to the trituration facility where it is discharged into a sump and solids in the wastewater are ground up. Next, wastewater is pumped away for treatment, the lavatory vehicle fills the blue water tank with diluted blue water and proceeds to the next aircraft, and the process is repeated. The other utility related to aviation is the aircraft refueling, which can be done with a fuel refueler truck or a fuel hydrant network and dispenser. The former one, transports the fuel from a fuel farm (storage of fuel at the airport) to the aircraft with a truck and then pumps it into the fuel storage tanks of the aircraft. In the latter one, the fuel is pumped from the fuel farm via a looped pipe network to fuel hydrants located in pits under the wings of the aircraft. Then, a vehicle called a dispenser connects to the fuel hydrant and uplifts the fuel into the aircraft. Coming to one of the last utilities, the de-icing and anti-icing processes are found. De-icing means removing ice and snow from the aircraft by applying a de-icing fluid, while anti-icing means preventing the formation of ice on the aircraft. There are two main types of de-icing fluid, propylene glycol and ethylene glycols, in both fluid is heated and sprayed under pressure onto the wings of the aircraft. Finally, the last aviation related utility is the aircraft washing, which is required to improve the aerodynamics and safety of the aircraft. There are two types of washing, dry wash and wet wash. The dry wash uses little amount or no water at all, where the cleaning product is applied manually, and a microfiber fabric is then used to remove the cleaning product. While in the wet wash, the cleaning product is applied to the surface of the aircraft and then high-water pressure wash is used to rinse the surface of the aircraft.

- Air Traffic Management

  The main function of the Air Traffic Management (**ATM**) system according to Horonjeff (2010) is to prevent accidents between aircrafts and between aircrafts and obstructions, in order to maintain a safe and ordered flow of air traffic.

  As stated by Roling (2022a), **ATM** components englobe procedures and regulations, air traffic controllers, automation systems, communication systems, surveillance systems and navigation systems. Some of the most important requirements for **ATM**s is that they need an exceptional level of safety, they should take advantage of new technology, operate cost effectively and they should accommodate growing numbers of diverse users efficiently (Roling, 2022a).

  To briefly describe some of the most important components of the **ATM** system, it can be mentioned the characteristic Air Traffic Control Tower (**ATCT**) and the Navigational Aids (**NAVAIDS**). According to Horonjeff (2010), the **ATCT** is the building that directs and monitors the different arrival and departure flights at an airport and within 5 mi of distance in the airspace of it. Moreover, it provides different meteorological information to pilots as wind, barometric pressure, temperature and operating conditions at the airport, by means of the Meteorological (**MET**) systems. Some examples of **MET**s is the Automated Weather Observing System (**AWOS**) and the Illuminated Wind Direction Indicator (**IWDI**). On the other hand, Horonjeff (2010) defines the **NAVAIDS** as systems that provides aids on navigation to pilots, and classifies them into two groups, the satellite-based systems, and the ground-based systems. In one side, in the satellite-based systems, the Global Positioning System (**GPS**) is the greatest impact on **ATM** in the 21st century. The **GPS** is based on a satellite radio positioning and navigation system, and it is designed for high accuracy position and velocity information in a continuous way to unlimited number of equipped users. On the other side, the ground-based systems are several and some of them are the Very High Frequency Omnirange Radio (**VOR**), the Distance Measuring Equipment (**DME**) and the Instrument Landing System (**ILS**). The **VOR** was developed after the World War II, and what the system does is to send radio signals in all directions. Each of the signals is a radial that can be followed by an aircraft to reach its destination. The **VOR** emits that radials are in an interval of 1 degree and there are 360 radials (from 0 degrees according to the magnetic north to 359 degrees in clockwise direction). Then, the **DME** is an instrument that can be installed together with the **VOR** and indicates the distance from the aircraft to the **VOR** station. Finally, the **ILS** is the one in charge of providing the aircraft with vertical and lateral guidance in the approach to the runway. The **ILS** is composed of a localizer and a glide slope. The former one is the one in charge of providing lateral guidance to the aircraft according to the centerline of the runway. While the latter one is in charge of the vertical guidance indicating the correct angle of descent to the runway (Horonjeff, 2010).

- Miscellaneous Elements
  In this category all those items that were not mentioned in any of the previous categories, but still related to airsides, are mentioned here. These elements are the fences in the airside, jet blast barriers for aircrafts, bollards protecting different zones in the airside, trash and litter receptacles, curbs, hangars for aircraft maintenance and infrastructure provided for alternative power sources (as electricity or hydrogen), among others.

Then, the different activities are defined in the following.

- Aircraft Movement
  Of course, the main activity on the airside is the movement of aircrafts, since they touch down in the runway until they arrive to the parking position or, the other way around, from the parking stand until they take off in the runway. The taxiing distances at some airports can be large (e.g. as that of the polderbaan runway at Schiphol Airport in the Netherlands (Schiphol, 2020a)), and the traffic can be quite high as well, as in the Hartsfield – Jackson Atlanta International airport for example (Ranabhat, 2023).

- Ground Support Equipment
  Ground Support Equipment is referred in ICAO (2014) as the category of vehicles and equipment that provide different services to the aircrafts. These includes the vehicles used for towing, maintenance, providing electric power, fuel services, loading and unloading for passengers and cargo, and other services.

  The diversity of equipment for **GSE** is large and the different categories can be seen in Figure 5-11.

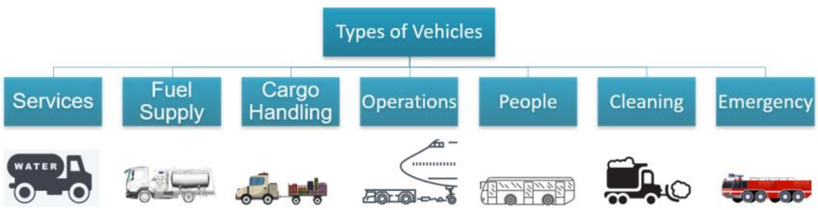


Figure 5-11. Different types of vehicles in GSE (NACO Aviation Academy, 2023d).

The first category seen in Figure 5-11 is the **GSE** related to aircraft services. This category includes water trucks, sewage/lavatory trucks, **GPU**s (see Figure 5-12), **PCA** units and Air Starting units. The second category related to fuel supply includes fuel bowsers and fuel hydrant dispensers. The third category is cargo handling and englobes the pallet tractor, pallet dolly, pallet mover, pallet loader, baggage tractor, baggage dollies, baggage conveyor belts and the catering truck. The fourth category is the operations one and includes the push-back/pull tractor (see Figure 5-12) and the follow me car (NACO Aviation Academy, 2023d).

Figure 5-12. GPU and push/pull tractor (NACO Aviation Academy, 2023d).

Then, in the fifth category of Figure 5-11, the vehicles and equipment for people can be found. This category englobes the stairs for people to board or deboard the aircraft, the airport passenger buses and vehicles for people with reduced mobility. The sixth category is the cleaning equipment and this includes the sweeper/ broom, the aircraft de-icing vehicle, the pavement de-icing vehicle and the snow removal equipment. Finally, the last category is the emergency vehicles and this includes the Airport Fire Fighting (**ARFF**) vehicle, **ARFF** command vehicle, ambulance, police vehicle, different types of customs vehicles and the security vehicle (NACO Aviation Academy, 2023d).

5.2.2 Activities and disciplines related to Airside infrastructure

In this section, the disciplines and activities (or elements of them) that are related to the airside infrastructure are chosen from those previously defined in section 5.2.1. This is done to comply with the scope defined in section 1.3 of this thesis.

Table 5-1 presents all the elements per discipline/activity that are related to the airside infrastructure and are explained in the following.

First coming to the disciplines, from the pavements and drainage categories, all the elements are related to the infrastructure because they are infrastructure works themselves. Then, in the case of visual aids, also all the elements are considered to be infrastructural works, which are there to guide pilots or different vehicles through the airport. In the case of utilities, just those related to buildings are considered part of infrastructure, and the services are considered to be ‘’non-related’’. Hence, all those buildings that need to be there for the utilities are the ones related to infrastructure. Next, in the case of **ATM**, the **ATCT** is excluded because is a building that is mostly found in the landside of airports and its generally related to the terminal of an airport. While the **NAVAIDS** and **MET**s are systems that are found in the airside to help in the navigation, and they are also part of the infrastructure of it. Finally, miscellaneous elements are all part of the infrastructure of an airport's airside and, therefore, related to it.

Then, in the case of activities, and more specifically, aircraft movements, all of the movements happening in the airside are related to the infrastructure. This is because they depend on the design of the infrastructure to move around the airside. Large taxiways will result in more taxiing time for aircrafts for example, so they are highly attached. Lastly, in the case of **GSE**, a similar situation to aircraft movements happens, where the vehicles move through an airport airside based on the design provided, so the distance traveled by them is related to the infrastructure. Moreover, aircrafts and **GSE** are highly attached to the infrastructures serving them, as charging stations or fueling facilities.

Table 5-1. Elements related to Airside Infrastructure.

Discipline/Activity	Elements related to Airside infrastructure	
	Related	Non-related
Pavements	Runway, Taxiway, Apron and Service Roads	-
Drainage	Pipes, Culverts, Channels, Ditches, Oil-Water separators, Grated and Slotted drains and Ponds	-
Visual Aids	Airfield Ground Lighting, Marking and Signage	-
Utilities	Medium and low voltage sub-stations*, Storage of potable water*, non-potable water and firewater, Firefighting building, Fuel Farm	Telecommunications, Potable Water, Wastewater, Firewater, Heating and Cooling, Pre-Conditioned Air, Ground Power Unit, Potable Water for aircrafts, Wastewater from Aircrafts, Fuel for the aircrafts, De-icing, Washing the aircraft
Air Traffic Management	Navigational Aids and Meteorological Systems	Air Traffic Control Tower*
Miscellaneous Elements	Fences, Jet blast barriers, Bollards, Curbs, Trash and litter receptacles, Hangars for Aircraft Maintenance, Infrastructure for alternative power sources	-
Aircraft Movements	Taxiing, taking off and landing	-
Ground Support Equipment	Vehicles of Services, Fuel Supply, Cargo Handling, Operations, People, Cleaning and Emergency	-
** They can be located in both landside or airside, depending on the need of the airport*		

5.2.3 Main activities and disciplines considered for the rating system

After having defined the elements of each activity and discipline that can be found on airside and are related to the infrastructure (see Table 5-1), now, those that are considered to be the most important in terms of environmental impacts during the whole life of the infrastructure for the development of a rating system in this thesis are defined in this section.

To start with, the pavements are the main component of the airside given that they support the aircraft activities, and the direction on how to locate them depends on wind conditions from the site (Roling, 2022b). Pavements are large areas that can be flexible or rigid, this means made from asphalt or concrete respectively, which are main sources of **GHG** emissions (Greer et al., 2020). The concrete industry contributes to 8.6% of global **CO_2** emissions (Miller et al., 2016), which on average the production of 1m^3 of concrete generates from 240 to 320 kg **CO_2**eq/m^3. While for the asphalt, the emissions generated are almost half, reaching 150 kg **CO_2**eq/m^3 (Emerald, Eco Label, 2021). Therefore, is key to take them into account in the analysis. Pavements also pollute in different ways, not just in the material production, for instance in the equipment used to lay down the pavements or the vehicles that transport the materials. The emissions from a paver according to CO2 emissiefactoren (2023) are 2.652 kg **CO_2**eq/l, and for transportation of materials, according to Klein et al. (2020) a 20 ton truck emits 0.08 kg **CO_2**eq/ton-km. Therefore, all its elements are relevant to consider in the rating system.

Furthermore, these large, paved surfaces should be located somewhere thus, site selection is a crucial aspect to take into account given the environmental impacts that airports can create to the surrounding ecosystem and biodiversity as stated in Belant et al. (2014) and Zhao et al. (2019). Impacts to soil, water, air and animal species, among others, are one of the main effects that site selection can have (Greer et al., 2020).

In the case of the drainage discipline, the main environmental impact that they relate to its not the construction of the system, but rather the water conveying system that they generate. Large airports consume a large amount of water, compared to that of a small and medium sized city (Carvalho et al., 2013). Not just in the terminal building but also in the airside for different activities, like irrigation and infrastructure or aircraft washing (Greer et al., 2020). The water consumption in the terminal building is estimated to be 85%, while that one consumed in airsides 15%, according to the utility expert from **NACO** (third expert from Table C-1) and Baxter et al. (2019). Moreover, some water conveyed in the airside can be contaminated due to different activities such as de-icing or fueling (among others), which then discharge to the environment can create significant environmental impacts to the ecosystem (Baxter et al., 2019). Last, but not least, drainage systems have a great impact on the flood risk of airports, aiding to manage the amount of surface run-off (Gómez Comendador et al., 2019). Hence, a drainage system with solutions able to reduce water consumption in terminal buildings and airside, able to prevent pollutants to water bodies, and able to manage run-off water is needed (Baxter et al., 2019; ICAO, n.d.). That is why all the elements conforming the drainage system in this case are considered relevant.

Then, in the visual aids discipline, the **AGL** component is the one considered relevant, given that they are responsible for a 50% of the energy consumption in the airside according to the **AGL** expert from **NACO** (first expert from Table C-1), while the signage elements are negligible compared to the **AGL**. Then, the markings of the pavements are not relevant given that its environmental impacts are negligible.

In the case of utilities, the most relevant element to consider is that of storage of water (which can be both potable and non-potable), which for the case of this thesis will be considered together with the drainage system solutions to aid the water consumption in terminal buildings and airsides. The rest of the supporting buildings are left out of the scope of this thesis, given that their impacts from an infrastructural perspective are negligible.

When coming to the air traffic management discipline, although they are infrastructure themselves, none of the elements are taken into account for this thesis. This is because they are supporting buildings and their most relevant solutions to environmental impacts are rather from an operational perspective and not from an infrastructural perspective, according to the **ATM** systems expert at **NACO** (second expert from Table C-1).

Then, the last discipline are the miscellaneous elements, where just the infrastructure for alternative power sources is considered for this thesis. This is because they are considered to be futuristic solutions for the aviation industry, where now the most common ones are solar panels for electricity generation, hydrogen production or Sustainable Aviation Fuels (**SAF**) (NACO Aviation Academy, 2023a). Airport operators should start considering providing this infrastructure for an environmental improvement in the sector. As it was mentioned before in section 3.1.1, the airlines are in charge of 94% of the $\mathbf{CO_2}$ emissions in the aviation sector, and these alternative power sources are being developed to reduce this percentage (NACO Aviation Academy, 2023a). The rest of the miscellaneous elements are not relevant for this thesis because they have no significance on any environmental impact, they are just supporting elements with no relevance regarding environmental impacts.

In the case of the activities, when coming to aircraft movements, just the taxiing movements are considered relevant for this thesis, while the landing and take-off not. The latter ones are not considered relevant because the length of the runway depends on other factors mainly attached to the critical aircraft characteristics (ICAO, 2018; Roling, 2022b) rather than the design of the airport itself. Hence, there is not much that can be done in that respect, while the taxiing distances is something that can be influenced with different approaches (Di Mascio et al., 2022). Moreover, it is fair to mention that around 10% of aircraft emissions are produced during ground operations (Kurniawan & Khardi, 2011), hence, considering taxiing is crucial for this thesis. Some of the main pollutants that are generated by aircraft engines during operation due to combustion are **NOx**, Carbon Monoxide (**CO**), **PM** and Volatile Organic Compounds (**VOCs**) contributing to air pollution, and **CO_2** contributing to **GHG** (Kurniawan & Khardi, 2011). Furthermore, it is important to remark that **PM** generated can be of different sizes, as ultrafine particles with diameters of less than 100 nm, fine particles with a diameter size of less than 2.5 µm and coarse particles with diameter size between 2.5 µm and 10 µm (Koch, 2012).

Finally, coming to the last activity, more specifically **GSE**, several vehicles can be found in this category, but not all of them are considered relevant for this thesis. The most relevant impact from **GSE** is about emissions due to fuel burning, given that all vehicles are largely diesel, and therefore very polluting (NACO Aviation Academy, 2023a). According to Bao et al. (2023), **GSE** consumes about 13% of the total energy consumption of gasoline and diesel fuel, and produces 15% of the airport carbon emissions. Hence, those that are considered relevant are the ones that make the longer distances in an airport during the day, meaning those **GSE** operating between aircrafts stands and logistic stations, and those operating between aircraft stands, or those that are polluting the most. While all those that are fixed at the gate frequently or those which are not motorized (no emissions) are left out from this thesis. Hence, from the service vehicle category, the ones considered are the water trucks, sewage/lavatory trucks and **GPU**s, given that although they are fixed at the gate, they are highly polluting, accounting for 42% of the **CO_2** emissions from all the turnaround vehicles (ITW GSE, 2023). While **PCA** and Air Starting unit out of the analysis because they are fixed at the gate. From the fuel supply category, the fuel bowsers are considered while the fuel hydrant dispensers are actually a good solution to the distances made by the bowsers. Then, from the cargo handling vehicles, the pallet dollies and baggage dollies are left out because they are not motorized. The ones considered from this category are the pallet tractor, pallet mover, pallet loader, baggage conveyor belt, baggage tractor and catering truck. Next, from the operations category, the push/pull tractor and the follow me car are considered for this thesis. Then, in the people category, the buses and the vehicles for people with reduced mobility are considered, while the stairs are generally fixed at the gate, hence, left out from the analysis. Finally, the two last categories of vehicles, namely cleaning and emergency, are all considered for this thesis. A summary for all the relevant elements to be considered in the development of a rating system for airports can be seen in Table 5-2.

Table 5-2. Main activities and disciplines considered for the development of a rating system.

Discipline/Activity	Relevant elements to consider for the development of a rating system
Pavements	Runway, Taxiway, Apron and Service Roads
Drainage	Pipes, Culverts, Channels, Ditches, Oil-Water separators, Grated and Slotted drains and Ponds, water collection systems
Visual Aids	Airfield Ground Lighting
Utilities	-
Air Traffic Management	-
Miscellaneous Elements	Infrastructure for alternative power sources
Aircraft Movements	Taxiing
Ground Support Equipment	water trucks, sewage/lavatory trucks, GPU, fuel bowsers, pallet tractor, pallet mover, pallet loader, baggage conveyor belt, baggage tractor, catering truck, push/pull tractor, follow me car passenger buses and vehicles for people with reduced mobility, cleaning and emergency vehicles

5.3 Functional Boundaries

By functional boundaries is intended to define the specific functions or processes that the rating system encompasses from each activity or discipline from a planning and design perspective as well as its environmental impacts, as stated in the scope of this thesis in section 1.3. This means identifying the relevant part of the process of each element that is considered in this rating system (see Table 5-2) and indicate those which are more significant to take into account from a design perspective.

From a planning and design perspective, the whole life cycle of a system can be influenced (material production, construction, operations, maintenance and end-of-life), but not all of them are equally important. Therefore, the relevance of this section relies on identifying which part of the cycle per activity/discipline can be most improved from a planning and design perspective, to reduce the environmental impacts (which will be the functional boundaries for the rating system). The description is done per discipline and activity in the following.

5.3.1 Pavements

First, when coming to the pavement elements defined in Table 5-2 and considering their whole life cycle (material production, construction, operations, maintenance and end-of-life), it is important to mention that different sources of pollution happen in each of the phases. But, as the scope of this thesis is in the planning and design phase of an infrastructure, it can be said that in the case of pavements this means selecting the corresponding materials and geometrical properties to get the best design (Harvey et al., 2014). Hence, none of the emissions from vehicles or equipment used to construct, operate, maintain, or demolish a pavement are considered in this case. Therefore, the phase that can be most influenced from a design perspective is the material production one via material selection. This phase is significantly important due to the emissions produced mentioned in section 5.2.3. Nevertheless, it's still important to mention that the material selection also influences the other phases. The construction phase is influenced by the availability of the materials selected in the design.

Hence, if material is not locally available, longer distances should be made in terms of transport from the quarry to the site creating more emissions. Also, the use and maintenance phases are influenced due to the durability of the material selected (based on heat, rain, wear, etc.) (Pittenger, 2014). Meaning that a weaker material will cause less usable life of the pavement and more maintenance. Finally, the end-of-life stage is also influenced by the design, given that professionals can choose to use the old material to recycle in a new pavement or to send all the old material to landfill (Miller et al., 2016). All in all, it can be seen that design is key for pavements influencing the whole life cycle of them and all the stages are considered for this thesis as it can be seen in Figure 5-13. Finally, its important to highlight also that the site selection for the airside pavements during design is also considered for this thesis, due to the environmental impacts mentioned in section 5.2.3.

5.3.2 Drainage

In the case of the drainage discipline and its elements (see Table 5-2), a similar situation to pavements happens. Where from a design perspective professionals should select materials and geometrical properties to design a proper drainage system. The design of them also influences the whole life cycle of a drainage system, however, in this case, the most interesting environmental impacts that can be improved from the design, are related to the operational phase (as stated in section 5.2.3) rather than the material production phase. This is because the amount of material needed for the drainage system is negligible compared to that of pavements, while the operation phase is important because is when water runs through the infrastructure and should be managed correctly. Hence, professionals should do their best with the designs in airports airside so as to convey, conserve and treat water in the best possible way, avoiding pollution of water bodies or creating problems downstream, and conserving the resource. However, every phase is considered for this thesis, please see Figure 5-13.

5.3.3 Visual Aids

In the case of visual aids, and more specifically in the **AGL** system (the only element considered for this thesis), from a planning and design perspective all the life cycle stages can be influenced. However, the most interesting one is the operational phase (see Figure 5-13) due to the energy consumption of the lights, which is the main environmental impact related to them as stated in section 5.2.3. The material production in this case is insignificant given that the amount of materials is negligible when compared to pavements (**AGL** expert from **NACO**, first expert from Table C-1). Hence, the main thing to be considered when designing an **AGL** system by professionals so as to be environmentally friendly, is achieving the best design where energy consumption can be reduced in the operational phase.

5.3.4 Miscellaneous elements

In the case of the category of miscellaneous elements, the only element to be considered is the infrastructure for alternative sources of power, meaning hydrogen, electricity, and **SAF**. In the case of the design perspective for this infrastructure, the relevance for this element has more to do with the operational phase of it rather than the construction of it. This is because, as said before, airlines are the most polluting activity in the aviation industry, and new sources are being developed to reduce their percentage of **CO_2** emissions. These developments have to do with hydrogen flights, electric flights and flights powered by **SAF** (NACO, 2023; NACO Aviation Academy, 2023a; NACO & nlr, 2021). Moreover, the same technologies are considered to reduce the emissions from **GSE** (Postorino & Mantecchini, 2014). Hence, the focus of this discipline for this thesis is more related to the extent of which airports consider providing this type of infrastructure for an improvement in operations phase, reducing **GHG** emissions (see Figure 5-13).

5.3.5 Aircraft Movements

When coming to the first activity, just the taxiing movements are considered for this thesis (see Table 5-2). Emissions during this movement are high, as mentioned in section 5.2.3. The taxiing of an aircraft is related clearly to the operation phase of an aircraft and the infrastructure. Therefore, it is important to consider this phase (see Figure 5-13) and from a planning and design perspective, try to design an airport where the taxiing movements pollutes as less as possible with different solutions.

5.3.6 Ground Support Equipment

In the case of **GSE** and its relevant elements to consider (see Table 5-2), the analysis is similar to the one of aircraft movements. Where the emissions produce by them are high, as mentioned in section 5.2.3 and it's also clearly referred to the operations phase from the vehicles and the infrastructure. Hence, it's necessary to consider this phase in this thesis from a design perspective (see Figure 5-13). From a planner and designer perspective different solutions should be proposed in in an airport to reduce the emissions from the **GSE**, these can be related to the planning and design of the infrastructure or the vehicles.

Figure 5-13 presents an illustration of the phases that are considered in this rating system from a planning and design perspective.

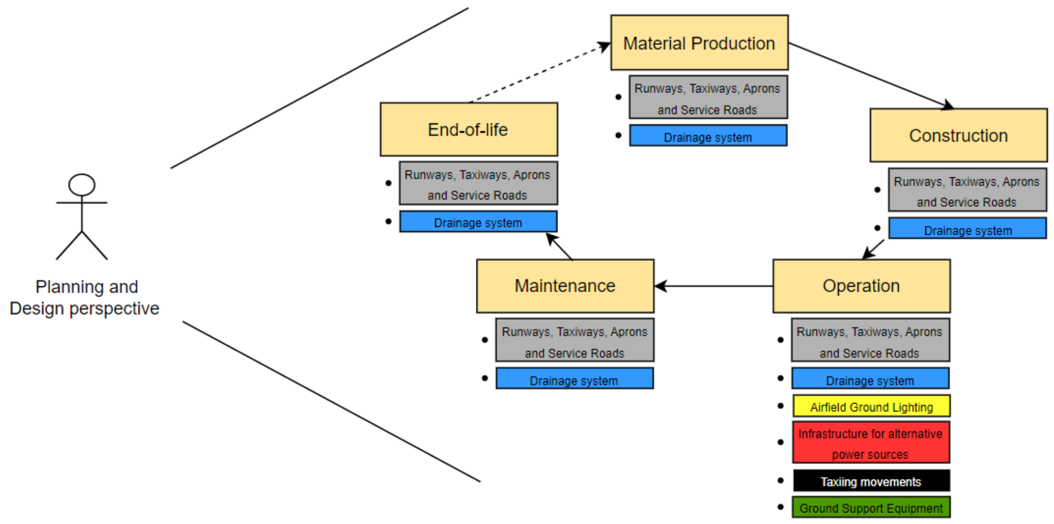


Figure 5-13. Part of process to be considered per activity and discipline in the rating system.

Having finish defining the boundaries that this rating system considers, now in chapter 6, the structuring and weighting of this system is provided.

6 STRUCTURING AND WEIGHTING

In this chapter is where (part of) the design of the rating system happens, namely where the structuring and weighting of the system is developed. To achieve this, a credit system is decided to follow, where the rating categories to be defined are called credit categories, and the indicators are called credits. These rating criteria evaluates environmental effects, as already stated in the scope of this thesis in section 1.3 (further explanation in section 6.1). Moreover, the credits (indicators) are the ones to be rated and the ones that an airport airside is evaluated against. Hence, in this chapter a weight is given to each credit (based on their relevance) and is further explained in section 6.2. Then, a level of certification is given to the evaluated project depending on the achieved credits, which is further explained also in section 6.2. Hence, the aim of this chapter is to get the structure of a rating system with credit categories and credits, with their corresponding weights and different levels of certification achievable (which can be seen in section 6.3). In this way, then it will be possible in chapter 7 to allocate the metrics to the most relevant indicators.

Summarizing, to achieve the aim of this chapter, in section 6.1 the rating criteria (credit categories and credits) to be considered are given. Then, in section 6.2 the process of allocation of weights to each rating criterion is explained and, finally, in section 6.3 a scorecard with shape of a matrix is given, where the rating criteria with its weights and different levels of certification are shown.

6.1 Rating Criteria

To determine the rating criteria several steps are taken. The main thing to consider for this are the **SDG**s defined by the United Nations in 2015, and the **TBL** defined earlier in section 1.1. Therefore, first in section 6.1.1, the Agenda 2030 and the **SDG**s are defined. Then, in section 6.1.2 the relationship of the **SDG**s with airports is provided, so as to later in section 6.1.3 select those goals that are of interest for this rating system, taking into account the **TBL** concept and the environmental impacts as defined in the scope in section 1.3. After that, in section 6.1.4 the credit categories are defined based on the **SDG**s that are selected in section 6.1.3, and the environmental pillar from the **TBL**. Next, in section 6.1.5, several credits are defined per credit category, based on the environmental impacts of each element defined in section 5.2, and the phases that they affect defined in section 5.3. Finally, in section 6.1.6, the structure of the credit categories and credits is presented. Please see Figure 6-1 for an illustration of the steps taken in section 6.1.

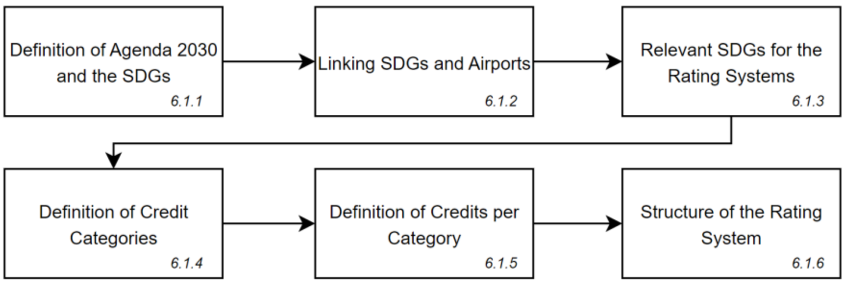


Figure 6-1. Steps to follow in section 6.1.

6.1.1 The Agenda 2030 and the Sustainable Development Goals

The Agenda 2030 or the Agenda 2030 for Sustainable Development is a plan of action adopted by the **UN** in September 2015 as part of the Paris Agreement (United Nations, 2015). This plan of action is intended for people, planet and prosperity, seeking universal peace that can be achieved by acting in collaborative partnership among all countries and stakeholders implementing the plan (this is also known as the five P´s - People, Planet, Prosperity, Peace and Partnership and are the five pillars of Agenda 2030) (United Nations, 2015).

The main concept of the Agenda 2030 is to provide a framework to address the social, economic and environmental challenges by the year 2030 following the five pillars. To achieve this, seventeen **SDG**s were defined in the Agenda 2030 (United Nations, 2015). These goals are a continuation of the eight Millennium Development Goals (**MDG**s) that were established in the **UN** Millenium Declaration in the year 2000 with a deadline of 2015 (Diaz-Sarachaga et al., 2016).

The five P´s are all interlinked and addressing one P affects another P and so on (see Figure 6-2). Addressing each of them, sustainable development can be fostered in line with the **SDG**s, permitting a positive impact on the region and nation at large (NACO Aviation Academy, 2023a). The seventeen goals defined by the **UN** can be seen in Figure 6-3 and in the next section these are linked to airports, which is the focus of this thesis.

Figure 6-2. The five P´s pillar (NACO Aviation Academy, 2023a).

Figure 6-3. Sustainable Development Goals (United Nations, n.d.).

6.1.2 Relationship of Sustainable Development Goals and airports

The **SDG**s are defined for a global application and can be linked to each of industry in a different way. Each sector has the possibility to contribute to a better world by following each of these goals (or as much as they can). In the case of this thesis, the aviation industry itself has the objective to be net zero by 2050 in both airlines stated by IATA (n.d.), and airports with the development of the **ACA** program from **ACI** and all the tools mentioned earlier in section 3.2.

As this thesis focuses on the development of a rating system for the airside of airports to collaborate with a sustainable development, its key to link the **SDG**s defined in section 6.1.1 with airports. This means identifying goal by goal, how airports contribute to them, which was done following the ACI (2021) report, and can be seen in Figure 6-4. This is useful to do so as to then in next section, select those goals that are relevant for the development of the rating system for this thesis.

Figure 6-4. Linking SDGs to Airports (ACI, 2021).

6.1.3 Relevant Sustainable Development Goals for the Rating System

After having linked the **SDG**s with airports, this section defines the goals associated with the activities and disciplines outlined in section 5.2 and section 5.3, as well as those related to the environmental pillar of the **TBL** (scope of this thesis defined in section 1.3). These defined goals are the ones taken into account to define the credit categories in the following section.

First, it is important to recall and define a bit more in depth each pillar of the **TBL** (Social, Economic and Environmental) of sustainability as done in ACI (2021) report.

- Social Sustainability takes into account the well-being of society as a whole based on the contribution of an organization. This means that the organization ensures the wellbeing of employees, customers, and local communities.

- Economic Sustainability encompasses the efficient use of resources from an organization to sustain its operations and return a profit. Moreover, it considers the contribution from the organization to the local, national, and international economy, in both ways directly and indirectly.

- Environmental Sustainability is focused on the consumption of natural resources at a sustainable rate while limiting damaging activities. Natural resources being fuels, raw materials, land and water.

Now, considering the **TBL** pillars, relevant topics associated to each pillar can be recognized, and are referred as material issues. These issues were defined in ACI (2021) report and can be seen in Figure 6-5. This thesis focuses on tackling the issues from the environmental pillar.

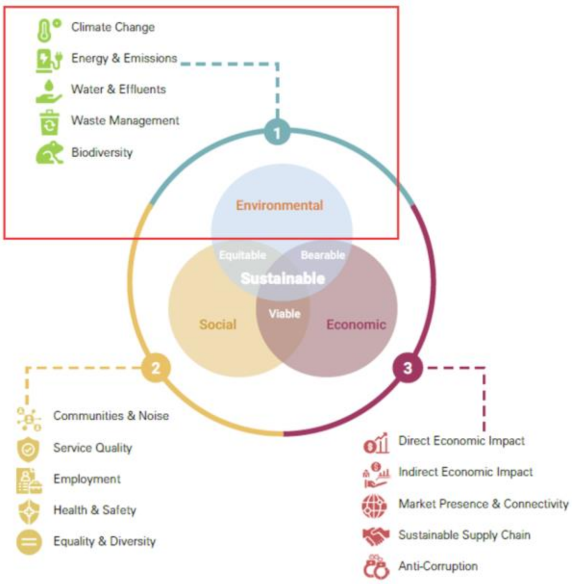


Figure 6-5. The TBL with typical material issues for each pillar (ACI, 2021).

Material issues are important to define because they indicate what a project from an environmental perspective (in the case of this thesis) should strive for. Therefore, the categories for the rating system need to be related to them. In the case of this thesis, the rating system being developed aims for improving in all the material issues related to the environmental pillar (see figure Figure 6-6).

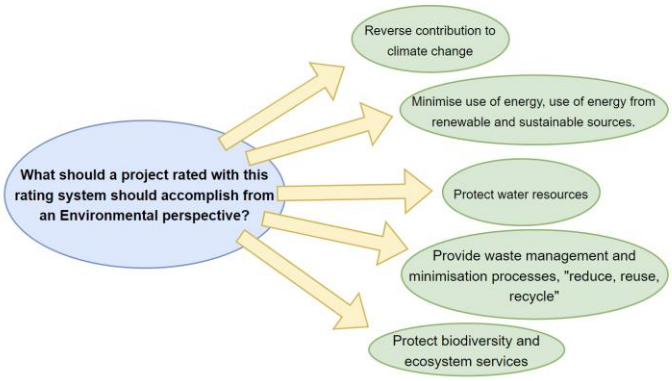


Figure 6-6. Objective of the rating system based on material issues.

After having defined the material issues that this rating system should aim for in the environmental pillar, it is now possible to relate these issues to the corresponding **SDG**s that can tackle them, considering the impacts from the disciplines and activities defined in section 5.2 and section 5.3.

The main objective of the Climate Change issue is to reduce harmful emissions. In the case of airports, there are several sources of **GHG** emissions and they are mainly related to the power source for **GSE** fleet, aircrafts, energy production and material production for pavements. Therefore, the **SDG**s related to Climate Change are 7 and 13 from Figure 6-4.

In the case of Energy & Emissions issue, where the use of energy should be minimized or the energy should come from renewable sources, this is directly related to the energy consumption from the **AGL** discipline, to the infrastructure for alternative power sources and the power source for **GSE** and aircrafts. Hence, the goals related from Figure 6-4 are again 7 and 13.

For the case of Water & Effluents issue, the main objective is to protect the water resources, achieving a better water quality. In the case of airports, this can be achieved with the drainage system to keep clean water and protect life below water. Therefore, the **SDG**s related from Figure 6-4 are 6 and 14.

In the case of Waste Management issue, the main goal is to provide waste management with minimization processes via reduce, reuse and recycle techniques. This is mainly related to the materials used to construct the pavements and drainage system, creating a direct bond with goal 12 from Figure 6-4.

Lastly, in the case of the Biodiversity material issue, the main goal is to protect the local habitats and ecosystems, which in an airport is linked to keep water free of pollution, protecting life below water and wildlife close to the airport area. All this, makes this issue be related to **SDG**s 6, 14 and 15 from Figure 6-4. All the relationships between material issues and the **SDG**s can be seen in Figure 6-7.

	Material Issue	Related SDG
Environmental	Climate Change	7, 13
	Energy & Emissions	7, 13
	Water & Effluents	6, 14
	Waste Management	12
	Biodiversity	6, 14, 15

Figure 6-7.Link between relevant SDGs and material issues.

Having defined the relationships between the material issues that are going to be addressed and the **SDG**s that tackle them, it is now possible to summarize those relevant goals which are useful for the development of the credit categories and credits of the rating system together with their impacts from the corresponding disciplines and activities (see Figure 6-8).

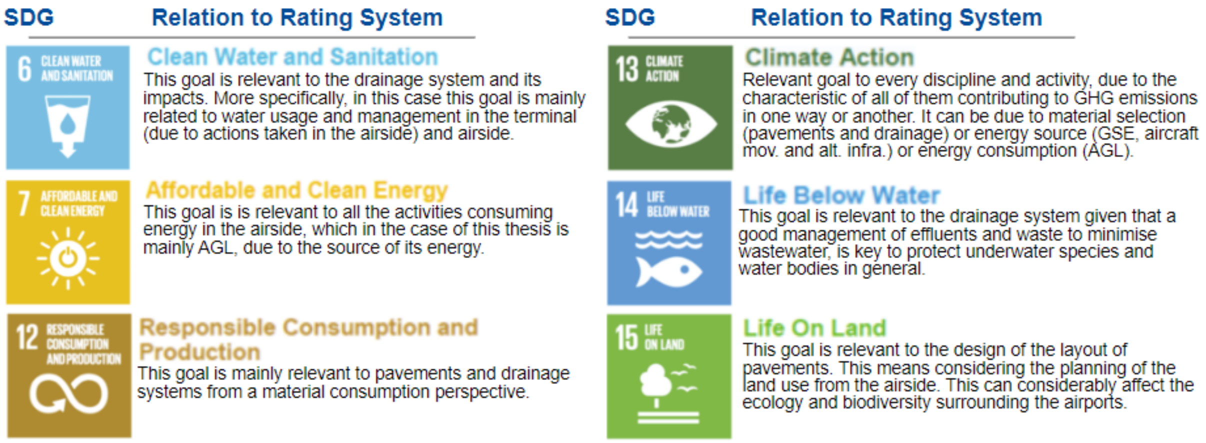


Figure 6-8.Relevant SDGs for the Rating System.

6.1.4 Credit Categories

Once the main **SDG**s to be considered were defined in section 6.1.3, in this section the focus is to define the credit categories based on them. It is of utmost importance to consider the **SDG**s to provide the credit categories of the rating system because as it was mentioned earlier in section 6.1.1, this framework is aimed for a sustainable development of the world taking into account the 5 P´s pillar and the **TBL** pillars or challenges. Therefore, when developing a rating system for airports airside, is key to consider the goals so as to contribute to a better and more sustainable world, as stated by the United Nations (2015) in the Agenda 2030, and to a more sustainable future in the aviation industry.

To define the different credit categories, the six relevant goals were considered, and hence, six different categories were obtained. These categories are related directly to the **SDG**s but their names were modified to keep it more related to the disciplines and activities on an airside. Moreover, two categories are added: one to represent aspects of the managerial perspective and one to include innovations that are not covered in the rest of the categories. In this way rendering a total of eight categories.

The different categories are shown in Figure 6-9 and were named as: Water Usage (related to **SDG** 6), Energy (related to **SDG** 7), Materials (related to **SDG** 12), Pollution and Emissions from Aviation Community (related to **SDG** 13), Effluents (related to **SDG** 14), Ecology and Land Use (related to **SDG** 15), Management and Innovation (as the two extra categories).

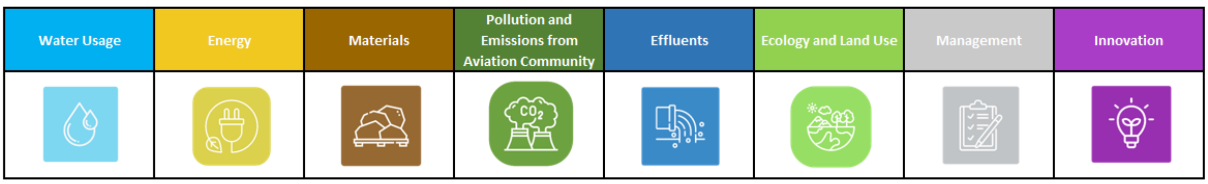


Figure 6-9. Credit Categories.

It is important to mention that in the case of **SDG** 13, the **GHG** emissions from material selection and energy consumption will be considered in the categories of materials and energy, respectively. This is done to keep unified everything under each of the categories. That is why, the category mainly related to **SDG** 13 is called Pollution and Emissions from Aviation Community, as to keep the emissions mainly related to **GSE** and aircrafts.

6.1.5 Credits per category

Once the credit categories were defined in section 6.1.4, in this section the focus is to define the credits (indicators) per category. To do this, it is significant to conduct desk research methodology, while also consider the environmental impacts from each discipline and activity defined in section 5.2 and section 5.3. For the desk research, several standards, manuals from already existing rating systems, and papers were collected, and then filtered to keep those useful, as already explained in section 2.2.3 from the current thesis.

Those studies that were kept for this section, were analyzed in detail, and contrasted one with each other, inspecting which credits are deemed important for the disciplines and activities of this thesis, and also it was investigated how they allocated credits in categories. As in section 6.1.4 the credit categories for this thesis were already defined, the relevant credits were extracted from the different literature from the desk research and then allocated to the different eight categories. To highlight the relevant credits, it was important to keep in mind the boundaries and environmental impacts of each discipline and activity, defined in chapter 5. Then, to allocate the credits in the different categories, the paper from Wen et al. (2020), Ramakrishnan et al. (2022), and the Agenda 2030 from United Nations (2015) were useful. Wen et al. (2020) analyzes how the different **SDG**s are tackled by the rating systems and their credits, Ramakrishnan et al. (2022) develops an airport-specific green rating framework and the Agenda 2030 from United Nations (2015) explains each **SDG** deeply. Hence, considering these three papers, it was possible to relate the different relevant credits to the six categories (related to the **SDG**s), while the management and innovation categories were filled with credits based on the most used rating systems.

The main papers and manuals from existing rating systems used for this section were ten (10): four (4) of them related to rating systems for infrastructures in general (**CEEQUAL** analyzed by Diaz-Sarachaga et al. (2016), the Envision version 3 manual (Institute for Sustainable Infrastructure, 2018), the **BREEAM** infrastructure guide version 6 developed by BRE Group (2022) and a private rating system developed by Diaz-Sarachaga et al. (2017a)), four (4) of them related to rating systems for airport infrastructures specifically (private rating systems developed by Gómez Comendador et al. (2019) and Chao et al. (2017), a sustainability ranking of airports index to benchmark the performance of airports across multiple factors developed by Kılkış & Kılkış (2016), and the study from Ramakrishnan et al. (2022)), and two (2) of them related to rating systems for buildings in general (the **LEED** guide version 4.1 for Building Design and Constructions (LEED, 2023), and a private rating system developed by Yu et al. (2015)).

With all these studies, eight different tables (one per credit category) were made comparing the relevant credits from each of the papers. After this, credits analyzing the same topic were grouped into one general credit and given a name according to the developed rating system in this master thesis (to see the tables please go to Appendix A). In this way, a total of twenty-two (22) credits were obtained: one for the Water Usage category, two for the Energy category, five for the Materials category, two for the Pollution and Emissions from Aviation Community category, two for the Effluents category, seven for the Ecology and Land Use category, two for the Management category and one for the Innovation category. In the following, a brief explanation of each credit is given, with the objective to familiarize the reader with the intent of each credit, while a deeper and more elaborated description of them with its metrics, is scope of chapter 7.

Water Usage

In this category, the main thing to consider is the use of water in the airside and in the terminal due to actions taken in the airside, during operations, from a planning and design perspective. This means that this category is closely related to the drainage system and how this can impact the use of water. Therefore, one credit was defined and can be seen in Table 6-1. The credit is called ''Water Consumption in Operation'' and relates to the consumption of water during operations of the airport. The objective of this indicator is to measure and guide the user achieving solutions that reduce water consumption.

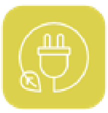
Table 6-1. Water Usage Credits.

Water Usage	
1. Water Consumption in Operation	

Energy

In this category, the main thing to consider is the energy consumption in the airside, during operation, from a planning and design perspective. This means that this category is closely related to the energy sources in an airport feeding the **AGL** system, **GSE**, and aircrafts, and how they can impact in the use of energy. Therefore, two credits were defined and can be seen in Table 6-2. The first credit called ''Energy Consumption in Operation'' is quite clear and relates to the consumption of energy during operations of the airport. The objective of this indicator is to measure and guide the user achieving solutions that reduce energy consumption. The second credit is called ''Renewable Energy'', and relates to the possibility of using renewable energy to feed the different systems. The objective of this indicator is to measure and guide the user achieving solutions where the airport can use renewable energies generated both, on-site and/or off-site.

Table 6-2. Energy Credits.

Energy	
1. Energy Consumption in Operation 2. Renewable Energy	

Materials

In this category, the main thing to consider is the environmental impacts related to the materials needed for the construction of the airside of an airport, from a planning and design perspective. This means that this category is closely related to the pavements and the drainage system disciplines.

Therefore, five credits were defined and can be seen in Table 6-3. The first credit is called ''Environmental Impact of Materials'' and relates to the embodied impacts of materials used for pavements and the drainage system. The objective of this indicator is to aid the user in analyzing the impacts and emissions of the materials to be selected. The second credit is called ''Choice of Materials'' and relates to the possibility of designing efficiently from the point of view of materials used. The objective of this indicator is to guide the user designing the pavements and drainage system for more durability with as much recycled materials as possible. The third credit is called ''Balance Earthwork on Site'' and relates to the possibility of balancing cut and fill prior to construction. The objective of this indicator is to measure and guide the user designing an even terrain with as less movement of soil as possible. Then, the fourth credit is called ''Responsible Sourcing of Materials'' and relates to the process involved during material sourcing. The objective of this indicator is to incentivize the user sourcing materials locally to reduce the transportation distances. The last credit is called ''Construction Waste Management'' and relates to the management of waste during construction. The objective of this indicator is to measure and guide the user applying different strategies to reduce waste from demolition and construction works while also disposing waste in a responsible way.

Table 6-3. Materials Credits

Materials	
1. Environmental Impact of Materials	
2. Chocie of Materials	
3. Balance Earthwork on site	
4. Responsible sourcing of materials	
5. Construction Waste Management	

<u>Pollution and Emissions from Aviation Community</u>

In this category, the main thing to consider are the **GHG** emissions and effect on climate change from the **GSE** and aircrafts in the airside of an airport, from a planning and design perspective. Therefore, two credits were defined and can be seen in Table 6-4. The first credit called ''Ecological Ground Support Equipment'' relates to the possibility of reducing **GHG** emissions from **GSE**. The objective of this indicator is to guide the user reducing emissions from **GSE** with infrastructural measures. The second credit called ''Aircraft Carbon Management'', relates to the possibility of reducing **GHG** emissions from aircrafts. The objective of this indicator is to guide the user reducing emissions from aircrafts with infrastructural measures as well.

Table 6-4. Pollution and Emissions from Aviation Community Credits.

Pollution and Emissions from Aviation Community	
1. Ecological Ground Support Equipment	
2. Aircraft Carbon Management	

Effluents

In this category, the main thing to consider is the pollution to the effluents from the airport airside. Hence, this category is closely related to the drainage system and the effect that this system can have in the quality of effluents, from a planning and design perspective. Therefore, two credits were defined and can be seen in Table 6-5. The first credit called ''Water Pollution'' relates to the pollution of groundwater, surface water and other water bodies. The objective of this indicator is to measure and guide the user achieving solutions to prevent the pollution of water bodies and aquatic environment. The second credit called ''Management of Run-Off'', relates to the management of run-off water during operations of the airside. The objective of this indicator is to guide the user reducing the risk of floods in the airside and identifying opportunities to manage run-off water as best as possible, keeping the quantity of discharge of run-off within specified limits.

Table 6-5. Effluents Credits.

Effluents	
1. Water Pollution 2. Management of Run-Off	

Ecology and Land Use

In this category, the main aspect to consider are the environmental impacts generated from the placement of the airside to the surroundings, meaning the biodiversity and ecology. This means that this category is closely related to the planning of land use and placement of the airport. Therefore, seven credits were defined and can be seen in Table 6-6. The first credit called ''Site Selection'' relates to the siting of the project. The objective of this indicator is to measure and guide the user achieving a correct placement of the airside, where several location alternatives are considered, reducing the impacts to its surroundings as much as possible. The second credit called ''Soil Protection'' relates to the possibility of conserving the soil quality. The objective of this indicator is to guide the user preserve the composition, structure and function of site soils. The third credit is called ''Protection of Biodiversity'' and relates to the possibility of preserving sites with high ecological value. The objective of this indicator is to minimize the interference to ecosystems and organisms present in the potential location of the airside. Then, the next credit is called ''Landscape Protection'' and relates to the local landscape of the siting of the airside. The objective of this indicator is to guide the user conserving and enhancing the local landscape where the airport is projected to be located. The fifth credit is called ''Historic and Cultural Resources'' and relates to the historical resources that can be encountered in the site of the airside. The objective of this indicator is to guide the user preserve those significant historical and cultural resources in the airside sites. The sixth credit is called ''Light Pollution'' and relates to the pollution of the lights from the airport's airside. The objective of this indicator is to measure and guide the user minimizing the light pollution from the different activities emitting lights in the airside. Finally, the last credit is called ''Heat Island Effect'' and relates to the heat effect generated from pavements in the airport's airside. The objective of this indicator is to measure and guide the user reduce the heat effect from pavements as much as possible to not affect the surrounding temperature.

Table 6-6. Ecology and Land Use Credits.

Ecology and Land Use	
1. Site Selection	
2. Soil Protection	
3. Protection of Biodiversity	
4. Lndscape Protection	
5. Historic and Cultural Resources	
6. Light Pollution	
7. Heat Island Effect	

Management

In this category, the main thing to consider is the management to achieve a sustainable development of the infrastructure. For this, two credits were defined and can be seen in Table 6-7. The first credit called ''Sustainable Management Plan'' relates to the consideration of the principles of sustainability in the design (which due to the scope of this thesis defined in section 1.3, just the environmental pillar should be considered). The objective of this indicator is to incentivize the user planning for sustainable development beforehand, considering the selection process of designers and contractors, and assigning a special person (group of people) to occupy the role of keeping track of the sustainability of the airport. The second credit called ''Plan for End-of-Life'', relates to the consideration of understanding the full impacts of the project's end-of-life from the corresponding team. The objective of this indicator is to guide the user identifying end-of-life impacts and minimize them as much as possible.

Table 6-7. Management Credits.

Management	
1. Sustainable Management Plan	
2. Plan for End-of-Life	

Innovation

This last category is somehow special and not related to anything in particular. This category was particularly defined to cope with all the innovative aspects that a project team would like to achieve, and which is not covered by the rest of the credits. Therefore, one credit was defined which is called ''Innovation'' and can be seen in Table 6-8. The main objective of this credit is to incentivize project teams to think about innovative aspects that could bring airside more environmentally friendly solutions and thus, reduce environmental impacts.

Table 6-8. Innovation Credits.

Innovation	
1. Innovation	

Having briefly defined the intent of each credit of the rating system developed in this thesis, in the next section the whole structure of the rating system is presented.

6.1.6 Structure of the Rating System

In this section an overview of the rating system's structure (credit categories and credits) is presented, and it can be seen in Figure 6-10.

Credit Categories			
Water Usage	Energy	Materials	Pollution and Emissions from Aviation Community
Credits per category			
1. Water Consumption in Operation	1. Energy Consumption in Operation 2. Renewable Energy	1. Environmental Impact of Materials 2. Choice of Materials 3. Balance Earthwork On Site 4. Responsible Sourcing of Materials 5. Construction Waste Management	1. Ecological Ground Support Equipment 2. Aircraft Carbon Management

Credit Categories			
Effluents	Ecology and Land Use	Management	Innovation
Credits per category			
1. Water Pollution 2. Management of Run-Off	1. Site Selection 2. Soil Protection 3. Protection of Biodiversity 4. Lndscape Protection 5. Historic and Cultural 6. Light Pollution 7. Heat Island Effect	1. Sustainable Management 2. Plan for End-of-life	1. Innovation

Figure 6-10. Rating System structure

Having finished with section 6.1, now in section 6.2, the allocation of weights to each credit category and credit is explained.

6.2 Allocation of weights

The weights are defined for credits and credit categories to set an order of relative relevance between them. In this thesis the weight allocation is done via desk research, and with them it will be possible to evaluate an airside project. Moreover, the different levels of certification can be determined with the different weight allocation. Hence, in this section, indicators and categories are weighted according to their relevance. First, in section 6.2.1 the weight allocation for credits and credit categories is explained, and then, in section 6.2.2 the breakpoints for the different levels of certification are given.

6.2.1 Weight Allocation to Credits and Credit Categories

Coming to the relevance analysis, weight and point allocation for credits, first it is important to highlight that normally in rating systems this is done via stakeholder engagement. Where different stakeholders with different points of view and area of expertise, are required to rate the different indicators and get involved in an iterative process. However, in the case of this thesis, due to a different time availability, it was decided that the background information to obtain weights will be obtained from the desk research mainstream information. To this end, several different rating systems and studies developing rating systems were carefully analyzed and used as input for this section. This means that the ''rating method'' is done following the current practices from different experts from the different sources.

The main studies involved in the weight and point allocation process for credits and credit categories were eight (8): four (4) of them related to rating systems for infrastructures in general (**CEEQUAL** analyzed by Diaz-Sarachaga et al. (2016), the Envision version 3 manual (Institute for Sustainable Infrastructure, 2018), the **BREEAM** infrastructure guide version 6 developed by BRE Group (2022) and a private rating system developed by Diaz-Sarachaga et al. (2017a)), two (2) of them related to rating systems for airport infrastructures specifically (private rating systems developed by Gómez Comendador et al. (2019), and Chao et al. (2017)), and two (2) of them related to rating systems for buildings in general (the **LEED** guide version 4.1 for Building Design and Constructions (LEED, 2023), and a private rating system developed by Yu et al. (2015)).

With all these studies, it was possible to allocate weights and points to the different credits and credit categories from section 6.1.5 and section 6.1.4 respectively, after a detailed process that is explained in the following.

Due to the large dataset obtained from the different literature used in this process, different tables that are helpful for the reader to follow are used and also to keep the reproducibility of this thesis. Therefore, the steps to follow in this weight allocation explanation are: first the relevant credits from Appendix A are shown in tables next to their weights assigned by each author. Second, relevant credits are grouped according to the credits developed in this thesis to provide weights. Third and last, a table gathering all the weights of the credits across all the authors is shown and explained, where the weights are then converted into points and the final allocation of them is carried out.

As a first step, the relevant credits from Appendix A are shown with their weights next to it, divided per author in different tables. It is important to highlight that while in Appendix A the studies from Kılkış & Kılkış (2016) and Ramakrishnan et al. (2022) were useful, for this section these two could not be used because they did not provide information about points allocation. Hence, the total of studies used for this purpose are eight as already mentioned in the beginning of the current section.

Please see in Table 6-9 the credits and weight allocation used from Gómez Comendador et al. (2019). Please note credits covering 51% of the points have been used for this thesis, while the other ones were deemed not relevant for the scope of this thesis.

Table 6-9. Credits and weights according to Gómez Comendador et al. (2019).

Gómez Comendador et al. (2019)		
Credits	Points according to author	Weight according to author
Water resources		
reducing water consumption outdoor	3	3%
reducing water consumption indoor	2	2%
water metering	1	1%
wastewater	1	1%
management of runoff	2	2%
Energy		
energy consumption and management	4	4%
use of renewable energy	2	2%
Pollution and emissions		
Ecological cars	4	4%
Biofuels use	2	2%
restrictions on the use of engine groun	4	4%
Materials and Waste		
infra LC impact	4	4%
choice of building materials	5	5%
Land Use		
Site selection	3	3%
Soil protection	3	3%
Biodiversity and Landscape		
Landscape protection	4	4%
reducing light pollution	1	1%
Reduced heat island effect	1	1%
Protection of biodiversity	4	4%
TOTAL	50	50%
Innovation		
Innovation	1	1%
TOTAL	51	51%

Please see in Table 6-10 the credits and weight allocation used from Chao et al. (2017). Please note credits covering 62% of the points have been used for this thesis, while the other ones were deemed not relevant for the scope of this thesis.

Table 6-10. Credits and weights according to Chao et al. (2017).

Chao et al. (2017)		
Credits	Points according to author	Weight according to author
Green Airport Design		
energy conservation in airport building	0,035	4%
use of green building materials	0,038	4%
rwys and twys designed for carbon reduction	0,055	6%
Energy conservation and carbon reduction in airport operations		
use of low-emission vehicles	0,085	9%
installation of water-saving devices	0,045	5%
Energy-saving control	0,118	12%
Use of renewable resources		
use of renewable energies	0,047	5%
use of recycled water	0,029	3%
Airport environmental sustainability management		
Aircraft carbon management	0,093	9%
Environmental and ecological conservation	0,075	8%
TOTAL	0,62	62%

Please see in Table 6-11 the credits and weight allocation used from **CEEQUAL** according the paper from Diaz-Sarachaga et al. (2016). Please note credits covering 51% of the points have been used for this thesis, while the other ones were deemed not relevant for the scope of this thesis.

Table 6-11. Credits and Weights from CEEQUAL according to Diaz-Sarachaga et al. (2016).

CEEQUAL - Diaz-Sarachaga et al. (2016)		
Credits	Points according to author	Weight according to author
Project Management		
sustainable management	160	3%
Land Use and Landscape		
basic principles in the use of land	233	5%
contamination of lands and beds of the sea	242	5%
basic principles of landscape issues	55	1%
The historic Environment		
baseline studies of the historic environment	23	0%
conservation and enhancement	141	3%
Ecology and Biodiversity		
basic principles of ecology and biodiversity	61	1%
conservation and enhancement of biodiversity	79	2%
habitat creation measures	64	1%
The Water Environment		
basic principles of the water environment	70	1%
protection of the freshwater and marine environments	141	3%
enhancement of the water environment	48	1%
Physical Resources		
basic principles of resources	44	1%
embodied impacts	112	2%
design for resource efficiency	109	2%
design for reduced energy consumption and carbon emissions in use	97	2%
energy and carbon performance on site	109	2%
water use	291	6%
responsible sourcing, reuse and recycling amterials	106	2%
minimising use and impacts of hazardous amterials	47	1%
site waste management planning and legal compliance	89	2%
waste and management of arisings	213	4%
TOTAL	2613	51%

Please see in Table 6-12 the credits and weight allocation used from Diaz-Sarachaga et al. (2017a). Please note credits covering 36% of the points have been used for this thesis, while the other ones were deemed not relevant for the scope of this thesis.

Table 6-12. Credits and Weights according to Diaz-Sarachaga et al. (2017a)

Diaz-Sarachaga et al. (2017a)		
Credits	Points according to author	Weight according to author
Management	0,14	
Project Sustainability Management Plan	0,23	3%
Society	0,324	
Cultural Heritage	0,174	6%
Environment	0,289	
Natural Ecosystems conservation		
impacted ecosystem area ratio	0,169	5%
Energy consumption	0,102	3%
Energy savings rate		
renewable energy use rate		
Water Management	0,143	4%
fresh water consumption reduction		
runoff water stored		
Flooding risk	0,09	3%
floodplains areas		
Waste Management	0,098	3%
waste production decrease		
recycled reuse waste		
Economy	0,247	
Agriculture impacts		
farmland area impacted	0,256	6%
Local materials consumption		
local materials use rate	0,145	4%
TOTAL		36%

Please see in Table 6-13 the credits and weight allocation used from **BREEAM** infrastructure guide version 6 developed by BRE Group (2022). Please note credits covering 39% of the points have been used for this thesis, while the other ones were deemed not relevant for the scope of this thesis.

Table 6-13. Credits and Weights according to BREEAM infrastructure guide version 6 developed by BRE Group (2022).

BREEAM infrastructure - BRE Group (2022)		
Credits	Points according to author	Weight according to author
Management		
Sustainability leadership		
principles of sustainable development	31	1%
selection process for designers and contractors	24	0%
Environmental and social performance in contracts	20	0%
Resilience		
Flooding and surface water run-off		
Flood risk assessment	18	0%
Flood risk based enhancements	56	1%
Sustainable Drainage Systems	5	0%
Implementation of flood risk based enhancements	28	1%
Implementation of sustainable drainage systems	14	0%
Managing runoff at source	24	0%
Land Use and Ecology		
Land Use and value		
project Icoation alternatives	27	1%
consideration of project location alternatives	27	1%
site suitability	27	1%
justification of site suitability	27	1%
land use efficiency	26	1%
previous use of the site	20	0%
conservation of soils and other on-site resources	14	0%
land contamination and remediation		
Contamination risk assessment	8	0%
Further Assessment of contamination	14	0%
Land contamination specialists	27	1%
Evaluation of remediation options	38	1%
Prevention of future contamination	11	0%
protection of biodiversity		
Survey and evaluation of ecological valie	18	0%
land of high ecological value	17	0%
change and enhancement of biodiversity		
New wildlife habitats	4	0%
Improving the water environment	4	0%
Landscape and historic environment		
landscape and visual impadct		
Landscape and visual factors	27	1%
impact on landscape character	26	1%
landscape development policies	9	0%
local landscape character	24	0%
appropriatness of species selected	26	1%
assessment of existing vegetations	9	0%
retention of existing vegetation	4	0%
non-vegetation features	18	0%
Long term management plan	17	0%
Heritage assets		
baseline studies and surveys	9	0%
use of suitable professionals and standards	14	0%
Consultation	12	0%
integration of lsited or registered heritage assets	14	0%
integration of non-registered heritage assets	16	0%
Pollution		
Water pollution		
Consultation with regulatory authorities	12	0%
preventing pollution in operation	14	0%
control of impacts on the water environment from the completed project	22	0%
Long term monitoring of impacts on the water environment	18	0%
light pollution	76	2%
Resources		
environmetnal impact of construction products		
Life Cycle Assessment	100	2%
Hazardous materials	6	0%
circular use of construction products		
durability and low maintenance	11	0%
on-site use of demolition arisings	32	1%
reclaimed or recycled materials	7	0%
reclaimed or recycled bulk fill and sub-base	5	0%
cut and fill optimisation	11	0%
beneficial re use of excavated material	32	1%
responsible sourcing of construction products		
responsible sourcing of construction products, consideration	16	0%
locally sourced and recycled material - early consideration	5	0%
locally sourced and recycled material - further consideration	5	0%
construction waste management		
site waste management planning - preparation	11	0%
site waste management planning - implementation	16	0%
clearance and disposal of existing vegetation - consideration	20	0%
clearance and disposal of existing vegetation - implementation	18	0%
Energy use		
energy and carbon emissions reduction for operation	45	1%
implementation of energy and carbon reductions for operation	70	1%
opportunities for renewable/low carbon/ zero carbon nergy witihn the operatior	25	1%
incorporating renewable/low carbon/ zero carbon nergy witihn the operational s	60	1%
Watwer use		
capturing run-off beneficial use	5	0%
water consumption in operation - consideration during desgin	16	0%
water consumption in operation - reduction measures included in the design	25	1%
TOTAL	1615	29%
Innovation	500	10%
TOTAL	2115	39%

Please see in Table 6-14 the credits and weight allocation used from Envision version 3 manual (Institute for Sustainable Infrastructure, 2018). Please note credits covering 41% of the points have been used for this thesis, while the other ones were deemed not relevant for the scope of this thesis.

Table 6-14. Weights and Credits according to Envision version 3 manual (Institute for Sustainable Infrastructure, 2018).

Envision - Institute for Sustainable Infrastructure (2018)			
	Credits	Points according to author	Weight according to author
Quality of Life			
Wellbeing	minimize light pollution	12	1%
Community	preserve historic and cultural resources	18	2%
	enhance views and local character	14	1%
Leadership			
Planning	establish a sustainale management plan	18	2%
	plan for end of life	14	1%
Collaboration			
Resource allocation			
Materials	use recycled materials	16	2%
	reduce construciton waste	16	2%
	balance earthwork on site	8	1%
Energy	Reduce operational energy consumption	26	3%
	Use renewable Energy	24	2%
	Comission and Monitor energy systems	14	1%
Water	Preserve water resources	12	1%
	reduce operational water consumption	22	2%
	monitor water systems	12	1%
Natural World			
Siting	Preserve sites of high ecological value	22	2%
	preserve prime farmland	16	2%
	preserve undeveloped land	24	2%
Conservation	Manage stormwater	24	2%
	protect surface and ground water quality	20	2%
Ecology	Enhance functional habitats	18	2%
	enhance wetland and surface water functions	20	2%
	maintain floodplain functions	14	1%
	protect soil health	8	1%
Climate and resilience			
Emissions	Reduce net embodied carbon	20	2%
	TOTAL	490	41%

Please see in Table 6-15 the credits and weight allocation used from Yu et al. (2015). Please note credits covering 54% of the points have been used for this thesis, while the other ones were deemed not relevant for the scope of this thesis.

Table 6-15. Weights and Credits according to Yu et al. (2015).

Yu et al. (2015)			
	Credits	Points according to author	Weight according to author
Landscape		11,25	11%
	Land Use		
	Outdoor environment		
	site design and site ecology		
Energy efficiency		17,5	18%
	Lighting and electrical system		
	Energy utilization		
Water efficiency		10	10%
	Water-saving system		
	Water-saving utensils and facilities		
	utilization of non-traditional water resources		
Material and resources		15	15%
	material saving design		
	material selection		
	TOTAL	53,75	54%

Please see in Table 6-16 the credits and weight allocation used from **LEED** guide version 4.1 for Building Design and Constructions (LEED, 2023). Please note credits covering 64% of the points have been used for this thesis, while the other ones were deemed not relevant for the scope of this thesis.

Table 6-16. Weights and Credits according to LEED guide version 4.1 for Building Design and Constructions (LEED, 2023).

LEED v4.1 Building Design and Construction - LEED (2023)		
Credits	Points according to author	Weight according to author
Location and Transportation		
Sensitive Land protection	1	1%
Sustainable sites		
site assessment	1	1%
protect or restore habitat	2	2%
rainwater management	3	3%
heat island reduction	2	2%
light pollution reduction	1	1%
Water efficiency		
indoor water use reduction	6	6%
outdoor water use reduction	2	2%
water metering	1	1%
Energy and Atmosphere		
Advanced energy metering	1	1%
Optimise energy performance	18	18%
Renewable energy	5	5%
Materials and resources		
building LC impact reduction	5	5%
sourcing of raw matyerials	2	2%
material ingredients	2	2%
construction and demolitionw aste mana	2	2%
TOTAL	54	54%
Innovation	10	10%
TOTAL	64	64%

After showing all the relevant credits used in the point allocation for this thesis, as a second step, a table was arranged with all the authors in its columns, and the credits developed in section 6.1.5 in its rows. In this way, all the relevant credits from the different authors were grouped according to the credits developed in this thesis (as shown in Appendix A for the different tables) and are shown in Table 6-17. In this table it's also important to remark that there are 6 items colored in green, and this refers to three different credits that were split in two, given that the definition of the author had in one same credit the content of two different credits of those developed in this thesis.

Table 6-17. Credits considered for each credit to assign the percentages.

Credits	Gómez Comendador et al. (2019)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Envision - Institute for Sustainable Infrastructure (2018)	LEED v4.1 Building Design and Construction - LEED (2023)	Yu et al. (2015)
Water Usage								
Water Consumption in Operation	reducing water consumption outdoor reducing water consumption indoor water metering	installation of water-saving devices use of recycled water	water use	fresh water consumption reduction runoff water stored	capturing run-off beneficial use water consumption in operation - consideration during desgin water consumption in operation - reduction measures included in the design	reduce operational water consumption monitor water systems	indoor water use reduction outdoor water use reduction water metering	Water-saving system Water-saving utensils and facilities utilization of non-traditional water resources
Energy								
Energy Consumption in Operation	energy consumption and management	energy conservation in airport building Energy-saving control	design for reduced energy consumption and carbon emissions in use energy and carbon performance on site	Energy savings rate	energy and carbon emissions reduction for operation implementation of energy and carbon reductions for operation	Reduce operational energy consumption Comission and Monitor energy systems	Advanced energy metering Optimise energy performance	Lighting and electrical system Energy utilization
Renewable Energy	use of renewable energy	use of renewable energies		renewable energy use rate	opportunities for renewable/low carbon/ zero carbon nergy witihn the operational scheme incorporating renewable/low carbon/ zero carbon nergy witihn the operational scheme	Use renewable Energy	Renewable energy	
Materials								
Environmental Impact of Materials	infra LC impact		embodied impacts minimising use and impacts of hazardous amterials		Life Cycle Assessment Hazardous materials	Reduce net embodied carbon	building LC impact reduction material ingredients	material selection
Choice of Materials	choice of building materials	basic principles of resources design for resource efficiency waste and management of arisings		recycled reuse waste	durability and low maintenance on-site use of demolition arisings reclaimed or recycled materials reclaimed or recycled bulk fill and sub-base	use recycled materials		material saving design
Balance Earthwork On Site					cut and fill optimisation beneficial re use of excavated material	balance earthwork on site		
Responsible Sourcing of Materials		responsible sourcing, reuse and recycling materials		local materials use rate	responsible sourcing of construction products, consideration locally sourced and recycled material - early consideration locally sourced and recycled material - further consideration		sourcing of raw matyerials	
Construction Waste Management		site waste management planning and legal compliance waste and management of arisings		waste production decrease		reduce construciton waste	construction and demolitionw aste management	

Continuation Table 6-17. Credits considered for each credit to assign the percentages.

Pollution and Emissions from Aviation Com.								
Ecological Ground Support Equipment	Ecological cars	use of low-emission vehicles						
Aircraft Carbon Management	Biofuels use restrictions on the use of engine ground	rwys and twys designed for carbon reduction Aircraft carbon management						
Effluents								
Water Pollution	wastewater	basic principles of the water environment protection of the freshwater and marine environments			Consultation with regulatory authorities preventing pollution in operation control of impacts on the water environment from the completed project Long term monitoring of impacts on the water environment	Preserve water resources protect surface and ground water quality		
Management of Run-off	management of runoff				Flood risk assessment Flood risk based enhancements Sustainable Drainage Systems Implementation of flood risk based enhancements Implementation of sustainable drainage systems Managing runoff at source	Manage stormwater	rainwater management	
Ecology and Land Use								
Site Selection	Site selection		basic principles in the use of land	floodplains areas farmland area impacted	project location alternatives consideration of project location alternatives site suitability justification of site suitability land use efficiency previous use of the site conservation of soils and other on-site resources	preserve prime farmland preserve undeveloped land maintain floodplain functions	Sensitive Land protection site assessment	Land Use site design and site ecology
Soil Protection	Soil protection		contamination of lands and beds of the sea		Contamination risk assessment Further Assessment of contamination Land contamination specialists Evaluation of remediation options Prevention of future contamination	protect soil health		
Protection of Biodiversity	Protection of biodiversity	Environmental and ecological conservation	basic principles of ecology and biodiversity conservation and enhancement of biodiversity habitat creation measures enhancement of the water environment	impacted ecosystem area ratio	Survey and evaluation of ecological valie land of high ecological value New wildlife habitats Improving the water environment	Preserve sites of high ecological value Enhance functional habitats enhance wetland and surface water functions	protect or restore habitat	site design and site ecology
Lndscape Protection	Landscape protection	Environmental and ecological conservation	basic principles of landscape issues		Landscape and visual factors impact on landscape character landscape development policies local landscape character appropriatness of species selected assessment of existing vegetations retention of existing vegetation non-vegetation features Long term management plan	enhance views and local character		Outdoor environment
Historic and Cultural Resources			baseline studies of the historic environment conservation and enhancement	Cultural Heritage	baseline studies and surveys use of suitable professionals and standards Consultation integration of lsited or registered heritage assets integration of non-registered heritage assets	preserve historic and cultural resources		
Light Pollution	reducing light pollution				light pollution	minimize light pollution	light pollution reduction	
Heat Island Effect	Reduced heat island effect						heat island reduction	
Management								
Sustainable Management Plan			sustainable management	Project Sustainability Management Plan	principles of sustainable development selection process for designers and contractors Environmental and social performance in contracts	establish a sustainale management plan		
Plan for End-of-life						plan for end of life		
Innovation								
Innovation	Innovation				Innovation		Innovation	

In order to obtain the weights per credit developed in this thesis per author, the weights of each of the grouped credits (that can be found from Tables 6-9 to 6-16) were summed and arrange as in Table 6-18. This table is divided in two sections: the first section accounts for the airports and infrastructure studies (green and orange, respectively), while the second section accounts for the building studies (pink). This division is done to allocate the similarity of the studies together. Then, an average was obtained from the weights found in literature for the pink section (building section), and another average was calculated for the green and orange studies (infrastructure and airports section). This is done to obtain an average weight for all the studies considering buildings separately from those considering airports and infrastructures. Next, a total average was obtained from the sum of these two averages but is important to highlight that a 75% of weight was given to the airport and infrastructure average value, while a 25% weight to the building values. This is done to underscore the importance of infrastructure and airports related aspects when developing specifically a rating system for airports airsides from an infrastructural perspective (scope of this thesis).

Table 6-18. Table developed for Point Allocation.

Credits	Airports		Infrastructure					Buildings					
	Gómez Comendador et al. (2019)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Envision - Institute for Sustainable Infrastructure (2018)	Average INFRA	LEED v4.1 Building Design and Construction - LEED (2023)	Yu et al. (2015)	Average BUILDINGS	TOTAL Average	Weight in 100%	Final Point
Water Usage													
Water Consumption in Operation	6%	7%	6%	4%	1%	3%	5%	9%	10%	10%	6%	8%	8
										SUB-TOTAL	6%	8%	8
Energy													
Energy Consumption in Operation	4%	15%	4%	1%	2%	4%	5%	19%	18%	18%	8%	11%	11
Renewable Energy	2%	5%		1%	2%	2%	2%	5%		5%	3%	4%	4
										SUB-TOTAL	11%	15%	15
Materials													
Environmental Impact of Materials	4%	4%	3%		2%	2%	3%	7%	8%	7%	5%	6%	6
Choice of Materials	5%		5%	1%	1%	2%	3%		8%	8%	5%	6%	6
Balance Earthwork On Site					1%	1%	1%			-	1%	1%	1
Responsible Sourcing of Materials			2%	4%	1%		2%	2%		2%	2%	3%	3
Construction Waste Management			4%	1%	1%	2%	2%	2%		2%	2%	3%	3
										SUB-TOTAL	15%	19%	19
Pollution and Emissions from Aviation Com.													
Ecological Ground Support Equipment	4%	9%					6%			-	6%	8%	8
Aircraft Carbon Management	6%	15%					10%			-	10%	14%	14
										SUB-TOTAL	16%	22%	22
Effluents													
Water Pollution	1%		4%		1%	3%	2%			-	2%	3%	3
Management of Run-off	2%			0%	3%	2%	2%	3%		3%	2%	3%	3
										SUB-TOTAL	4%	6%	6
Ecology and Land Use													
Site Selection	3%		5%	9%	3%	5%	5%	2%	6%	4%	5%	6%	6
Soil Protection	3%		5%		2%	1%	3%			-	3%	3%	3
Protection of Biodiversity	4%	4%	5%	5%	1%	6%	4%	2%	2%	2%	4%	5%	5
Lndscape Protection	4%	4%	1%		3%	1%	3%		4%	4%	3%	4%	4
Historic and Cultural Resources			3%	6%	1%	2%	3%			-	3%	4%	4
Light Pollution	1%				2%	1%	1%	1%		1%	1%	1%	1
Heat Island Effect	1%						1%	2%		2%	1%	2%	2
										SUB-TOTAL	20%	25%	25
Management													
Sustainable Management Plan			3%	3%	2%	2%	3%			-	3%	3%	3
Plan for End-of-life						1%	1%			-	1%	2%	2
										SUB-TOTAL	4%	5%	5
										TOTAL	75%	100%	100
Innovation													
Innovation	1%				10%		6%	10%		10%	7%	9%	9
TOTAL	51%	62%	51%	36%	39%	41%		64%	54%	SUB-TOTAL	7%	9%	9

Once having the TOTAL average from both sections, this summed up to 75% across all the credits. In order to make a rating system with a hundred points as total amount of points, all the percentages from the TOTAL average were scaled to sum 100%. And in order to get points, the percentages were converted in a 1:1 scale to points.

An important highlight is the innovation credit which obtained a value of 9 points (apart from the total of 100 points). This is an extra credit separated from the rest because this credit is developed to incentivize teams on thinking out of the box and proposing innovative solutions which are not considered under the rest of the credits. In this way, it is possible to achieve points with sustainable solutions proposed by the different teams, that are not included in this rating system. In section 6.2.2, more details are given on how the application of these 9 extra points works. Finally, to see all the points and weights arranged for the different credits please see Table 6-19.

Table 6-19. Weight allocation to credits.

Credit Category		Credit	Weight (%)	Points
Water Usage			8%	8
	1	Water Consumption in Operation	8%	8
Energy			15%	15
	1	Energy Consumption in Operation	11%	11
	2	Renewable Energy	4%	4
Materials			19%	19
	1	Environmental Impact of Materials	6%	6
	2	Choice of Materials	6%	6
	3	Balance Earthwork On Site	1%	1
	4	Responsible Sourcing of Materials	3%	3
	5	Construction Waste Management	3%	3
Pollution and Emissions from Aviation Community			22%	22
	1	Ecological Ground Support Equipment	8%	8
	2	Aircraft Carbon Management	14%	14
Effluents			6%	6
	1	Water Pollution	3%	3
	2	Management of Run-off	3%	3

Credit Category		Credit	Weight (%)	Points
Ecology and Land Use			25%	25
	1	Site Selection	6%	6
	2	Soil Protection	3%	3
	3	Protection of Biodiversity	5%	5
	4	Lndscape Protection	4%	4
	5	Historic and Cultural Resources	4%	4
	6	Light Pollution	1%	1
	7	Heat Island Effect	2%	2
Management			5%	5
	1	Sustainable Management Plan	3%	3
	2	Plan for End-of-life	2%	2
TOTAL			100%	100
Innovation			9%	9
	1	Innovation	9%	9

From Table 6-19, it can be seen that the heaviest credits are ''Aircraft Carbon Management'' and ''Energy Consumption in Operation''. This is due to the effects that these credits have on **GHG** emissions, and hence, the different rating systems assigned these credits a high value. This also makes sense with the environmental impacts mentioned in section 3.1, where the **GHG** emissions take a main role for climate change. The emissions from the aircrafts are of main consideration for the pollution in the aviation sector as mentioned in section 5.2.3, and with this credit is possible to incentivize airlines in changing the source of energy from their aircrafts, generating less tailpipe emissions. In the case of energy consumption, this is also relevant for climate change due to the process needed for the energy production, which is stated that over 40% of energy-related $\mathbf{CO_2}$ emissions are caused by the burning of fossil fuels for the generation of electricity (World Nuclear Association, 2022). With this credit, is possible to guide users on finding measures to reduce the energy consumption in airports airsides, and thus, reduce also the impact on climate change. Moreover, due to the weights of the credits, it is also relevant to mention the credits of ''Water Consumption in Operation'', ''Ecological Ground Support Equipment'' and ''Innovation''. In the case of water consumption, it is logic that this credit receives quite a high score given the importance in the conservation of water all around the world, due to the increasing difficulties to preserve this resource due to climate change (Moglia et al., 2018). With this credit, it is possible to guide the user on identifying opportunities to reduce the water consumption during operations of airports. Now, coming to the **GSE** credit, it can be recognized that this follows the same approach than the ''Aircraft Carbon Management'' credit, given the emissions from **GSE** mentioned in section 5.2.3 and contribution to climate change. Therefore, with this credit is possible to guide and incentivize the user on changing the source from the **GSE** on an airport's airside. Finally, the ''Innovation'' credit, this receives a quite high score due to the different measures that can be taken to reduce impacts and, most importantly, **GHG** emissions, in the different disciplines apart from those considered in this rating system developed in this thesis. With this credit, teams are incentivized on finding state-of-the-art solutions to reduce environmental impacts and develop an out of the box thinking for the airport's airside project.

When looking into the weights for credit categories in Table 6-19, it can be seen that ''Ecology and Land Use'' and ''Pollution and Emissions from Aviation Community'' are the heaviest ones, surpassing the 20% of the points. However, the weight from the ''Ecology and Land Use'' category can be explained due to the number of credits that this category encompasses, while the single credits itself are not receiving highest scores from the whole system. On the contrary, the weight of 22% received by the ''Pollution and Emissions from Aviation Community'' can be explained due to the relevance of its credits. This category encompasses just two credits, but the two of them are significant when coming to the emissions from the aviation industry as explained in the previous paragraph. Therefore, it can be said that this category is the heaviest one in terms of credit categories and credits.

After this, in the next section the different possible levels of certification that can be achieved with the rating system developed in this thesis are explained.

6.2.2 Levels of certification

First, it's important to define that the levels of certifications are the different ranges of points that provide a recognition to airport airsides. Their aim is to give a certification to projects that are evaluated against a rating system achieving different number of points across the different credits. Hence, these levels are based on the point structure of the specific rating system. The more points achieved by a project, the more sustainable the project is, and the better the certification obtained, which in turn, improves the image of the project, client, and stakeholders around it.

In this master thesis, in order to define the different levels of certification, literature review was conducted as explained in section 2.2.1 of this report. Therefore, different rating systems were analyzed, namely **LEED** guide version 4.1 for Building Design and Constructions (LEED, 2023), **BREEAM** infrastructure guide version 6 developed by BRE Group (2022), **BREEAM** for buildings also developed by BRE Group, Envision version 3 manual (Institute for Sustainable Infrastructure, 2018), and Green Star NZ analyzed by Doan et al. (2017). From all of them, similar definitions of levels were found. Normally, the base level for the minimum certification is with 30% of the points obtained, with an incremental of 10-15% for the next level of certification. In the case of this thesis, it was decided to follow these common practices, assigning a 30% for the minimum level of certification, and with an incremental of 15% for the following categories, rendering a total of 5 levels of certification, plus one level without certification below 30%. This approach was approved by the sustainability consultant from Royal HaskoningDHV, expert in sustainable rating systems (ninth expert from Table C-1). The different levels defined in this thesis can be seen in Table 6-20, and are similar to those proposed by **BREEAM** infrastructures rating system.

Table 6-20. Levels of certification.

Levels of certification	Overall score, %
Airside of Tomorrow	≥ 90
Leading	75-90
Advanced	60-75
Improving	45-60
Pass	30-45
Assessed	< 30

By looking into Table 6-20, it can be seen that the highest level of certification possible is the one called ''Airside of Tomorrow'' when more than 90% of the points are obtained. This name was decided because it suggests a futuristic approach to airports airsides, where the applied practices should be the latest ones, and the airside is already being as much sustainable as possible. The next level is called ''Leading'' and it is obtained when more than 75% of the points are achieved. This name was decided because the word ''Leading'' signifies a distinguished performance and something that can be as an example for other projects. In this case, the leading means the leader in sustainability practices. Then, the ''Advanced'' level is obtained with more than 60% of the points. This name was decided because something ''Advanced'' means a significant step forward in practices of any discipline, in this case is related to sustainability. Hence, all the airports having an ''Advanced'' level, means that they already took significant sustainable measures into practice. Next, is the ''Improving'' level, which is obtained with more than 45% of the points. This name was decided given that the word suggests being in the path towards something better. In the field of sustainability, this can be related to airports with dedication and commitment that little by little are applying new sustainable practices to their airports and get better results environmentally wise. After that comes the ''Pass'' level, which is obtained with more than 30% of the points. This name was decided because this word implies meeting the minimum criteria in any aspect. In the sustainability field, this can be related to an airport's airside applying the minimum practices that are currently in existence. Finally, it's important to remark that the lowest level is called ''Assessed'', but this does not get any certification, and it is when the points obtained by an airport's airside are below 30%. This name was decided to suggest that the airside was assessed but is not enough yet to achieve any certificate. Hence, at least 30% of the points are required to achieve the lowest level of certification called ''Pass''. The different certification ''stamps'' that were created for the different levels can be seen in Figure 6-11, from left to right, representing from the highest to the lowest level.

Figure 6-11. Level of certification stamps.

Moreover, it's important to highlight that the different levels of certification are assigned with a percentage because not always all the credits are applicable to every project. This means that first, the corresponding team using the rating system should scope out all those credits that are not applicable for their project. Once having done that, the total number of points that can be obtained will be the sum of all the maximum points of all the applicable credits. And then, once the airside is evaluated against the applicable credits, a percentage will be obtained by dividing the achieved number of points with the maximum number of points applicable for the case. Figure 6-12 shows an example for a better interpretation. It can be seen that the maximum points that the project of this example can achieve is 92 after scoping (leaving 3 credits out marked in red, that sums up to 8 points), and the project got 57 points from the standard credits and no points from the innovation credit. This means that 57/92 = 62%, which is equal to an ''Advanced'' level of certification based on Table 6-20.

Water Usage		**8**
1	Water Consumption in Operation	8
Energy		**15**
1	Energy Consumption in Operation	11
2	Renewable Energy	4
Materials		**19**
1	Environmental Impact of Materials	6
2	Choice of Materials	6
3	Balance Earthwork On Site	1
4	Responsible Sourcing of Materials	3
5	Construction Waste Management	3
Pollution and Emissions from Aviation Community		**22**
1	Ecological Ground Support Equipment	8
2	Aircraft Carbon Management	14
Effluents		**6**
1	Water Pollution	3
2	Management of Run-off	3

Ecology and Land Use			**25**
1	Site Selection		6
2	Soil Protection		3
3	Protection of Biodiversity		5
4	Lndscape Protection		4
5	Historic and Cultural Resources		4
6	Light Pollution		1
7	Heat Island Effect		2
Management			**5**
1	Sustainable Management Plan		3
2	Plan for End-of-life		2
TOTAL after scoping out			**92**
Innovation			**9**
1	Innovation		9
Standard Points Achieved			**57**
Points from Innovation			**0**
Level of Certification achieved		**Advanced**	**62%**

Figure 6-12. Example for level of certification obtention after scoping credits.

Moreover, it's important to highlight that if points from the innovation credit are obtained, these are summed to the standard points and divided by the total after scoping out. This is because the innovation credit is a way to get extra points from measures taken by the project team which were not considered in the other credits of this rating system.

Having finished with the levels of certification, now the formal scorecard of the developed rating system is presented in the following section.

6.3 Scorecard

Finally, coming to the last section of chapter 6, it is possible to provide the final structuring of the developed rating system with its points, in a shape of a scorecard. The scorecard gathers the credit categories and credits (defined in section 6.1), their corresponding points (defined in sections 6.2.1), the different levels of certification (defined in section 6.2.2) and the maximum amount of points achievable. Please see the final scorecard in Figure 6-13.

As a final remark, it's important to mention that the developed rating system was named as ''Airports Rating System'' (**ARS**), and its developed logo can be seen attached to the scorecard. The name is straightforward, and the slogan was defined as *Airports of Tomorrow*. This slogan is aimed to show the intention of a state-of-the-art rating system and looking into the future of the aviation industry regarding airports infrastructures. Moreover, it's important to remark that as a name ''Airside Rating System'' could be more suitable for this thesis, but the intention is to continue developing this rating system in the future. Hence, **ARS** could become the name of the company and three different packages could be derived from it: one package for airside infrastructure (this thesis), one package for terminal building and one package for landside infrastructure. Also, other packages could be developed in the field of aircraft navigation and strategies applied by airports operators in order to complement the infrastructural perspective.

Airports Rating System

Scorecard

Water Usage	8
1. Water Consumption in Operation	8

Energy	15
1. Energy Consumption in Operation	11
2. Renewable Energy	4

Materials	19
1. Environmental Impact of Materials	6
2. Choice of Materials	6
3. Balance Earthwork On Site	1
4. Responsible Sourcing of Materials	3
5. Construction Waste Management	3

Pollution and Emissions from Aviation Community	22
1. Ecological Ground Support Equipment	8
2. Aircraft Carbon Management	14

Effluents	6
1. Water Pollution	3
2. Management of Run-off	3

Ecology and Land Use	25
1. Site Selection	6
2. Soil Protection	3
3. Protection of Biodiversity	5
4. Lndscape Protection	4
5. Historic and Cultural Resources	4
6. Light Pollution	1
7. Heat Island Effect	2

Management	5
1. Sustainable Management Plan	3
2. Plan for End-of-life	2

TOTAL	Possible points	100
Levels of Certifications		
Airside of Tomorrow: ≥ 90% of possible points		
Leading: ≥ 75% of possible points		
Advanced: ≥ 60% of possible points		
Improving: ≥ 45% of possible points		
Pass: ≥ 30% of possible points		

Innovation	9
1. Innovation	9

Figure 6-13. Scorecard for Airports Rating System.

Now, in chapter 7 the metrics to assess each credit are defined. With them, it will be possible to assess airports airsides and get a level of certification, which is done in chapter 8 as a validation of this rating system developed in this thesis.

7 METRICS AND BEST PRACTICES

In this chapter the main credits are given metrics. This means, indicating how many points per credit a certain airport's airside gets when being evaluated against each credit. In this way, it will be possible to assess a whole airport's airside against all the corresponding credits, and at the end get a total amount of points for it. Then, this total amount of points gives the corresponding level of certification to the project.

To organize this chapter, first in section 7.1 those considered main credits are defined. Then, in section 7.2, the metrics for those main credits are given. Finally, in section 7.3, best practices for those main credits are provided to guide users achieving the highest score possible.

7.1 Main credits

Those considered main credits are the ones that have received the highest score allocation in section 6.2 of this master thesis. As the highest point allocation for one indicator is 14 points, a ''high'' score allocation in this thesis is considered when the points received by a certain credit are equal to the 50% of 14 points (7 points) or more. However, if this approach is followed, just five credits would be given metrics (23% of the total amount of credits), which is consider a low number, considering that then in chapter 8 the main credits are used for the validation of the rating system. Therefore, a further analysis was executed to reach the best compensation possible and avoid having a too low or too high number of credits to be given metrics. The best compensation is defined as when the number of credits to be given metrics are the closest to 50% of the total number of credits (50% of 22 total credits = 11) as possible. Therefore, it was calculated that giving metrics to those credits having a score allocation of 5 points or higher, accounts for a 41% of the total number of credits (9 credits), and it's the closest to 50% (11 credits). Table 7-1 shows the process followed.

Table 7-1. Defining the main credits.

	Number of credits	Percentage
Total	22	100%
Above 50% of 14 (7)	5	23%
Above 40% of 14 (5.6)	8	36%
Above 30% of 14 (4.2)	9	41%
Above 25% of 14 (3.5)	14	64%
Above 20% of 14 (2.8)	18	82%

Finally, those 9 credits defined as main credits for this thesis are shown and highlighted in green in Table 7-2. Nevertheless, there are three special credits highlighted in yellow called ''Renewable Energy'', ''Water Pollution'' and ''Management of Run-Off''. These credits are considered to be also quite relevant from a Civil Engineering perspective (as discussed with the supervisor from **NACO** of this thesis) besides the score they got, and valuable for the validation to be done in chapter 8. For this reason, these credits are also given metrics in section 7.2 and in this way, a total of 12 credits (55% of the total number of credits) are given metrics.

Table 7-2. Main credits.

Water Usage	**8**
1. Water Consumption in Operation	8
Energy	**15**
1. Energy Consumption in Operation	11
2. Renewable Energy	4
Materials	**19**
1. Environmental Impact of Materials	6
2. Choice of Materials	6
3. Balance Earthwork On Site	1
4. Responsible Sourcing of Materials	3
5. Construction Waste Management	3
Pollution and Emissions from Aviation Community	**22**
1. Ecological Ground Support Equipment	8
2. Aircraft Carbon Management	14
Effluents	**6**
1. Water Pollution	3
2. Management of Run-off	3
Ecology and Land Use	**25**
1. Site Selection	6
2. Soil Protection	3
3. Protection of Biodiversity	5
4. Landscape Protection	4
5. Historic and Cultural Resources	4
6. Light Pollution	1
7. Heat Island Effect	2
Management	**5**
1. Sustainable Management Plan	3
2. Plan for End-of-life	2
TOTAL	**100**
Innovation	**9**
1. Innovation	9

After having defined the main credits in this section, now in the next section the metrics and assessment for them are assigned.

7.2 Metrics for Main Credits

To be able to define the metrics in this section, also an extensive desk research was followed, where the different studies were used as a guide and source of point allocation. Also for the assessment of each credit, it is of utmost importance to consider the effects from the different disciplines in airports as defined in section 5.2.3 and the phases considered for each of them explained in section 5.3.

The main studies used in this section are the same that were used in section 6.2.1, and are eight (8): four (4) of them related to rating systems for infrastructures in general (**CEEQUAL** analyzed by Diaz-Sarachaga et al. (2016), the Envision version 3 manual (Institute for Sustainable Infrastructure, 2018), the **BREEAM** infrastructure guide version 6 developed by BRE Group (2022) and a private rating system developed by Diaz-Sarachaga et al. (2017a)), two (2) of them related to rating systems for airport infrastructures specifically (private rating systems developed by Gómez Comendador et al. (2019), and Chao et al. (2017)), and two (2) of them related to rating systems for buildings in general (the **LEED** guide version 4.1 for Building Design and Constructions (LEED, 2023), and a private rating system developed by Yu et al. (2015)).

The first thing to define for each of the main credits defined in section 7.1, is the structure. It was decided that each of the credits will contain the ''Intent'', the ''Applicability'' and the ''Level of Achievement'' as it is done in **BREEAM**, **LEED** and Envision rating systems. The ''Intent'' refers to the intention of each of the credits, the purpose of them. The ''Applicability'' refers to the condition of when to apply each credit, and a project team should evaluate this condition to know if a certain credit should be considered for their airside or not. Finally, the ''Level of Achievement'' is the set of questions defined to assess the projects against the credits. Hence, the ''Level of Achievement'' defines the score that a certain airside gets in each of the credits, based on the answers to the different questions.

Before going credit by credit, it is important first to mention that some of the credits are ''continuous'' and other ''fixed''. The ''continuous'' ones mean that their effect considered in the design phase of the airside can vary after the airport airside is already in operation. While the ''fixed'' ones, are a one-time decision that will not vary after the airport airside is in operation. Therefore, for those credits considered as ''continuous'', three types of assessment questions were prepared: one question related to the current situation that they are designing for, one question related to what can be done to improve the current situation that they are designing for, and a last question related to the monitoring of their designs. So, those main credits defined as ''continuous'' are: Water Consumption in Operation, Energy Consumption in Operation, Ecological Ground Support Equipment, Aircraft Carbon Management, Water Pollution and Management of Run-Off. The rest of the credits are defined as ''fixed'' and these are: Renewable Energy, Environmental Impact of Materials, Choice of Materials, Site Selection and Protection of Biodiversity, while the Innovation credit does not belong to any of the two categories.

Now the different main credits are shown with their Intent, Applicability and Level of Achievement together with their maximum achievable points in section 7.2.1. To follow the process of assigning points to each assessment question please see Appendix B. To see best practices for each credit please refer to section 7.3.

7.2.1 Main Credits Assessment

Water Consumption in Operation:

The defined credit is shown in Figure 7-1. The intent of it, is clearly to reduce water consumption in the airside and terminal due to actions taken in the airside. This credit is applicable to all airports consuming water during their operations, and hence, it's difficult to deem it not applicable. The first question (indicated with letter A) is related to the impact of water consumption and if the consumption of this resource was estimated. In this way it is possible to know the figures of the expected water consumption. Then, if it was estimated, the next logical question is if measures were applied to reduce the water consumption and to what extent it was reduced, both in the terminal (due to actions taken in the airside so as to still comply with the scope defined in section 1.3) and in the airside (questions indicated with letter B and C respectively). Specially in this type of questions is important to highlight that the reduction is measured against a baseline that should be calculated by the project team, and in the case of this thesis the baseline is defined as a seriously considered alternative or the industry standard practice, whichever is more favorable to the team. Once the baseline is defined, also the reduction in percentage from that baseline (due to the measures applied) should be defined. Depending in the percentage that can be reduced is also the score that each airside gets in this question. For this case, the percentages that can be seen in question B were taken from the credit of Water Consumption Indoor in **LEED** guide version 4.1 for Building Design and Constructions (LEED, 2023), given that the question refers to the terminal building and this credit is related to it, and the 5 points were gradually divided between these percentages. In the case of question C, the percentages were extracted from the credit called ''Reduce Operational Water Consumption'' in Envision version 3 manual (Institute for Sustainable Infrastructure, 2018) due to its focus on infrastructures, and the 1.5 points were gradually divided between these percentages. The last question, namely letter D, refers more to the monitoring of the water consumption, to incentivize project teams to keep track and control of the resource consumption in case that exaggerated values arise.

Water Consumption in Operation		8 points
Intent	To reduce overall water consumption in an airports airside, with some consideration of the terminal.	
Applicability	The credit is applicable to all airports (airside and terminal) consuming water during operations. Airports not including operational water consumtpion may apply this credit deemed not applicable.	
Level of Achievement:		Score
Water consumption impact		
A	Was the water consumption from the airside during operation estimated?	0,5
Water consumption reduction measures		
B	Were measures to reduce water consumption in the terminal due to actions taken in the airside in operation included? To what extent has the airport reduced water use in the Terminal due toa ctions taken in the airside? 25% - 1 pt, 30% - 1,75 pts, 35% - 2,5pts, 40% - 3,25 pts, 45% - 4 pts, 50% - 5 pts	5
C	Were measures to reduce water consumption in the airside during operation included? To what extent has the airport reduced water use in the Airside? 20% - 0,5 pts, 30% - 0,75 pts, 40% - 1 pt, 50% - 1,5 pts	2
Water metering		
D	Were measures to meter water consumption in the airside implemented?	0,5
	TOTAL	8

Figure 7-1. Water Consumption in Operation Credit.

Energy Consumption in Operation:

The defined credit is shown in Figure 7-2. The intent of it, is clearly to reduce energy consumption and carbon emissions and other pollutants related to it, in the airside. This credit is applicable to all airports consuming energy during their operations, and hence, it's difficult to deem it not applicable. The first question (indicated with letter A) is related to the impact of energy consumption and its carbon emissions, and if the consumption of this resource was estimated. In this way it is possible to know the figures of the expected energy consumption and carbon emissions (and other pollutants) generated. Then, if this was estimated, the next logical question is if measures were applied to reduce the energy and carbon emissions related and to what extent they were reduced in the airside (question indicated with letter B). Specially in this type of questions (and same case as in the credit of water consumption during operation) is important to highlight that the reduction is measured against a baseline that should be calculated by the project team, and in the case of this thesis the baseline is defined as the existing conditions, or a seriously considered alternative or the industry standard practice, whichever is more favorable to the team. Once the baseline is defined, also the reduction in percentage from that baseline (due to the measures applied) should be defined. Depending in the percentage that can be reduced is also the score that each airside gets in this question. For this case, the percentages that can be seen in question B were taken from the credit called ''Reduce Operational Energy Consumption'' in Envision version 3 manual (Institute for Sustainable Infrastructure, 2018) due to its focus on infrastructures, and the 8 points were gradually divided between these percentages. The last question, namely letter C, refers more to the monitoring of the energy consumption and carbon emissions related, to incentivize project teams to keep track and control of the resource consumption and the carbon emissions that can be generated, in case that exaggerated values arise.

Energy Consumption in Operation		11 points
Intent	To reduce overall energy consumption and minimise carbon emissions and other pollutants associated with it in an airports airside.	
Applicability	The credit is applicable to all airport airsides consuming energy during operations. Airports not including operational energy consumtpion may apply this credit deemed not applicable.	
Level of Achievement:		Score
Energy and carbon emissions impact		
A	Were the energy consumption and carbon emissions related to it, from the airside during operation estimated?	1,5
Energy and carbon emissions reduction measures		
B	Were measures to reduce energy consumption and carbon emissions related to it, in the airside during operation included? To what extent has the airport reduced energy and carbon emissions in the airside? 10% - 2 pts, 30% - 4 pts, 50% - 6 pts, 70% - 8 pts	8
Energy Metering		
C	Were measures to meter energy consumption in the airside implmented?	1,5
	TOTAL	11

Figure 7-2. Energy Consumption in Operation Credit.

Renewable Energy:

The defined credit is shown in Figure 7-3. The intent of it, is clearly to reduce the environmental impacts from fossil fuel energy production and to incentivize the use of energy from renewable sources in the airside. This credit is applicable to all airports consuming energy during their operations, and hence, it's difficult to deem it not applicable. The first question (indicated with letter A) is related to the opportunities and studies of renewable energy application on an airport's airside. In this way it is possible to have a master plan analysis of how the airside would accommodate the production of on-site renewable sources, or how the airside would accommodate the usage of off-site renewable energy. Then, if the application of renewable energy sources is feasible, the next logical question is if measures were implemented in the airside, and to calculate the percentage of energy that would be used in the airside from renewable sources (question indicated with letter B). Specially in this type of question, as a reduction is not the objective, a baseline should not be calculated, but the estimation of energy that would be met from renewable sources is needed from the project team. Once this percentage is defined, depending on the percentage that is met with renewable sources, is also the score that each airside gets in this question. For this case, the percentages that can be seen in question B were taken from the credit called ''Use Renewable Energy'' in Envision version 3 manual (Institute for Sustainable Infrastructure, 2018) due to its focus on infrastructures, and the 3 points were gradually divided between these percentages. The last question, namely letter C, refers to the positive impact that can be generated due to the production of on-site renewable energy in the airside. This is done to incentivize project teams also to think in the beneficial measures that can be taken for the surroundings of an airport.

Renewable Energy		4 points
Intent	To reduce the environmental harms associated with fossil fuel energy and reduce greenhouse gas emissions by increasing the supply of renewable energy projects.	
Applicability	This credit is applicable to all airports that consume energy (fuel or electricity) during their operation.	
Level of Achievement:		Score
Opportunities for Renewable Energy		
A	Were opportunities for the incorporation of energy from renewable sources generated in the airside and/or off-site explored?	0,5
Incorporation of Renewable Energy		
B	Was energy from renewable sources in the project implemented? Which percentage of the consumed energy of the airport is met with renewable energy generated in the airside? 5% - 0,50 pts, 15% - 1 pts, 30% - 1,50 pts, 50% - 2 pts, net positive - 3 pts	3
Net Positive Impact		
C	Does the airports airside generates energy that can be used by the community?	0,5
	TOTAL	4

Figure 7-3. Renewable Energy Credit.

Environmental Impact of Materials:

The defined credit is shown in Figure 7-4. The intent of it, is clearly to reduce the environmental impacts from the materials used when designing the pavements and drainage system from the airside, but mainly the pavements. This credit is applicable to all airports consuming physical materials in their designs, and hence, it's difficult to deem it not applicable. The first and only question (indicated with letter A) is related to the assessment of the environmental impact from the materials chosen for the pavements and drainage system. For this, a Life Cycle Assessment (**LCA**) should be followed and depending on the type of **LCA** executed, it is also the distribution of points. Moreover, it is important to remark that in order to obtain points in this question, a **LCA** should be executed and used to select the corresponding materials, it is not enough just executing a **LCA** but not using it. The different types of **LCA** were extracted from the **BREEAM** infrastructure guide version 6 developed by BRE Group (2022). The **LCA** are important tools to consider in the design of pavements (Harvey et al., 2014) given that all the materials involved can be analyzed from an environmental perspective, considering several phases (from material production till end-of-life). In this way, good decisions on which materials to use can be taken.

Environmental Impact of Materials		6 points
Intent	To minimise the impacts on the environment from the construction materials of airside pavements and drainage system.	
Applicability	This credit is applicable to all airports airsides that consume physical materials in their design.	
Level of Achievement:		Score
Materials impact assessment		
A	Was a Life Cycle Assessment of the pavements and drainage system materials executed, and has this been used to select materials that can reduce environmental impacts? Complete Carbon footprint - 4 pts, Simplified LCA - 5 pts, Complete LCA - 6 pts	6
	TOTAL	6

Figure 7-4. Environmental Impact of Materials Credit.

Choice of Materials:

The defined credit is shown in Figure 7-5. The intent of it, is to select the materials for pavements and drainage system that most will last while in function, minimizing the maintenance needed, while also including recycled materials in the design as much as possible. This credit is applicable to all airports consuming physical materials in their designs, and hence, it's difficult to deem it not applicable. The first question (indicated with letter A) is related to the long-term design, where teams should design for durability and low maintenance. It is important to remark that in order to obtain points in this question, durability and low maintenance should be considered and applied when designing, it is not enough just considering these aspects but not applying these principles. The second question (indicated with letter B) is related to the recycled materials, to guide teams to include as much recycled materials as possible in the design of airfield pavements. Specially in this type of question, as a reduction is not the objective, a baseline should not be calculated, but the estimation of the percentage of recycled material to be used is needed from the project team. This percentage can be expressed by volume or weight. Once this percentage is defined, depending on the percentage of recycled material used, is also the score that each airside gets in this question. For this case, the percentages that can be seen in question B were taken from the credit called ''Use Recycled Materials'' in Envision version 3 manual (Institute for Sustainable Infrastructure, 2018) due to its focus on infrastructures, and the 3 points were gradually divided between these percentages.

Choice of Materials		6 points
Intent	To ensure that material resources of airside pavements and drainage system remain in use for as long as possible, that maximum value is extracted whilst in use, and that can be recovered at the end of each service life.	
Applicability	This credit is applicable to all airports airsides that include the use or consumption of physical materials.	
Level of Achievement:		Score
Long term design		
A	Was durability and low maintenance considered and applied when designing the airside pavements and drainage system?	3
Materials recycle		
B	Were recycled materials included in the pavements and drainage structure design? at least xx% (by weight or volume) of recycled materials including materials with recycled content and/or reused existing structures or materials. 5% - 0,5 pts, 15% - 1 pt, 25% - 1,5 pts, 50% - 3 pts	3
	TOTAL	6

Figure 7-5. Choice of Materials Credit.

Ecological Ground Support Equipment:

The defined credit is shown in Figure 7-6. The intent of it, is to reduce the emissions from the **GSE** in an airport's airside. The applicability of this credit is Fixed given that an airport mandatorily should have **GSE** in order to operate, therefore this credit cannot be scoped out. The first question (indicated with letter A) is related to the energy estimation from the **GSE** that will run on an airside (the energy could be from carbon fuel, biofuel, electricity or hydrogen). In this way it is possible to know the figures of the expected energy consumption and carbon emissions (and other pollutants) generated from the **GSE**. Then, if this was estimated, the next logical question is if measures were applied to reduce the energy and carbon emissions related to **GSE**. For this, two questions were prepared (letter B and C), one related to the incorporation of infrastructure for **GSE** powered by biofuels, and the other one related to the incorporation of infrastructure for **GSE** powered by electricity or hydrogen. In this way it is possible to incentivize teams to think in the incorporation of **GSE** powered by alternative energy sources and make the airside more sustainable. Specially in question B, where percentages are defined, as a reduction is not the objective, a baseline should not be calculated, but the estimation of energy that would be met with biofuels is needed from the project team. Then, the last question (indicated with letter D), refers more to the monitoring of the energy consumption from the **GSE**, to incentivize project teams to keep track and control of the emissions generated by **GSE**.

Ecological Ground Support Equipment		8 points
Intent	To reduce the impacts of emissions from Ground Support Equipment in the airside of airports.	
Applicability	Fixed	
Level of Achievement:		Score
Energy Estimation		
A	Was infrastructure for Aircrafts using Sustainable Aviation Fuels incorporated? What percentage from the fuel consumption does biofuel meet?	1
Infrastructure for Ecological Vehicles		
B	Was the corresponding infrastructure to cope with Ground Support Equipment using biofuels incorporated? What percentage from the fuel consumption does biofuel meet? 2% - 0,5 pts, 6% - 0,75 pt, 20% - 1,25 pts, 35% - 1,75 pts, 40% - 2 pts , 55% - 2,5 pts	2,5
C	Was the corresponding infrastructure to cope with electric/hydrogen Ground Support Equipment incorporated?	4
Monitoring		
D	Was a tracking system able to reveal the amount of charged fuel into the GSE (biofuel, electricity or hydrogen) incorporated?	0,5
	TOTAL	8

Figure 7-6. Ecological Ground Support Equipment Credit.

Aircraft Carbon Management:

The defined credit is shown in Figure 7-7. The intent of it, is to reduce the emissions from the aircrafts and aviation industry in general. The applicability of this credit is Fixed given that an airport is designed for aircrafts activities, therefore this credit cannot be scoped out. The first question (indicated with letter A) is related to the energy estimation from the aircrafts that will run on a specific airport (the energy could be from carbon fuel, biofuel, electricity or hydrogen). In this way it is possible to know the figures of the expected energy consumption and carbon emissions (and other pollutants) generated from the aircrafts. Then, if this was estimated, the next logical question is if measures were applied to reduce the energy and carbon emissions related to aircrafts. For this, two questions were prepared (letter B and C), one related to the incorporation of infrastructure for aircrafts powered by **SAF**, and the other one related to the incorporation of infrastructure for aircrafts powered by electricity or hydrogen. In this way it is possible to incentivize airports to think in the incorporation of infrastructure for alternative powered aircrafts and also indirectly push airlines to make the change, making the aviation industry more sustainable. Specially in question B, where percentages are defined, as a reduction is not the objective, a baseline should not be calculated, but the estimation of energy that would be met with **SAF** is needed from the project team. Then, the next question (indicated with letter D), is special for the taxiing of aircrafts, and it is related to the design of layouts and to evaluate if project teams have designed for reduction of taxiing times, and thus, emissions during taxiing. The last question (marked with letter E) refers more to the monitoring of the energy consumption from the aircrafts, to incentivize airport operators to keep track and control of the emissions generated by the aircrafts they serve.

Aircraft Carbon Management		14 points
Intent	To reduce the impacts of emissions from Aircrafts in the airports airsides and for the aviation industry in general.	
Applicability	Fixed	
Level of Achievement:		Score
Energy Estimation		
A	Was the energy consumption (fuel, biofuel, electricity or hydrogen) that the Aircraft requires estimated?	0,5
Aircraft Emissions		
B	Was infrastructure for Aircrafts using Sustainable Aviation Fuels incorporated? What percentage from the fuel consumption does biofuel meet? 2% - 0,5 pts, 6% - 1 pt, 20% - 2 pts, 35% - 3 pts, 40% - 3,5 pts , 55% - 4,5 pts	4,5
C	Was infrastructure for Aircrafts using electricity or hydrogen as fuel incorporated?	7
D	Were aircraft taxiing emissions considered when detailing the airport layout?	1,5
Monitoring		
E	Was a tracking system able to reveal the amount of charged fuel into the aircraft (fuel, electricity or hydrogen) incorporated?	0,5
	TOTAL	14

Figure 7-7. Aircraft Carbon Management Credit.

Water Pollution:

The defined credit is shown in Figure 7-8. The intent of it, is to protect the water environment from pollution as the result of the operation of an airport airside. This credit is applicable to all airports airsides that use polluting substances that can contaminate water bodies. The first question (indicated with letter A) is related to the regulatory measures applied in a specific region, where the project team should consult with the authorities about the water issues in the region. In this way it is possible to be aware about the water concerns in the specific region where the airside is planned to be developed. It is important to remark that in order to obtain points in this question, regulatory authorities should be consulted, and the outcome should be communicated to project team members, it is not enough just consulting the authorities but not communicating the outcome to project team members. Then, if the concerns are known, the next logical question is if a plan and measures were applied to control the impacts on the water environment from the airside (question B). In this case, it is also important to remark that in order to obtain points in this question, a plan to control impacts on the water environment should be developed and its elements should be incorporated on the final design, it is not enough just developing a plan but not incorporating its elements. The last question, namely letter C, refers to the monitoring of the water to be discharged to the environment, to incentivize project teams to keep track and control of the water quality, to discharge it as clean as possible, complying with local regulatory requirements.

Water Pollution		3 points
Intent	To protect the local water environment from pollution as the result of the operation of an airports airside.	
Applicability	This credit is applicable to all airsides that use polluting substances with the potential to contaminate water sources.	
Level of Achievement:		Score
Regulatory measures		
A	Were regulatory authorities consulted about water issues related to the airport's airside, and has the outcome been communicated to project team members?	0,5
Control of imapact on the water environment		
B	Has a plan to control the impacts on the water environment from the airside in operation been developed? And were elements of this plan incorporated on the final design?	2
Monitoring		
C	Were measures to track the water quality from the drainage systems so as to satisfy local regulatory requirements included?	0,5
	TOTAL	3

Figure 7-8. Water Pollution Credit.

<u>Management of Run-Off:</u>

The defined credit is shown in Figure 7-9. The intent of it, is to minimize the impact from the airside on runoff quantity. This credit is applicable to all airport's airsides impacting on run-off water. The first question (indicated with letter A) is related to the assessment of flood/draught risk that can be generated due to the existence of the airport's airside. In this way it is possible to be aware about the consequences that this may have on the airport and the surroundings. Then, if the consequences are known, the next logical question is if systems were included in the design to manage run-off (question B). It is important to remark that in order to obtain points in this question, systems to manage water run-off should be considered and applied, it is not enough just considering them but not applying them. The last question, namely letter C, refers to the monitoring of the water to be discharged to the environment, to incentivize project teams to keep track and control of the water quantity, to discharge it in correct volumes, complying with local regulatory requirements.

Management of Run-Off		3 points
Intent	Minimize the impact of the airside development on runoff quantity.	
Applicability	This credit is applicable to all airports airsides impacting on run-off water.	
Level of Achievement:		Score
Floodrisk		
A	Was the flood/draught risk of run-off as a consequence of the airside during operations assessed?	0,5
Control of run-off water		
B	Were systems in the design to manage water run-off considered and implemented?	2
Monitoring		
C	Were measures to track the quantity of run-off discharged to the environment in order to satisfy local regulatory requirements included?	0,5
	TOTAL	3

Figure 7-9. Management of Run-Off Credit.

Site Selection:

The defined credit is shown in Figure 7-10. The intent of it, is to avoid developing an airside of an airport on sensitive lands that provide critical ecosystem services. The applicability of this credit is set as fixed, given that a site to develop the airside needs to be mandatorily selected and hence it is impossible to scope it out. The first question (indicated with letter A) is related to the studies undertaken when analyzing different alternatives to develop the airside. In this way it is possible to have a clear view of which areas would be impacted by the development of the airport's airside. It is important to remark that in order to obtain points in this question, relevant information about the alternatives for the airside location should be collected and studies to assist the site selection should be undertaken, it is not enough just collecting relevant information but not undertaking site studies. Then, if the correct studies were undertaken and a site was classified as suitable, the next question is which percentage of the development would be located on previously developed land (question indicated with letter B). Specially in this type of question, as a reduction is not the objective, a baseline should not be calculated, but the estimation of percentage of the project area that would be sited in previously developed land is needed from the project team. Once this percentage is defined, depending on the percentage of undeveloped land that is used for the project, is also the score that each airside gets in this question. For this case, the percentages that can be seen in question B were taken from the credit called ''Preserve Undeveloped Land'' in Envision version 3 manual (Institute for Sustainable Infrastructure, 2018) due to its focus on infrastructures, and the 2.5 points were gradually divided between these percentages. The last question, namely letter C, refers to the compensatory measures that the team is planning to take given the impact generated from the location of the airside on sensitive lands. This is done to incentivize project teams also to think wider and compensate for their impacts on or off site.

Site Selection		**6 points**
Intent	To avoid the development of the airports airside on environmentally sensitive lands that provide critical ecosystem services.	
Applicability	Fixed	
Level of Achievement:		Score
Planning for site selection		
A	Was sufficient relevant information collected about the alternatives for the airside location and were studies undertaken to assisst with the suitability of the site selection of the airside?	2
Sensitive locations to be considered		
B	To what extent is the airside sited on previously developed land? 25% - 0,5 pts, 50% - 1pt , 75% - 1,5 pts , 100% - 2,5 pts	2,5
C	Were compensatory measures incorporated according to the site slection?	1,5
	TOTAL	6

Figure 7-10. Site Selection Credit.

Protection of Biodiversity:

The defined credit is shown in Figure 7-11. The intent of it, is to minimize the interference with ecosystems present in the airport surrounding. The applicability of this credit is set as fixed, given that different ecosystems are present all over the world, not matter where the project is. Therefore, studies for biodiversity are mandatorily and impossible to scope it out. The first question (indicated with letter A) is related to the studies undertaken when analyzing the ecological impacts of the site where the airports airside is developed. In this way it is possible to have a clear view of which ecological areas would be impacted by the development of the airport's airside. It is important to remark that in order to obtain points in this question, a qualified ecologist should be appointed to conduct an appropriate study of the site to determine the ecological impacts and the information should be shared with project team members, it is not enough just appointing an ecologist but not communicating the outcome to project team members. Then, if the correct studies were undertaken, the next question to ask would be if the site selected is avoiding land of high ecological value (question indicated with letter B). Moreover, and a special topic for airports and aviation industry within the biodiversity topic, is the presence of birds in airports that can damage the aircrafts and attempt to the safety of travelers (Hongxuan et al., 2023). Therefore, question letter C, was specially developed for this topic, and it relates to the control measures applied on an airside for birds. This question aims to incentivize teams to consider the birds on the surroundings of the airport to keep both, the integrity of biodiversity and passengers. The last question, namely letter D, refers to the compensatory measures that the team is planning to take given the impact generated from the location of the airside on biodiversity. This is done to incentivize project teams also to think wider and compensate for their impacts on or off site. It is important to remark that in order to obtain points in this question, a specialist should be appointed to identify opportunities for creating new wildlife habitats and these measures should be incorporated into the project, it is not enough just appointing a specialist but not incorporating the measures into the project.

Protection of Biodiversity		**5 points**
Intent	To minimize the possible interference to ecosystems and organisms present in the airport environment.	
Applicability	Fixed	
Level of Achievement:		Score
Ecosystem Assessment and control		
A	Was a qualified ecologist to conduct an appropriate study and evaluation of the site and its zone of influence appointed to determine the ecological impacts? And has the information been shared with the project team members?	1
B	Is the airside placement avoiding land identified as of high ecological value?	1
C	Were measures to control the bird impacts implemented on the airside?	1,5
Enhancement of Habitats		
D	Was a specialist appointed to identify opportunities for creating new wildlife habitats and have these been incorporated into the project?	1,5
	TOTAL	5

Figure 7-11. Protection of Biodiversity Credit.

Innovation:

The defined credit is shown in Figure 7-12. The intent of it, is to support innovation within the aviation industry and more specific, within airports. This credit is applicable as long as the project team has an innovative idea to propose which is not covered in any other of the credits of the **ARS**. This credit has just one assessment question which basically is not a question but an opportunity for teams to suggest innovations with the corresponding proof. Hence this is an opportunity for teams to achieve 9 points extra from those standard 100 points.

Innovation		**9 points**
Intent	To support innovation in the aviation industry, whether related to infrastructure or aircrafts and ground support equipment.	
Applicability	Extra credit apart	
Level of Achievement:		Score
A	Innovations can be suggested by the project team. Most considered ones are those achieving a demonstrable performance in reduction of carbon emissions.	9
	TOTAL	9

Figure 7-12. Innovation Credit.

Having finished with the description of every main credit defined in this section, now in section 7.3, different best practices for each of the credits are recommended.

7.3 Best Practices for Main Credits

In this section, in order to recommend best practices to the users of **ARS**, literature research was conducted on current practices in different airports in the world. Also, experts at **NACO** were consulted for recommendations in each of the disciplines.

Once again, now credit per credit (from the main credits defined in section 7.1) the different best practices will be given. It is important to highlight that not all the questions receive best practices but just those where is possible (given that some questions need further analysis of the specific situation) and that are considered more relevant per credit.

Water Consumption in Operation:

For this credit, best practices are given for questions B and C, where implemented measures permit the reduction of water consumption in the terminal (due to actions taken in the airside) and the airside. According to ICAO (n.d.) and NACO Aviation Academy (2023a), to be able to reduce water consumption in the terminal due to actions in the airside, what can be done is to collect rainwater, groundwater, seawater and greywater to use it for toilet flushing, which consumes a large amount of water, even reaching 50% of the water consumed in the terminal, according to the utility expert from **NACO** (third expert from Table C-1). Another practice where non-potable water can be applied is for fire sprinklers in the terminal (NACO Aviation Academy, 2023a). Therefore, these practices can achieve a significant reduction of water consumption in the terminal.

For the airside, according to Gómez Comendador et al. (2019) and ICAO (n.d.), to be able to reduce water consumption a good practice is also to collect and reuse rainwater, groundwater, seawater and grey water as an alternative to non-potable water supply that can be used for maintenance activities. One of the possible practices is to reuse greywater for irrigation (NACO Aviation Academy, 2023a). Also, water collected from different sources can be used for aircraft washing, **GSE** washing, firefighting or harvesting (NACO Aviation Academy, 2023a). Finally, an interesting approach mentioned by Gómez Comendador et al. (2019) is to reuse the water from de-icing activities, given that to defrost aircrafts in winter, a mix of water and glycol is used.

Energy Consumption in Operation:

For this credit, best practices are given for question B, where implemented measures permit the reduction of energy consumption in the airside. The main component of energy consumption in the airside is the **AGL** (as already mentioned in section 5.2.3), which consumes 50% of the energy in the airside. According to **AGL** experts from **NACO** (first and fourth experts from Table C-1), the main practices nowadays to reduce energy consumption in **AGL** are the use of LED lights (most common practices nowadays in airports all around the world), integration of brightness control for operation and ''follow the green'' features which permits to do segments of lights and the only path which is needed to guide the aircraft is turned on and the rest of lights are off. Moreover, it is relevant to mention that LED lights permit a 50% reduction of energy consumption compared to halogen lights according to **AGL** experts from **NACO** (first and fourth experts from Table C-1). In the new Western Sydney Airport (**WSA**) in Australia, all three measures have been implemented.

Renewable Energy:

For this credit, best practices are given for question B, where implemented measures permit the use of renewable energy sources generated on-site in the airside or off-site. With them, it is possible to meet certain percentage of energy of energy consumption in the airside from these clean sources. According to sustainability experts from **NACO** (fifth expert from Table C-1), nowadays the most prone clean source of energy able to be used for **AGL** or other uses, is the installation of solar panels in the airside, which still have different implications with the glare that they generate, but this is not scope of this thesis. One example of the use of solar panels on-site is the airport of Budapest in Hungary. Furthermore, all other types of renewable sources can be mentioned as the current studies going on now to produce and stock green hydrogen on-site (NACO Aviation Academy, 2023a). Another clean source of energy that can be mentioned is the geothermal energy, which now is being under study to be used for the heating in the airport's terminal of Budapest also, according to the sustainability expert from **NACO** (fifth expert from Table C-1). Last but not least, a good source of clean energy that can be implemented in roof of buildings are the inclusion of small wind turbines as in the case of Boston Logan International Airport in the **US** (Flusberg, 2023).

Environmental Impact of Materials:

Now, coming to the materials category and the credit of Environmental Impact of Materials, best practices are given for the only question that this credit has, which is letter A. To perform a **LCA**, the best practice that can be suggested here is to hire an expert on performing **LCA**s (BRE Group, 2022) to be aid in the process of choosing materials for the airfield pavements and drainage systems. It is interesting to mention that in **NACO** currently a specific **LCA** tool is being developed to be applied in the selection of materials for pavements. With this, pavement's experts can make more informed decisions on how to design the structure of the pavement regarding sustainability.

Choice of Materials:

For this credit, best practices are given for question B, regarding the inclusion of recycled materials in pavements and drainage structures. More importantly for pavements, according to Miller et al. (2016) and pavements expert from **NACO** (sixth expert from Table C-1), the materials demolished from old asphalts and concrete can be re-used in new pavements as aggregates in the foundations, this means sub-base courses and cement treated base courses. In the case of Queen Beatrix International Airport (**AUA**), 84% of the demolished old asphalt from the taxiway and concrete from the apron was re-used in the cement treated base course of the new asphalt for the taxiway and concrete for the apron (NACO Aviation Academy, 2023a). Another interesting best practice that can be mentioned is the inclusion of granulated blast furnace slag and fly ash in the concrete mixture as it was done in **WSA** (NACO Aviation

Academy, 2023a). By using industry by-products, the emissions generated from the cement production can be reduced, as mentioned in section 5.2.3 the concrete industry is responsible for 8.6% of global **CO_2** emissions (Miller et al., 2016). Finally, new practices that are being under investigation mainly for service roads according to NACO Aviation Academy (2023a), is the inclusion of recycled glass used as aggregate replacement, the inclusion of soft plastics used as a bitumen replacement/extender and the use of recycled materials from buildings demolition waste.

<u>Ecological Ground Support Equipment:</u>

For this credit, best practices are given for questions B and C, where infrastructural measures can be implemented to incentivize the use of biofuel powered **GSE**, and electricity/hydrogen powered **GSE** respectively. To be able to include biofuel as an alternative source of power is necessary that the airport has the corresponding infrastructure, which includes a stocking place and a refueling infrastructure (IATA, 2023).

In the case of inclusion of electric infrastructure for **GSE** what is needed from airports are power storage stations, cable lines and charging stations (NACO & nlr, 2021). In the best-case scenario, the energy could come from clean sources on-site or off-site. Moreover, the inclusion of infrastructure for centralized **GPU** in the ground to power aircrafts in the stand, is highly recommended to achieve a 48% reduction of emissions when compared to those from the use of **APU** according to Padhra (2018).

In the case of inclusion of hydrogen infrastructure for **GSE**, the needs are based on the part of the supply chain that would be included in the airside. In the presentation called preparing airports for hydrogen flights from NACO (2023), a remark of three different scenarios that can be seen in Figure 7-13 is done, and are explained in the following.

Figure 7-13. Scenarios for Hydrogen supply chain inclusion.

The first scenario is to include a storage place within the airside. The second scenario is a slightly more expanded supply chain where the process of liquefaction should also take place within the airside, allowing a dual-state input of hydrogen in both gaseous and liquid form. The third and last scenario is the most expansive supply chain, where every process occur within the airside, which means including the production of energy from renewable sources on-site together with the process of electrolysis (NACO 2023). The selection of which scenario to go for in certain airport depends on a series of factors such as the forecasted demand for hydrogen, the resource availability and the economic feasibility as stated in (NACO 2023).

<u>Aircraft Carbon Management:</u>

For this credit, best practices are given for questions B, C and D, where infrastructural measures can be implemented to incentivize the use of **SAF** powered aircrafts, electricity/hydrogen powered aircrafts and the reduction of taxiing distances respectively. For question B and C, the analysis is similar to that one of the previous credit. For the inclusion of **SAF** as an alternative source of power, it is necessary that the airport has the corresponding infrastructure. Although **SAF** is considered a drop-in fuel, still infrastructure such as distribution systems and storage tanks need to be fully compatible (IATA, 2023).

In the case of inclusion of electric infrastructure for aircrafts what is needed from airports are power storage stations, cable lines and charging stations (NACO & nlr, 2021). In the best-case scenario, the energy could come from clean sources on-site or off-site.

In the case of inclusion of hydrogen infrastructure for aircrafts, the needs are the same as those explained for **GSE** in the previous credit and there is no need for repetition. Therefore, reference can be done to that explanation and Figure 7-13.

In the case of question D, when it comes to the emissions of aircrafts during taxiing and their considerations during the layout design, it can be said that a best practice for this is not something special, but to recommend the designers doing the taxiing distances as short as possible so as to reduce emissions. As it was already mentioned in section 5.2.3, the emissions during taxiing are considerable, and according to Di Mascio et al. (2022), a one minute save in taxiing times can reduce up to 12% of emissions during taxiing.

Water Pollution:

For this credit, best practices are given for question B, where implemented measures permit the control of impacts on the water environment in the airside and to reduce the pollution to water bodies. According to Gómez Comendador et al. (2019) one of the basic practices that can be applied is to channel the superficial waters in such a way that they cannot be discharged to the environment without prior control of its quality. Also, the inclusion of oil-water separators is one of the measures recommended by Gómez Comendador et al. (2019), and it's a current practice in airsides designed by **NACO**. The next measure that can be applied are closing gates in the drainage system, which are closed in the case of a spill of hazardous substances as recommended by the drainage expert in **NACO** (seventh expert from Table C-1). Last but not least, one important measure that can be used to separate hazardous substances from water are the reedbeds. They are able to take out the glycol from de-icing activity and the hazardous substances from the firefighting foams. This practice was recommended by the utility expert from **NACO** (third expert from Table C-1), and reedbeds are usually located before discharging the waters from the airside to the environment so as to catch all the contaminants before discharging the water.

Management of Run-Off:

For this credit, best practices are given for question B, where implemented measures permit to manage as much as possible the runoff waters due to the existence of the airside. One measure to control the runoff is to create a channeling system that can direct the superficial waters correctly, together with an attenuation pond that can reduce peaks of runoff water that can create impacts downstream, as recommended by NACO Aviation Academy (2023a).

Site Selection:

For this credit, best practices are given for question C, where implemented measures can compensate for the impact caused due to site selection for the airside development. Normal compensation activities due to civil developments are reforestation, wetland mitigation or the riparian of buffer zones. More specifically, Gómez Comendador et al. (2019) mentions the example of the expansion project of the Madrid Airport, where compensatory measures as acquisitions of farms, reforestation and recovery actions on the banks of the Henares and Jarama river basins were applied.

Protection of Biodiversity:

For this credit, best practices are given for question C due to the relevance of the presence of birds in airports airsides (Hongxuan et al., 2023). While question D is also quite relevant, this follows the same trend as the compensatory measures from the previous credit, where the creation of new wildlife habitats should be fostered on or off-site. In the case of question C for bird control, several practices can be taken, according to Gómez Comendador et al. (2019), this can be related to visual measures, sound systems, chemical measures or natural. While talking to a design leader from **NACO** (eighth expert from Table C-1), other practices were recruited, as choosing a specific height of the grass on the airsides so as to birds cannot detect animals and feel attracted, using clicks on top of signals so as to avoid birds standing on them, not leaving holes in buildings that can be attractive to birds to create nests, creating special slopes in canals to prevent birds of standing on them or even paying farmers in the surroundings of the airport to not attract birds. Another interesting measure that was collected from other specialist within **NACO** (fourth expert from Table C-1), is the use of ''floating balls'' that were adapted in the airport of Luxembourg. This consist in special bubbles that pretend to be rigid balls on where to stand, but as soon as a bird touch it, this ball is vanished as a bubble and hence the bird cannot stand on it.

Innovation:

For this credit, no best practices are suggested given that the objective of this credit is that project teams can suggest their own innovative ideas that were missed by the rest of the credits in **ARS**.

Having finished with recommendations for best practices for the main credits, in chapter 8, the validation of the rating system created takes place.

8 VALIDATING THE RATING SYSTEM

In this chapter the validation of the rating system created in this thesis called **ARS** takes place. To do this, it was decided to do a workshop within **NACO** with professionals from different areas. The organization of the workshop is explained in section 8.1. Then, the case study applied on the workshop is further described in section 8.2. Finally, an expert review from the case study and the performance of **ARS** is given in section 8.3.

8.1 Workshop Organization

The workshop was carried out the on the 3rd October at the offices of **NACO** in the city of The Hague, in The Netherlands. The duration of it was of approximately 4 hours, from 09:00 hs to 13:00 hs. The experts invited from **NACO** where five, and the case study used was the new airport for the ''Bitcoin City'' in La Unión, El Salvador, called Aeropuerto Internacional Del Pacífico. This airport was chosen given that is relatively a small airport compared to other projects, and hence, a ''simple'' case that fits the validation purpose of this thesis. Moreover, this airport was chosen because it's a greenfield project and **NACO** was highly involved in every design aspect, so a large part of the information was available.

The five professionals invited to the workshop were chosen considering their involvement in El Salvador project and their field of expertise. As this rating system considers different disciplines from an airport (pavements, drainage, **AGL**, siting of the project and design in general), it was decided to include in the project the leading professionals involved in El Salvador project for their specific areas, and the supervisor of this thesis. The different professionals can be seen in Table 8-1. Hence, the team was a complete team of professionals from different fields, with a high level of understanding of the case study. It is important to remark that the professional number 2 in Table 8-1, was the leader for design in El Salvador, and was also highly involved in the drainage design for it. Also, it's important to highlight that although the supervisor (fifth expert from Table 8-1) of this thesis did not participate in El Salvador project, he has a great understanding of airside design topics and the objective of this thesis thus, a significantly useful expert for this workshop.

Table 8-1. Experts invited to the Workshop.

No.	Field of Expertise
1	Pavement Design Expert
2	Design Leader in Civil Engineering Department
3	Modelling and Layout Design Expert
4	AGL Expert
5	Design Leader in Civil Engineering Department – Supervisor

To do the workshop, first of all a presentation was given to the experts to familiarize them with the objective of this thesis and the workshop. This presentation was given in 20 minutes and after that, 10 minutes were provided for a Q&A session. Once finished with the presentation, the floor was given to the design leader for El Salvador project, where he explained and provided general information for the context of this airport, in terms of administrative information and highlighting what was the role of **NACO** in the project. This talk from the expert took around 15 minutes. After this brief presentation, the rating system with its credits and metrics was presented using Microsoft Excel, and the activity kicked-off. It was decided that the best way to face this workshop was going credit per credit, analyzing all the questions contained on them. Details of each of the credits and case study are presented in section 8.2. Then, once the round of the credits finished, the experts were asked for feedback on the rating system developed in this thesis and it can be seen in section 8.3.

8.2 Workshop Case Study

To start with, it's important to mention first that the development of Aeropuerto Internacional Del Pacífico is part of a bigger project launched by the current president of El Salvador, Nayib Bukele. The plan is creating a smart city called ''Bitocin City'' where the official currency used is the cryptocurrency known as bitcoin (Martinez Euklidiadas, 2022).

The project to design ''Bitocin City'' was assigned to a Mexican architectural firm called free, and this firm subcontracted **NACO** for the design of the airside of the airport. The location of the airport can be seen in Figure 8-1, while a clearer detail of the airside can be seen in Figure 8-2.

Figure 8-1. Location of Aeropuerto Internacion Del Pacífico, La Unión, El Salvador.

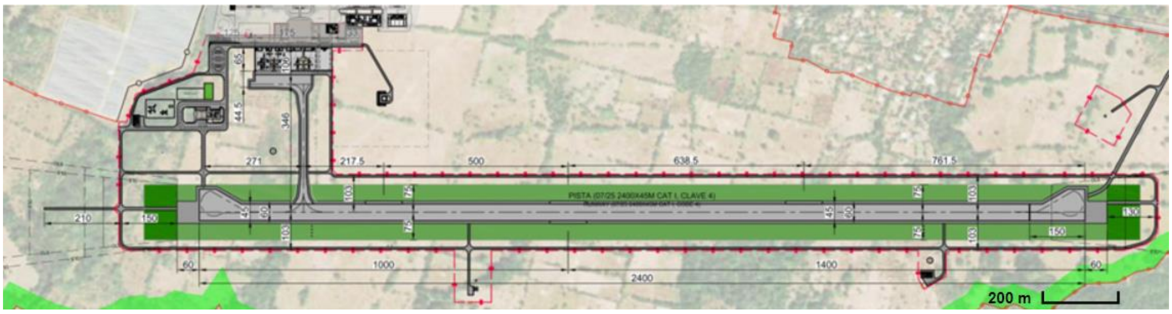


Figure 8-2. Airside detail from Aeropuerto Internacional Del Pacífico, Beta phase.

It is also important to mention that the layout that can be seen in Figure 8-2 is the first phase of the airport which is called ''Beta phase'', while a larger layout is expected in the coming years as a second phase known as ''1 MAP'' phase, and it can be seen in Figure 8-3. The Beta phase is expected to be finished by the end of the year 2024.

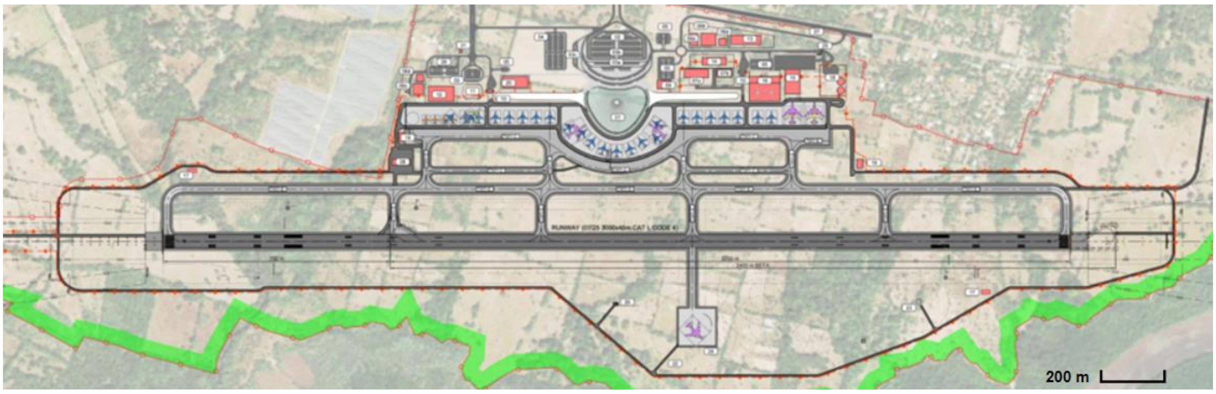


Figure 8-3. Airside detail from Aeropuerto Internacional Del Pacífico, 1 MAP phase.

For the validation purpose of this thesis, the beta phase is used, given that details about construction of the 1 MAP phase are yet not known.

In the following, the results for the environmental assessment of each credit from the workshop are shown. Please consider that just the main credits were used for the workshop, given that were the ones having metrics defined. At the end, also the overall result and level of certification achieved with **ARS** is provided.

<u>Water Consumption in Operation:</u>

The first credit to start with, is the credit called Water Consumption in Operation and it can be seen in Figure 8-4. The structure of the credit is of course the same to the credits presented in section 7.2, but with the only difference that now one column is added to show the score obtained by El Salvador project.

Water Consumption in Operation		**8 points**	
Intent	To reduce overall water consumption in an airports airside, with some consideration of the terminal.		
Applicability	The credit is applicable to all airports (airside and terminal) consuming water during operations. Airports not including operational water consumtpion may apply this credit deemed not applicable.		
Level of Achievement:		Max achievable points	**El Salvador**
Water consumption impact			
A	Was the water consumption from the airside during operation estimated?	0,5	0,5
Water consumption reduction measures			
B	Were measures to reduce water consumption in the terminal due to actions taken in the airside in operation included? To what extent has the airport reduced water use in the Terminal due toa ctions taken in the airside? 25% - 1 pt, 30% - 1,75 pts, 35% - 2,5pts, 40% - 3,25 pts, 45% - 4 pts, 50% - 5 pts	5	0
C	Were measures to reduce water consumption in the airside during operation included? To what extent has the airport reduced water use in the Airside? 20% - 0,5 pts, 30% - 0,75 pts, 40% - 1 pt, 50% - 1,5 pts	2	0
Water metering			
D	Were measures to meter water consumption in the airside implemented?	0,5	0,5
	TOTAL	8	1,0

Figure 8-4. Water Consumption in Operation for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, the water consumption from the airside was estimated, but no further detail could be given in figures for this question, given that a company from Uruguay was the one in charge of utilities. However, as **NACO** was in constant contact with them and different information was shared, they know that the water consumption was estimated. Therefore, the whole 0.5 possible points for this question were assigned to El Salvador project.

B- According to the professionals from **NACO**, no measures from the airside were taken to reduce the water consumption in the terminal. Therefore, 0 points were allocated to El Salvador in this question.

C- According to the professionals from **NACO**, no measures from the airside were taken to reduce the water consumption in the airside. Therefore, 0 points were allocated to El Salvador in this question.

D- According to the professionals from **NACO**, measures to meter the water consumption in the airside were implemented. Therefore, 0.5 points were awarded for this question.

The total points obtained for this credit is equal to 1 point out of 8 possible.

Energy Consumption in Operation:

The second credit is the one called Energy Consumption in Operation and it can be seen in Figure 8-5.

Energy Consumption in Operation		11 points	
Intent	To reduce overall energy consumption and minimise carbon emissions and other pollutants associated with it in an airports airside.		
Applicability	The credit is applicable to all airport airsides consuming energy during operations. Airports not including operational energy consumtpion may apply this credit deemed not applicable.		
Level of Achievement:		Max achievable points	El Salvador
Energy and carbon emissions impact			
A	Were the energy consumption and carbon emissions related to it, from the airside during operation estimated?	1,5	0
Energy and carbon emissions reduction measures			
B	Were measures to reduce energy consumption and carbon emissions related to it, in the airside during operation included? To what extent has the airport reduced energy and carbon emissions in the airside? 10% - 2 pts, 30% - 4 pts, 50% - 6 pts, 70% - 8 pts	8	2
Energy Metering			
C	Were measures to meter energy consumption in the airside implmented?	1,5	1,5
	TOTAL	11	3,5

Figure 8-5. Energy Consumption in Operation for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, the energy consumption and carbon emissions related to it from the airside were not estimated. Therefore, 0 points for this question were assigned to El Salvador project.

B- According to the professionals from **NACO**, LED lights were used for the **AGL** and floodlights. Although, in question A they said that the energy consumption and carbon emissions were not estimated, the **AGL** expert from **NACO** sustains that with these measures they are capable of reducing 25% from the energy on the airside compared to the halogen ones. Therefore, 2 points were allocated to El Salvador in this question.

C- According to the professionals from **NACO**, measures to meter the energy consumption in the airside were implemented. Therefore, 1.5 points were awarded for this question.

The total points obtained for this credit is equal to 3.5 points out of 11 possible.

Renewable Energy:

The third credit is the one called Renewable Energy and it can be seen in Figure 8-6.

Renewable Energy		4 points	
Intent	To reduce the environmental harms associated with fossil fuel energy and reduce greenhouse gas emissions by increasing the supply of renewable energy projects.		
Applicability	This credit is applicable to all airports that consume energy (fuel or electricity) during their operation.		
Level of Achievement:		Max achievable points	El Salvador
Opportunities for Renewable Energy			
A	Were opportunities for the incorporation of energy from renewable sources generated in the airside and/or off-site explored?	0,5	0,5
Incorporation of Renewable Energy			
B	Was energy from renewable sources in the project implemented? Which percentage of the consumed energy of the airport is met with renewable energy generated in the airside? 5% - 0,50 pts, 15% - 1 pts, 30% - 1,50 pts, 50% - 2 pts, net positive - 3 pts	3	0
Net Positive Impact			
C	Does the airports airside generates energy that can be used by the community?	0,5	0
	TOTAL	4	0,5

Figure 8-6. Renewable Energy for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, the opportunities for the incorporation of renewable sources of energy were explored. More specifically, the use of energy from a solar farm that is right next to the airside. Nevertheless, in the end this measure was not adopted due to contractual reasons. Although the measure was not adopted, still 0.5 points were awarded to this question because the opportunity was considered.

B- According to the professionals from **NACO**, no renewable energies were incorporated in the project. Therefore, 0 points were allocated to El Salvador in this question.

C- As no renewable energy was implemented in the project, also no positive impact was done. Therefore, 0 points were awarded for this question.

The total points obtained for this credit is equal to 0.5 points out of 4 possible.

Environmental Impact of Materials:

The fourth credit is the one called Environmental Impact of Materials and it can be seen in Figure 8-7.

Environmental Impact of Materials		6 points	
Intent	To minimise the impacts on the environment from the construction materials of airside pavements and drainage system.		
Applicability	This credit is applicable to all airports airsides that consume physical materials in their design.		
Level of Achievement:		Max achievable points	**El Salvador**
Materials impact assessment			
A	Was a Life Cycle Assessment of the pavements and drainage system materials executed, and has this been used to select materials that can reduce environmental impacts? Complete Carbon footprint - 4 pts, Simplified LCA - 5 pts, Complete LCA - 6 pts	6	0
	TOTAL	6	0,0

Figure 8-7. Environmental Impact of Materials for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, no **LCA** was conducted when designing the airfield pavements or drainage structures. Therefore, 0 points were allocated to this question for El Salvador.

The total points obtained for this credit is equal to 0 points out of 6 possible.

Choice of Materials:

The fifth credit is the one called Choice of Materials and it can be seen in Figure 8-8.

Choice of Materials		6 points	
Intent	To ensure that material resources of airside pavements and drainage system remain in use for as long as possible, that maximum value is extracted whilst in use, and that can be recovered at the end of each service life.		
Applicability	This credit is applicable to all airports airsides that include the use or consumption of physical materials.		
Level of Achievement:		Max achievable points	**El Salvador**
Long term design			
A	Was durability and low maintenance considered and applied when designing the airside pavements and drainage system?	3	3
Materials recycle			
B	Were recycled materials included in the pavements and drainage structure design? at least xx% (by weight or volume) of recycled materials including materials with recycled content and/or reused existing structures or materials. 5% - 0,5 pts, 15% - 1 pt, 25% - 1,5 pts, 50% - 3 pts	3	0
	TOTAL	6	3,0

Figure 8-8. Choice of Materials for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, durability and low maintenance was considered when selecting the materials to design the pavement and drainage structures. The correct materials were chosen according to the air traffic expected and the different areas of the airport, to reduce the maintenance cycles. Structures expecting to receive more weight were design with stronger materials. Specifically for pavements, the expert from **NACO** sustained that the design is planned for 20 years, with major maintenance at the 10^{th} year. Also, he suggested that anyway minor maintenance should be done annually. Therefore, 3 points were allocated to this question for El Salvador.

B- According to the professionals from **NACO**, no recycled materias were included in the airfield pavements or drainage system. Therefore, 0 points were allocated to El Salvador in this question.

The total points obtained for this credit is equal to 3 points out of 6 possible.

<u>Ecological Ground Support Equipment:</u>

The sixth credit is the one called Ecological Ground Support Equipment and it can be seen in Figure 8-9.

Ecological Ground Support Equipment		8 points	
Intent	To reduce the impacts of emissions from Ground Support Equipment in the airside of airports.		
Applicability	Fixed		
Level of Achievement:		Max achievable points	El Salvador
Energy Estimation			
A	Was the energy consumption (fuel, biofuel, electricity or hydrogen) that the GSE requires estimated?	1	1
Infrastructure for Ecological Vehicles			
B	Was the corresponding infrastructure to cope with Ground Support Equipment using biofuels incorporated? What percentage from the fuel consumption does biofuel meet? 2% - 0,5 pts, 6% - 0,75 pt, 20% - 1,25 pts, 35% - 1,75 pts, 40% - 2 pts , 55% - 2,5 pts	2,5	0
C	Was the corresponding infrastructure to cope with electric/hydrogen Ground Support Equipment incorporated?	4	4
Monitoring			
D	Was a tracking system able to reveal the amount of charged fuel into the GSE (biofuel, electricity or hydrogen) incorporated?	0,5	0,5
	TOTAL	8	5,5

Figure 8-9. Ecological Ground Support Equipment for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, the energy that will be consumed by the **GSE** was estimated. Therefore, 1 point were given for this question.

B- According to the professionals from **NACO**, no infrastructure was designed for **GSE** powered by biofuels. Therefore, 0 points were allocated to El Salvador in this question.

C- According to the professionals from **NACO**, 4 charging stations for electric **GSE** were provided. With them, 80% of the total **GSE** can be powered. Therefore, 4 points were allocated to El Salvador in this question.

D- According to the professionals from **NACO**, tracking systems were incorporated to be able to reveal the amount of charged fuel into the **GSE**. Therefore, 0.5 points were allocated to El Salvador in this question.

The total points obtained for this credit is equal to 5.5 points out of 8 possible.

Aircraft Carbon Management:

The seventh credit is the one called Aircraft Carbon Management and it can be seen in Figure 8-10.

Aircraft Carbon Management		14 points	
Intent	To reduce the impacts of emissions from Aircrafts in the airports airsides and for the aviation industry in general.		
Applicability	Fixed		
Level of Achievement:		Max achievable points	**El Salvador**
Energy Estimation			
A	Was the energy consumption (fuel, biofuel, electricity or hydrogen) that the Aircraft requires estimated?	0,5	0
Aircraft Emissions			
B	Was infrastructure for Aircrafts using Sustainable Aviation Fuels incorporated? What percentage from the fuel consumption does biofuel meet? 2% - 0,5 pts, 6% - 1 pt, 20% - 2 pts, 35% - 3 pts, 40% - 3,5 pts , 55% - 4,5 pts	4,5	0
C	Was infrastructure for Aircrafts using electricity or hydrogen as fuel incorporated?	7	0
D	Were aircraft taxiing emissions considered when detailing the airport layout?	1,5	1,5
Monitoring			
E	Was a tracking system able to reveal the amount of charged fuel into the aircraft (fuel, biofuel, electricity or hydrogen) incorporated?	0,5	0
	TOTAL	14	1,5

Figure 8-10. Aircraft Carbon Management for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, the energy that will be consumed by the aircrafts was not estimated. This is because, a lot of uncertainty is still on the aircraft mix that the owners of the project want to accommodate. Therefore, 0 points were given for this question.

B- According to the professionals from **NACO**, no infrastructure was designed for aircrafts powered by biofuels. Therefore, 0 points were allocated to El Salvador in this question.

C- According to the professionals from **NACO**, no infrastructure for electric or hydrogen aircrafts was provided. Therefore, 0 points were allocated to El Salvador in this question.

D- According to the professionals from **NACO**, the aircraft taxiing emissions were considered when designing the layout, and the taxiway was designed as short as possible as it can be seen in Figure 8-2. Therefore, 1.5 points were allocated to El Salvador in this question.

E- According to the professionals from **NACO**, tracking systems were not incorporated to be able to reveal the amount of charged fuel into the aircrafts. Therefore, 0 points were allocated to El Salvador in this question.

The total points obtained for this credit is equal to 1.5 points out of 14 possible.

Water Pollution:

The eighth credit is the one called Water Pollution and it can be seen in Figure 8-11.

Water Pollution		3 points	
Intent	To protect the local water environment from pollution as the result of the operation of an airports airside.		
Applicability	This credit is applicable to all airsides that use polluting substances with the potential to contaminate water sources.		
Level of Achievement:		Max achievable points	El Salvador
Regulatory measures			
A	Were regulatory authorities consulted about water issues related to the airport's airside, and has the outcome been communicated to project team members?	0,5	0,5
Control of imapact on the water environment			
B	Has a plan to control the impacts on the water environment from the airside in operation been developed? And were elements of this plan incorporated on the final design?	2	2
Monitoring			
C	Were measures to track the water quality from the drainage systems so as to satisfy local regulatory requirements included?	0,5	0
	TOTAL	3	2,5

Figure 8-11. Water Pollution for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, regulatory authorities were consulted about the water issues related to the airport's airside. Specially for the mangrove area next to the airside (the river discharging into the sea) that can be seen in Figure 8-1. Therefore, 0.5 points for this question were assigned to El Salvador project.

B- According to the professionals from **NACO**, two measures were taken to control the impacts from the airside on the water environment. One measure was the inclusion of **OWS** in order to catch oil substances and separate it from the water before discharging. The other measure was the inclusion of closing valves in the drainage system to be able to close the system in case of emergencies of chemical spills, for instance in the case of a firefighting activity where the hazardous foam used ends up in the drainage canals. Therefore, 2 points were allocated to El Salvador in this question.

C- According to the professionals from **NACO**, measures to track the water quality from the drainage system were not included. Therefore, 0 points were awarded for this question.

The total points obtained for this credit is equal to 2.5 points out of 3 possible.

Management of Run-Off:

The ninth credit is the one called Management of Run-Off and it can be seen in Figure 8-12.

Management of Run-Off		3 points	
Intent	Minimize the impact of the airside development on runoff quantity.		
Applicability	This credit is applicable to all airports airsides impacting on run-off water.		
Level of Achievement:		Max achievable points	El Salvador
Floodrisk			
A	Was the flood/draught risk of run-off as a consequence of the airside during operations assessed?	0,5	0,5
Control of run-off water			
B	Were systems in the design to manage water run-off considered and implemented?	2	2
Monitoring			
C	Were measures to track the quantity of run-off discharged to the environment in order to satisfy local regulatory requirements included?	0,5	0
	TOTAL	3	2,5

Figure 8-12. Management of Run-Off for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, the flood risk as a consequence of the airside it was assessed. Therefore, 0.5 points for this question were assigned to El Salvador project.

B- According to the professionals from **NACO**, one measures was implemented in El Salvador to manage water run-off. This was the inclusion of attenuation ponds, to reduce peaks of runoff water. Also, it prevents from sending water directly into the river and thus, the flat is not increased and buildings downstream the river are not compromised. Therefore, 2 points were allocated to El Salvador in this question.

C- According to the professionals from **NACO**, measures to track the quantity of water discharged from the drainage system were not included. Therefore, 0 points were awarded for this question.

The total points obtained for this credit is equal to 2.5 points out of 3 possible.

Site selection:

The tenth credit is the one called Site Selection and it can be seen in Figure 8-13.

Site Selection		6 points	
Intent	To avoid the development of the airports airside on environmentally sensitive lands that provide critical ecosystem services.		
Applicability	Fixed		
Level of Achievement:		Max achievable points	El Salvador
Planning for site selection			
A	Was sufficient relevant information collected about the alternatives for the airside location and were studies undertaken to assist with the suitability of the site selection of the airside?	2	2
Sensitive locations to be considered			
B	To what extent is the airside sited on previously developed land? 25% - 0,5 pts, 50% - 1pt , 75% - 1,5 pts , 100% - 2,5 pts	2,5	0
C	Were compensatory measures incorporated according to the site slection?	1,5	0
	TOTAL	6	2,0

Figure 8-13. Site Selection for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, three different alternatives were studied for the siting of the project. One of them was even building an island on the sea. However, the decided option is the one that can be seen in Figure 8-1. Therefore, 2 points for this question were assigned to El Salvador project.

B- According to the professionals from **NACO**, the project of El Salvador is not sited on previously developed land. Furthermore, its even located in a farmland zone, disturbing land with important value for agricultural activities. Therefore, 0 points were allocated to El Salvador in this question.

C- According to the professionals from **NACO**, no compensatory measures were applied or even studied to be applied. Therefore, 0 points were awarded for this question.

The total points obtained for this credit is equal to 2 points out of 6 possible.

Protection of Biodiversity:

The eleventh credit is the one called Protection of Biodiversity and it can be seen in Figure 8-14.

Protection of Biodiversity		**5 points**	
Intent	To minimize the possible interference to ecosystems and organisms present in the airport environment.		
Applicability	Fixed		
Level of Achievement:		Max achievable points	**El Salvador**
Ecosystem Assessment and control			
A	Was a qualified ecologist to conduct an appropriate study and evaluation of the site and its zone of influence appointed to determine the ecological impacts? And has the information been shared with the project team members?	1	1
B	Is the airside placement avoiding land identified as of high ecological value?	1	1
C	Were measures to control the bird impacts implemented on the airside?	1,5	1,5
Enhancement of Habitats			
D	Was a specialist appointed to identify opportunities for creating new wildlife habitats and have these been incorporated into the project?	1,5	0
	TOTAL	5	3,5

Figure 8-14. Protection of Biodiversity for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, an ecologist from El Salvador was appointed to conduct studies of the effects that the airside would have on biodiversity. Also, all the results from these studies have been passed to all the project members from the different parties. Therefore, 1 point was assigned to El Salvador project for this question.

B- According to the professionals from **NACO**, the project of El Salvador is not sited on land identified as of high ecological value. Therefore, 1 point was allocated to El Salvador in this question.

C- According to the professionals from **NACO**, measures to control the impact that birds can have on the airside were taken. This measure consisted of installing a radar that can detect big birds that are emigrating and passing close to the airport zone. Therefore, 1.5 points were allocated to El Salvador in this question.

D- According to the professionals from **NACO**, no specialist was appointed to identify opportunities for creating new wildlife habitats on-site or off-site. Therefore, 0 points were awarded for this question.

The total points obtained for this credit is equal to 3.5 points out of 5 possible.

Innovation:

The twelfth and last credit is the one called Innovation and it can be seen in Figure 8-15.

Innovation		9 points	
Intent	To support innovation in the aviation industry, whether related to infrastructure or aircrafts and ground support equipment.		
Applicability	Extra credit apart		
Level of Achievement:		Max achievable points	El Salvador
A	Innovations can be suggested by the project team. Most considered ones are those achieving a demonstrable performance in reduction of carbon emissions.	9	0
	TOTAL	9	0,0

Figure 8-15. Innovation for El Salvador.

Results for each question:

A- According to the professionals from **NACO**, no innovative measures were taken in this project. Therefore, 0 points were assigned to El Salvador project for this question.

No extra points were obtained from this category.

Having finished with all the analysis credit per credit, the total obtained points from El Salvador and the level of certification awarded as defined in section 6.2.3 can be seen in Figure 8-16. Please note that as not all credits were used for the workshop, the total number of possible points across the main credits is equal to 74 (with 9 more extra possible points from the innovation category), and El Salvador achieved 25.5 out of those 74 points (34%) and no points from the innovation category. Therefore, the certification achieved is the one defined as ''Pass'' in section 6.2.3, and the blue aircraft was awarded.

	Max achievable points	El Salvador
STANDARD POINTS OBTAINED	74	25,5
PERCENTAGE		34%
INNOVATION POINTS OBTAINED		0
PERCENTAGE		0%
TOTAL		34%
LEVEL		PASS

Figure 8-16. Level of Certification achieved by Aeropuerto Internacional Del Pacífico.

Now in the next section, the feedback given by the experts at the end of the workshop is provided.

8.3 Expert review

Once the round of credits was finished, the experts were asked for feedback on the rating system. Hence, one by one each of the experts gave their feedback. To make it easier and in a summarized way, the main feedback is given in bullet points below.

- *''The rating system is a good tool to have conversations with clients, where the framework can be used to trigger solutions that can be applied from a sustainability perspective''* common point between expert number 3 and 5 from Table 8-1.
- *''This framework is good to have a structure that we can apply in a systematic way, when approaching the projects''* expert number 2 from Table 8-1.
- *''It's a good way to detect where the weaknesses are and to see where we can improve from a sustainability perspective in every project''* expert number 4 from Table 8-1.
- *''The tool gives us a framework to understand what the sustainability word really entails. It helps us to see where to focus on and where to put our efforts''* expert number 1 from Table 8-1.
- *''It's a tool that can make airports become more sustainable and compete between them, wanting to have a better certification than the rest of the airports''* expert number 3 from Table 8-1.

All in all, it can be said that the mainstream of comments from the experts is that they see it as a useful tool, that can make sustainability (the environmental pillar of it in the case of this thesis) in airports airsides tangible. It's a way to trigger stakeholders and think about possible solutions to implement, that can make the project more sustainable.

However, they also provided a critical opinion in some credits. Specifically for the Ecological Ground Support Equipment and Aircraft Carbon Management credits, in the questions regarding to the infrastructure provided for electric/hydrogen **GSE** and aircrafts, respectively. The main point was that these questions should not be binary, and it should be studied further on how to give them different point allocation according to a specific percentage achieved, as done in some of the other credits. This was a relevant point where the rating system can be improved, and already clarified in Appendix B. These percentages are important to avoid the concept of ''green washing'' as defined by Zych et al. (2021).

Overall, the tool was well received, and the experts recognized it as useful, and with a real opportunity to continue developing it inside **NACO**, with contribution from other stakeholders. Moreover, the experts agreed that the ''Pass'' level achieved by Aeropuerto Internacional Del Pacífico, was fair. This is because they recognized that several environmentally friendly measures are still missing, and there is a lot of space to improve. Therefore, it can be concluded that the tool as it was presented performed ''correctly'' or ''good'', given that the result from the case study was expected. Also, because no comments were received on missing main points/aspects to be analyzed in the credits.

Having finished with the validation of the rating system performed in this thesis, now in chapter 9, a conclusion for this master thesis is given.

9 CONCLUSION AND DISCUSSION

This research conducted the development of a specific rating system for airport's airsides. The research consisted in five phases and all of them were addressed, presenting the corresponding results in each of them. Therefore, this chapter provides a conclusion and discussion to this master thesis. First, in section 9.1 an answer to the main research question and a conclusion to the thesis is given. Then in section 9.2, a discussion for the master thesis is provided. Lastly, in section 9.3 recommendations and limitations are given for the data and for further research.

9.1 Conclusion

This section presents a conclusion to this research, answering the main research question via the several **SQ**s determined. Hence, first the six defined **SQ**s are answered, and in the end, an answer is given to the main research question, followed by an overall conclusion in section 9.1.1.

1. **Who are the main stakeholders involved in a rating system for environmentally friendly airports airsides?**

   The main stakeholders to be considered for an environmentally friendly rating system for airports airsides are aviation regulators, governmental bodies, **AO**, **ACI**, staff on airside, airlines, service providers and local communities. A brief description of each of them is given in the following but for more details please refer to chapter 4.

   Aviation regulators are important stakeholders because they are the ones setting standards and regulations to be followed by the industry. Therefore, they can directly impact in the applicability of the **ARS** rating system. Then, governmental bodies are significant stakeholders given that they manage the transportation systems and infrastructure within a country, and nowadays they are more focused in developing sustainable policies and practices for these industries. Hence, they can also push for the applicability of rating system as **ARS**, for infrastructures within a country. Also, **AO** are key stakeholders because they are the responsible ones for the airport infrastructure management, and hence they are the ones to decide to apply these sustainable rating systems for the design of their infrastructures, and get their airsides certified. Next, **ACI** is the main association that represents airports around the world, and are focused in the support for the development of sustainability in airports. Therefore, **ARS** is a way to support them in this sustainable development. Then, staff on airside is also quite important stakeholder given that they are the day-to-day workers on an airside, and hence interested in a healthier work environment. **ARS** could give them the opportunity to have it. Airlines are important stakeholders given that they operate at airports and thus, they depend on the management of these infrastructures from the airport operators and the rules that they may apply. With **ARS**, airlines can be highly influenced. Then, different service providers are of importance given that they can be involved in key tasks, such as the design of the airside itself or even providing the **GSE**, and they can be significantly influenced by different decisions taken according to the **ARS**.

Lastly, local communities in the surrounding of airports are important stakeholders, because residents are impacted by different ways of pollution from the airsides and their main interest lies in a better air quality and fewer noise emissions. With **ARS**, the environment quality of the surroundings can be improved, providing a better quality of life to local communities. Therefore, the creation of **ARS** can push to a more sustainable industry, bringing different types of discussions to the table. In order to see the power-interest grid please refer to Figure 4-1.

2. **What are the boundaries that this rating system will evaluate at an airport?**

   The boundaries that the rating system developed in this master thesis evaluates are mainly three: spatial boundaries, component boundaries and functional boundaries. The spatial boundaries define the physical space within which **ARS** operates, in this case is the airside of airports. The component boundaries are the elements (subsytems or resources) that are part of the system. In the case of this thesis means the activities or disciplines that are considered for this rating system with their elements. Hence, in the case of **ARS**, the considered ones are: pavements (**RWY**s, **TWY**s, aprons and service roads), drainage (pipes, culverts, channels, ditches, **OWS**, drains, ponds and storage of water), visual aids (**AGL**), miscellaneous elements (infrastructure for alternative power sources), aircraft movements (taxiing) and different **GSE**. Then, the functional boundaries relate to the specific functions or processes that **ARS** encompasses for each element of each activity or discipline, from a planning and design perspective. Therefore, for pavements and drainage, the whole life cycle is included in **ARS**. For all the rest of elements (**AGL**, infrastructure for alternative power sources, taxiing movements and **GSE**), just the operation phase is included.

3. **What are the main rating criteria (credit categories and credits) to consider for this rating system? and how are they structured in the rating system?**

   The credit categories and credits were defined in a process which involved desk research. First, the credit categories were defined based on the **SDG**s and the link between them and airports, considering the boundaries of this thesis and the environmental pillar of the **TBL**. This pillar tackles relevant issues as climate change, energy & emissions, water & effluents, waste management and biodiversity. Therefore, based on the relevance of each of the **SDG**s linked with airports and the boundaries of this thesis, those goals that can help tackling the issues from the environmental pillar were extracted. Hence, six goals were used, namely number 6 (clean water and sanitation), 7 (affordable and clean energy), 12 (responsible consumption and production), 13 (climate action), 14 (life below water) and 15 (life on land). These **SDG**s were transformed into categories accordingly, and two more categories were added to consider the managerial and innovative perspective from an airport's airside. Therefore, eight categories were obtained in total and can be seen in Figure 9-1, under number 1 – Credit Categories.

   Then, credits were defined for each of the credit categories based on an intensive desk research, using as a guide different existing rating systems for buildings, airports and infrastructures. The relevant credits according to the boundaries of this thesis were extracted from the literature and grouped to form the credits of this thesis. The defined credits together with their categories, depicting the structure of **ARS** can be seen in Figure 9-1, under number 2 – Credits per category and Weights (W).

4. **What is the weight of each credit and what are the possible levels of certification?**

   The weight allocation and the possible levels of certification of this rating system were defined based on an intensive desk research, where different literature was used. Mainly, different rating systems from buildings, infrastructures and airports. For the weight allocation, values from each relevant credit across the different authors were gathered, and average values with some considerations were used (to see the whole process of weight allocation please see section 6.2.1). To see the final weight allocation please see Figure 9-1, under number 2 – Credits per category and Weights (W). For the different levels of certification, a similar process as that one done for weight allocation was conducted, where different authors were reviewed, and the mainstream was followed. To see them please refer to Figure 9-1, under number 4 – Levels of Certification.

5. **What are the metrics of each credit? And what are possible practices to achieve the highest level of certification?**

   The metrics of each credit were defined based on an extensive desk research, where different existing rating systems for buildings, infrastructures and airports were used as a guide and source of point allocation. Moreover, the ''intent'' and ''applicability'' of each credit was provided. Also, different credits were defined as ''continuous'' and other as ''fixed'', with this differentiation it was possible to assign a logic structure to the credits with different questions to assess them. In order to come up with the questions, it was highly relevant to consider the impacts defined for each activity and discipline in section 5.2.3 and in section 5.3. To have a general view of the different credits with their metrics please refer to Figure 9-1, under number 3 – Metrics per Credit. For more details on the metrics please refer to section 7.2.1.

   On the other hand, to recommend best practices for the different credits of **ARS** literature research was conducted on current practices in different airports in the world. Also, experts at **NACO** were consulted for recommendations in each of the disciplines. To see the best practices for each credit in detail please refer to section 7.3.

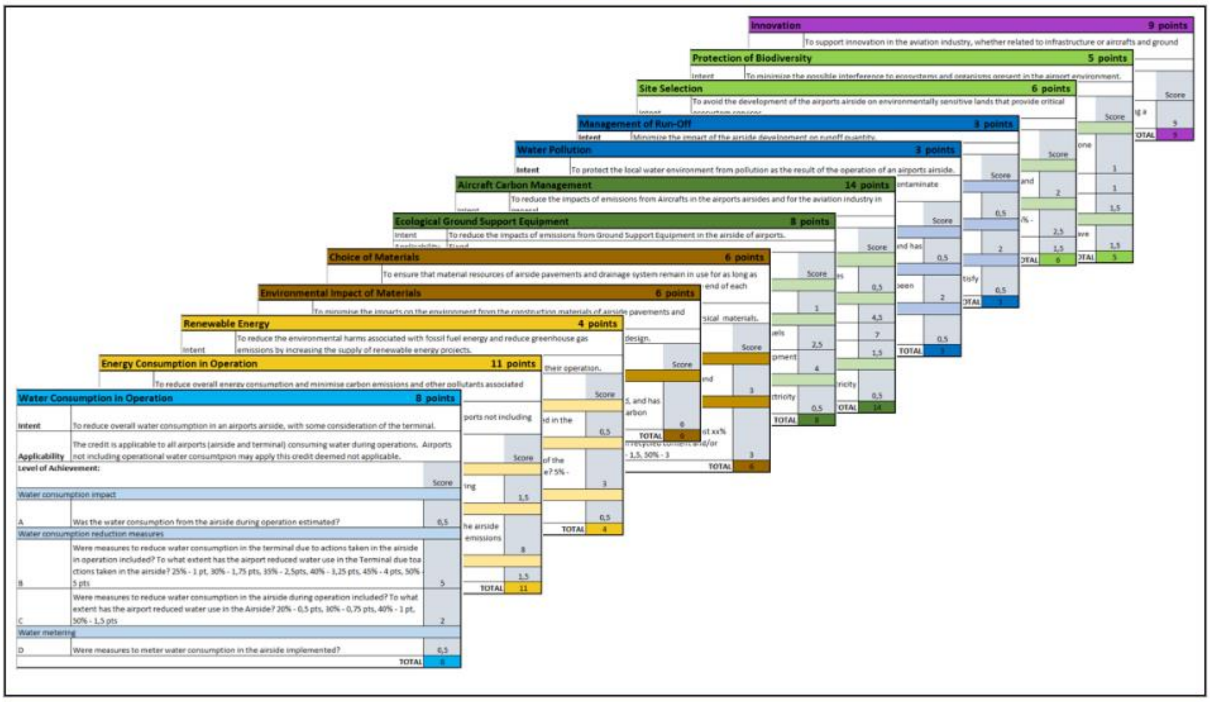
6. **To what extent is the achieved rating system practical to use in airfield development projects?**

   It's important to mention that the level of certification obtained by the case study applied, was as expected by the experts and thus, this can be considered already a sign that the tool works correctly. Moreover, according to the validation done at **NACO**, the experts from different areas agreed on defining the tool as a useful guidance framework that can be further developed, and definitely a good way to improve the sustainability of their projects and airsides in general. Moreover, the experts sustained that **ARS** could make that sustainability as a word becomes tangible when designing airsides, applying it on a systematic way on every project. For more details on the case study applied on the workshop and the expert feedback please refer to section 8.2 and section 8.3, respectively.

1 - Credit Categories

Water Usage	Energy	Materials	Pollution and Emissions from Aviation Community	Effluents	Ecology and Land Use	Management	Innovation
2 - Credits per Category and Weights (W)							
1. Water Consumption in Operation - **W:** 8p	1. Energy Consumption in Operation - **W:** 11p 2. Renewable Energy - **W:** 4p	1. Environmental Impact of Materials - **W:** 6p 2. Choice of Materials - **W:** 6p 3. Balance Earthwork On Site - **W:** 1p 4. Responsible Sourcing of Materials - **W:** 3p 5. Construction Waste Management - **W:** 3p	1. Ecological Ground Support Equipment - **W:** 8p 2. Aircraft Carbon Management - **W:** 14p	1. Water Pollution - **W:** 3p 2. Management of Run-Off - **W:** 3p	1. Site Selection - **W:** 6p 2. Soil Protection - **W:** 3p 3. Protection of Biodiversity - **W:** 5p 4. Lndscape Protection - **W:** 4p 5. Historic and Cultural Resources - **W:** 4p 6. Light Pollution - **W:** 1p 7. Heat Island Effect - **W:** 2p	1. Sustainable Management Plan - **W:** 3p 2. Plan for End-of-life- **W:** 2p	1. Innovation- **W:** 9p

3 - Metrics per Credit



4 - Levels of Certification

Figure 9-1. ARS overall structure.

<u>Main Research Question</u>: How should a rating system be given form in such a way that it can be used for assessing the environmental impacts of airports airsides from an infrastructural perspective?

A rating system that can be used to assess environmental impacts of airports airsides from an infrastructural perspective, should first of all define the boundaries of the airside and the relevant activities on it, based on the environmental impacts that they cause. Then, this rating system should provide an organized structure of credit categories and credits, where all the relevant issues of environmental impacts on airsides are addressed, and that can be tackled from an infrastructural perspective. This structure of credit categories and credits is important because it will provide organization to the system, and a user-friendly guide. With it, the different credits can be independently recognized and assessed one by one, helping the user to really see the differences between them. Then, the credits should be given weights based on their environmental relevance and to guide the user recognizing the most important ones. To do this, extensive research is needed from different sources. After this, it's needed that each credit contains a good way of assessment and structure, making sure that a whole credit is useful to tackle specifically those relevant environmental impacts recognized previously, from an infrastructural perspective. To achieve this, a logic structure within the credit is needed, where the user can be easily guided through the evaluation of each of them. The structure of each credit should explain what the objective of each of them is and guide the user towards it. In the case of **ARS**, this was done with questions, directly referring to the user. Then, an ''up-to-date'' list of best practices (from an infrastructural perspective) is needed to guide users making the airside more environmentally friendly. Users applying these best practices will score higher and in consequence, their airside will be indeed more environmentally friendly. Finally, before the rating system is officially used, this should be validated somehow. A good approach is to validate it with feedback from different experts based on a case study, as it was done in this thesis.

9.1.1 Overall Conclusion

It can be concluded that **ARS** it's a tool that is intended to be used by **AO**s in collaboration with airport consulting firms (as **NACO**) and other stakeholders, to be able to design airsides where its infrastructure can be certified with different levels of environmentally friendliness. Moreover, as it's a tool developed within **NACO**, it's certainly a way to contribute to the sustainability of the different projects currently going on in the company, probably also improving its image and sells. The sustainability can be achieved via the different measures recommended for the different credits. Another important point is that **ARS** is able to influence final decisions because users are able to analyze which are the different measures that should be applied to achieve the highest levels of certification and thus, a more environmentally friendly airside.

Furthermore, it can be said that **ARS** it's a tool that its feasible to be applied as it was shown in the case study conducted in this thesis, with some limitations. The main risks of using **ARS** as it is right now, is the lack of precise definition in some questions within credits (which is further explained in section 9.3.2) risking ending up on ''green washing''. However, the tool performed correctly in the case study. Hence, some more applications are also recommended in the future to have a bigger spectrum of the main weaknesses. Another risk is that the tool now is not able to evaluate tradeoffs from one solution against another, for instance deciding for a mobile **GPU** rather than constructing a whole infrastructure for centralized **GPU**s in small airports with little traffic. Hence, some considerations are still to be carefully considered. On the other hand, the main advantage of the tool, is the structure that it contains (with different credits and credit categories), where every important environmental issue can be tackled in a systematic way, developing kind of a ''checklist'', triggering and incentivizing users to think about the environmental pillar of sustainability from every angle, while also providing recommendations for best practices that can be used in their airside designs. Hence, it can be said that **ARS** is a guide for **AO**s and different stakeholders (as **NACO**) to come up with more sustainable airsides. Another advantage that can be mentioned is that **ARS** is a tool that can make the different **AO**s compete one with each other, striving to have higher levels of certification than their competitors, making the whole industry more sustainable, and also changing the image of the airports and aviation industry in general. Last but not least, a relevant advantage of the tool is that all the list of best practices for the different credits, finds a way to make the word ''sustainability'' tangible.

All in all, it can be said that **ARS** can be seen as a state-of-the-art methodology that could help the aviation industry to tackle the environmental issues from the **TBL**, with infrastructural solutions applied on airsides. The name given to the system with its slogan (''Airports of Tomorrow'') denotes this intention from the rating system to think in solutions to make airside more sustainable in the coming future.

As it was mentioned at the beginning of this master thesis, no rating system is officially developed yet for airports airsides to make it more sustainable or environmentally friendly, and this thesis has achieved the objective of providing one of them. This can be considered as a first step to tackle part of the 3.5% of the climate change that the aviation industry is responsible for, including the 2% of **CO_2** emissions and different environmental impacts as conservation of biodiversity, water resources and treatment of water effluents.

9.2 Discussion

This study provided the development of a sustainable rating system for airports airsides. Academically, this thesis is able to bridge the gap given that there is no specific rating system for airports' airside in existence yet. Related to this point, an important feedback from the expert in sustainable rating systems from Royal HaskoningDHV (ninth expert from Table C-1), was that the outcome of this thesis is quite interesting given that airports are always specific buildings with different characteristics. Moreover, this thesis contributes to the academy given that it can be seen as a model to follow to create analog sustainable rating systems in different industries as a first step. This last point could be of significant importance because with sustainable rating systems reaching the Agendas set by the **UN** could be easier, given that every stakeholder from every industry would know exactly where to focus on, and apply best practices for it.

The practicalities of this master thesis are that **ARS** could be useful for main stakeholders (as **ICAO**) to learn from it, and maybe push to make sustainable rating system mandatories always than an airport has to be designed. Also, **ARS** could be a useful way to make the aviation industry more environmentally friendly, where **AO**s could decide to use them in collaboration with different stakeholders, while communities around airports could get benefits from it. Last important point from practicalities, is that the image from airports could substantially change, attracting more passengers due to the provision of a more sustainable mode of transport/industry.

Finally, the research of this thesis can be linked to different courses taken along the masters. One of the courses is denominated AE4446 - Airport Operations from the Aerospace Engineering Faculty, conducted by Ir. Paul Roling, held on the third quarter of the academic year 2021/22. Important topics from airports were studied on that course, where lectures for environment, runway design and airside were given, among others. That course was useful to get a general knowledge from the world of airports, and the civil engineering part could be further exploded in this thesis. Some of the best practices for sustainability given in that course were applied to this master thesis. Another course that can be related to this thesis, is denominated as SEN1741 - Innovations in Transport and Logistics from the Transport, Policy and Management Faculty, conducted by Dr. Baiba Pudane, held on the fourth quarter of the academic year 2021/22. In this course different innovations were studied, while also the development of conceptual models was learnt. The relationship lies on the outcome of this thesis which can be seen as an innovation within the aviation and construction industry, and also one conceptual model was used to analyze the design characteristics of rating systems on indicators, which was done following the instructions from this course. Lastly, this thesis can be also related to the course TIL4030-20 - TIL Research and Design Methods from the Civil Engineering Faculty, conducted by Dr. ir. Arjan van Binsbergen, held on the first and second quarters of the academic year 2021/22. In this course several design methodologies were studied as the scorecard for instance, and how to come up with the design of a product. Therefore, the outcome of this thesis is related to this course given that some of the methodologies studied on that course were used for this research and also a final product was developed.

9.3 Recommendations and Limitations

This section presents recommendations and limitations of this study. First, in section 9.3.1 recommendations and limitations for the data are provided. Then, in section 9.3.2, recommendations for further research are given.

9.3.1 Recommendations and limitations for data

By far, the first most important limitation regarding data of this thesis is that weight allocations to credits were based on mainstream data from different building, infrastructure and studies from airports rating systems. A whole procedure calculating average values was followed. However, this is a limitation given that this is an expedited approach to develop a whole rating system. It is important to remind that rating systems are developed in teams of a considerable amount of people and time (years), with stakeholders' engagement. Those in charge of doing these kinds of systems are whole associations, where they develop and update every time the versions of their rating systems. Therefore, to comply with the objective of this thesis, the ''mainstream'' procedure was followed, with a check on them from experts from **NACO**. Nevertheless, it is highly recommended to involve all the stakeholders mentioned in this thesis for an iterative process, complementing them with a depth research per credit, conducted by a whole team of sustainability experts on airports, for a more precise allocation of weights to credits. By doing this, is expected that weights could slightly variate with respect to those defined in this thesis.

Also, and related to the previous point, the weight done for every assessment question (in the metrics) in each of the credits was done following mainstream information from literature, with a check from **NACO** experts. While it is highly recommended also to engage the stakeholders mentioned in this study and sustainability experts to reach a final decision on these weights. The input from the aviation industry stakeholders is valuable to get a more qualified opinion. By doing this, the weight of each question could variate, that in consequence could lead to a slightly different level of certification in the airport where the sustainable rating system is applied.

All in all, the main recommendation for data, it can be said it is the way that the weights for each of the credits and questions were obtained. Although a final check was done from experts from **NACO**, still this should have a more precise definition, with a wider perspective from different stakeholders and experts. The different opinions from stakeholders can make the weights to variate, and thus the order of the main credits could change.

9.3.2 Recommendations for further research

In the case of recommendations for further research, several things can be said. The first and most important one is that is highly suggested to include the two other pillars from the **TBL**, namely the social and economic pillars. In this way, new credits would be obtained and given weights. Two important credits that can be included are regarding air quality and noise for instance, that are of high importance (Janić, 2010). Related to this last point, it is also highly recommended to include operations and strategic decisions on the rating system, not just from an infrastructural point of view. For instance, assessing the strategies that an airport operator applies to aircrafts in order to generate less emissions (as the case of airport fees). Or also including the operation part from it, like how is the airport treating waste coming from aircrafts.

Regarding infrastructure itself, it is highly recommended also to include the construction and maintenance activities of them, to analyze also the emissions generated in those process, due to the construction and maintenance equipment for instance. Moreover, in this thesis the most relevant activities and disciplines from the airside were considered, while its recommended also to consider other buildings in the airside, such as hangars, fuel storage buildings or **NAVAIDS**.

Furthermore, in this thesis just the airside was analyzed, while its also recommended to consider landside, terminal and airside all together, given that some interfaces are generated and it's good to have the complete spectrum of them. This thesis developed the airside rating system but one possible thing to be done in future research is to create analogically rating systems for landside and terminal building. In this way it is possible to complement the airside, landside, and terminal building rating systems in one whole airport rating system, giving a level of certification to the whole airport.

Coming to the credits from this thesis, a good approach would be also to study further fixing some credits as mandatory, without score allocation. Hence, the mandatory credits need to be fulfilled, otherwise a certification cannot be given. In this way, some part of sustainability is mandatorily tackled in airports airsides with rating systems. Also, it is recommended to define the metrics for all the credits developed in this thesis and not just the ''main'' ones, and to apply a case study to the whole package, to analyze the performance of the entire rating system. Then, a point that it was already mentioned but is worthy to mention it again, is that the credits for ''Ecological Ground Support Equipment'' and ''Aircraft Carbon Management'', in the case of the electric/hydrogen question, should receive a percentage scale to allocate the points of those questions to avoid the concept of ''green washing'', those questions should not be based on a binary choice, and definitely further research is needed. Finally, another recommendation would be to include with a more in-depth analysis the effect of new technologies in contrails, given that these can have a great impact in climate change as mentioned in section 3.1.1.

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APPENDICES

A CREDIT SELECTION

In the tables presented in this Appendix it can be seen the credits that were used as guide to develop the credits for the rating system in this thesis for the eight categories. As it was explained in section 6.1.5, three different types of literature related to rating systems were gathered, namely related to infrastructures in general, to airports and to buildings in general.

In the columns the different authors can be seen, with a specific color code below. The orange columns refer to those studies related to infrastructures, the green ones refer to those studies related to airports, and the pink ones refer to those studies related to buildings.

Right below each table, credits developed for this thesis can be seen with a more in detail explanation in section 6.1.5. Now, the tables are presented category per category.

Water Usage:

Table A-1. Credits from the literature to come up with Credits for Water Usage.

			Water Usage					
Gómez Comendador et al. (2019)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	LEED v4.1 Building Design and Construction - LEED (2023)	Envision - Institute for Sustainable Infrastructure (2018)	Yu et al. (2015)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Ramakrishnan et al. (2022)
control of water consumption	fresh water consumption reduction	water consumption in operation - consideration during desgin	optimize process water use	reduce operational water consumption	utilization of non-traditional water resources	use of recycled water	water use	alternative water source
reducing of water consumption outdoor - reuse of rainwater and greywater for maintenance activities		water consumption in operation - reduction measures included in the design	indoor water use reduction	monitor water systems	Water saving system	installation of water saving devices		Outdoor water use
reduction of water consumption in handling			outdoor water use reduction		Water saving utensils and facilities			rainwater harvesting
reduction of water consumption indoor	Runoff water stored	capturing run off beneficial use						leakage detection
								irrigation system and landscaping

Credits developed for this thesis:

All the credits in this category were related to water consumption (and hence to part of the drainage system explained in section 5.3), that is why just one credit called ''Water Consumption in Operation'' was developed based in all the credits remarked in red in Table A-1, and it can be seen in Table A-2.

Table A-2. Water Usage Credit.

Water Usage
1. Water Consumption in Operation

Energy:

Table A-3. Credits from the literature to come up with Credits for Energy.

				Energy					
Yu et al. (2015)	Gómez Comendador et al. (2019)	CEEQUAL - Diaz-Sarachaga et al. (2016)	BREEAM infrastructure - BRE Group (2022)	LEED v4.1 Building Design and Construction - LEED (2023)	Envision - Institute for Sustainable Infrastructure (2018)	Diaz-Sarachaga et al. (2017a)	Chao et al. (2017)	Kilkis et al. (2016)	Ramakrishnan et al. (2022)
Energy utilization	Energy consumption management	design for reduced energy consumption and carbon emissions in use	energy and carbon emissions reduction for operation	Optimise energy performance	Reduce operational energy consumption	energy savings rate	energy-saving control	energy-saving measures	energy management
Lighting and electrical system		energy and carbon performance on site	implementation of energy and carbon reductions for operation				energy conservation in airport building	energy consumption	energy efficient appliances
	use of renewable energy		opportunities for renewable/low carbon/ zero carbon nergy witihn the operational scheme	Renewable energy	Use renewable Energy	renewable energy use rate	use of renewable energies	on-site production	offsite renewable energy
			incorporating renewable/low carbon/ zero carbon nergy witihn the operational scheme						onsite renewable energy

Credits developed for this thesis:

The credits found from the literature in this category were related to energy consumption and renewable energy (and hence mainly to **AGL** and miscellaneous elements from section 5.3), that is why two credits were developed. The ''Energy Consumption in Operation'' was developed based in all the credits remarked in red in Table A-3, and the ''Renewable Energy'' credit was developed based in all the credits remarked in light blue in Table A-3. These two credits are different because energy consumption, as the name states, refers to the goal of reducing energy consumption and, with it, carbon emissions. While, the renewable energy credit goal is to achieve a net-zero energy industry, where airports can produce their own energy on/off-site. Both credits can be seen in Table A-4.

Table A-4. Energy Credits.

Energy	
1. Energy Consumption in Operation	
2. Renewable Energy	

Materials:

Table A-5. Credits from the literature to come up with Credits for Materials.

			Materials					
Gómez Comendador et al. (2019)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Design and Construction - LEED (2023)	Envision - Institute for Sustainable Infrastructure (2018)	Yu et al. (2015)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Ramakrishnan et al. (2022)
infra LC impact		Life Cycle Assessment	building LC impact reduction	Reduce net embodied carbon	material selection	use of green building materials	basic principles of resources	material selection - LCA
		Hazardous materials	material ingredients				embodied impacts	material emissions
							minimize use and impacts of hazardous materials	
choice of building material		durability and low maintenance						
		reclaimed or recycled materials - excluding bulk fill and sub-base						design for material optimisation
		reclaimed or recycled bulk fill and sub-base		use recycled materials	material saving design		design for resource efficiency	recycled materials
	recycled reuse waste	on-site use of demolition arisings						
		cut and fill optimisation		balance earthwork on site				
		beneficial re use of excavated material						
		responsible sourcing of construction products, consideration	sourcing of raw matyerials				responsible sourcing, re-use and recycling amterials	
	local materials use rate	locally sourced and recycled material - early consideration						regional materials
		locally sourced and recycled material - further consideration						
	waste production decrease	site waste management planning - preparation	construction and demolitionw aste management	reduce construiciton waste			waste and management of arising	waste management and disposal policy - in construction
		site waste management planning - implementation						
		clearance and disposal of existing vegetation - consideration					site waste management planning and legal compliance	
		clearance and disposal of existing vegetation - implementation						

Credits developed for this thesis:

The credits found from the literature in this category were related to the environmental impact from materials, to the circularity of the materials, to the cut and fill balance of the terrain, to the sourcing of materials and to the waste management of materials during construction (and hence mainly to the pavements from section 5.3). For this category, five credits were developed. The first credit called ''Environmental Impact of Materials'' was developed based in all the credits remarked in light blue in Table A-5, the credit called ''Choice of Materials'' was developed based in all the credits remarked in black in Table A-5. The third credit called ''Balance Earthwork On Site'' was developed based in all the credits remarked in red in Table A-5, the fourth credit called ''Responsible Sourcing of Materials'' was developed based in all the credits remarked in purple in Table A-5, and the fifth credit called ''Construction Waste Management'' was developed based in all the credits remarked in blue in Table A-5. All the credits can be seen in Table A-6.

Table A-6. Materials Credits.

Materials
1. Environmental Impact of Materials
2. Chocie of Materials
3. Balance Earthwork On Site
4. Responsible Sourcing of Materials
5. Construction Waste Management

Pollution and Emissions from Aviation Community:

Table A-7. Credits from the literature to come up with Credits for Pollution and Emissions from Aviation Community.

	Pollution and Emissions from Aviation Community			
Kilkis et al. (2016)	LEED v4.1 Building Design and Construction - LEED (2023)	Chao et al. (2017)	Ramakrishnan et al. (2022)	Gómez Comendador et al. (2019)
low-emission ground vehicles	electric vehicles	use of low emission vehicles	Electric / green vehicle usage	Ecological cars
			charging stations	
biofuels in aviation		Aircraft carbon management		biofuels use
		Runways and Taxiways designed for carbon reduction		restrictions on the use of engine ground

Credits developed for this thesis:

The credits found from the literature in this category were related to low-emissions vehicles and to the measures taken to reduce emissions from aircrafts (and hence mainly to the miscellaneous elements, **GSE** and aircrafts movements from section 5.3). Therefore, two credits were developed. The ''Ecological Ground Support Equipment'' was developed based in all the credits remarked in black in Table A-7, and the ''Aircraft Carbon Management'' credit was developed based in all the credits remarked in red in Table A-7. Both can be seen in Table A-8.

Table A-8. Pollution and Emissions from Aviation Community Credits.

Pollution and Emissions from Aviation Community
1. Ecological Ground Support Equipment
2. Aircraft Carbon Management

Effluents:

Table A-9. Credits from the literature to come up with Credits for Effluents.

		Effluents			
Gómez Comendador et al. (2019)	BREEAM infrastructure - BRE Group (2022)	LEED v4.1 Building Design and Construction - LEED (2023)	Envision - Institute for Sustainable Infrastructure (2018)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Ramakrishnan et al. (2022)
wastewater treatment	preventing pollution in operation		protect surface and ground water quality	protection of the freshwater and marine environments	Wastewater treatment
	the water environment from the completed project			basic principles of the water environment	
	consultation with regulatory authorities				
	long term monitoring of impacts on the water environment		Preserve water resources - at a watershed level		
management of runoff	Floodrisk assessment	rainwater management	Manage stormwater		stormwater management
	floodrisk based enhancement				
	sustainable drainage systems				
	implementation of flood risk based enhancements				
	implementation of sustainable drainage systems				
	managing runoff at soruce				

Credits developed for this thesis:

The credits found from the literature in this category were related to the pollution in water bodies and to the flood risk and management of the run-off water (and hence mainly to the drainage system from section 5.3). Therefore, two credits were developed. The ''Water Pollution'' was developed based in all the credits remarked in red in Table A-9, and the ''Management of Run-Off'' credit was developed based in all the credits remarked in light blue in Table A-9. Both can be seen in Table A-10.

Table A-10. Effluents Credits.

Effluents
1. Water Pollution
2. Management of Run-Off

Ecology and Land Use:

Table A-11. Credits from the literature to come up with Credits for Ecology and Land Use.

				Ecology and Land Use					
Gómez Comendador et al. (2019)	Kilkis et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Design and Construction - LEED (2023)	Envision - Institute for Sustainable Infrastructure (2018)	Yu et al. (2015)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Ramakrishnan et al. (2022)
			project lcoation alternatives			Land Use		basic principles on the use of land (above or below water)	land use planning
site selection		farmland area impacted	consideration of project location alternatives	Sensitive Land protection	preserve prime farmland				
			site suitability						
		floodplains area	justification of site suitability	site assessment	maintain floodplain functions	site design and site ecology			Environmental site assessment
			previous use of the site	high priority site and equitable development	preserve undeveloped land				
			and other on-site resources						
			land use efficiency						
soil protection			contamination risk assessment		protect soil health			contamination of land and beds of the sea	sensitive land protection
			further assessment of contamination						
			land contamination specialists						
			evaluation of remediation options						
			prevention of future contamination						
protection of biodiversity	conserved area (biodiversity)	impacted ecosystem area ratio	survey and evaluation of ecological value					basic principles of ecology and biodiversity	
		Endangered species ratio	land of high ecological value	protect or restore habitat (protect and restore habitat)				conservation and enhancement of biodiversity	protection of ecological features
					Preserve sites of high ecological value		env and ecological conservation		
			New wildlife habitats		Enhance functional habitats			habitat creation measures	
			Improving the water environment					basic principles of the water environment	habitat creation and restorarion (on and off site)
					enhance wetland and surface water functions			enhancement of the water environment	
Landscape protection			Landscape and visual factors		enhance views and local character	outdoor environment		basic principles on landscape issues	enhancement - greenery provision
			impact on landscape character						irrigation system and landscaping
			landscape development policies						preserve and protect landscape on site
			character						
			appropriatness of species selected						
			assessment of existing vegetations						
			retention of existing vegetation						
			features						
			Long term management plan						
		cultural heritage	baseline studies and surveys		preserve historic and cultural resources			baseline studies if the historic environment	
			use of suitable professionals and standards					conservation and enhancement of the historic environment	
			Consultation						
			integration of lsited or registered heritage assets						
			integration of non-registered heritage						
reducing light pollution			LIGHT POLLUTION	light pollution reduction	minimize light pollution				light pollution
reduced heat island effect				heat island reduction					urban heat island reduction

Credits developed for this thesis:

The credits found from the literature in this category were related to the environmental impact due to the location of the project, to the impact on the soil, to the impact on the biodiversity, to the impact regarding landscape, to the impact on the cultural heritage, to the light pollution and the heat island effect generated by the project (and hence mainly to the location of the airside and pavements in general from section 5.3). Therefore, for this category, seven credits were developed. The first credit called ''Site Selection'' was developed based in all the credits remarked in red in Table A-11, the credit called ''Soil Protection'' was developed based in all the credits remarked in black in Table A-11. The third credit called ''Protection of Biodiversity'' was developed based in all the credits remarked in yellow in Table A-11, the fourth credit called ''Landscape Protection'' was developed based in all the credits remarked in blue in Table A-11, the fifth credit called 'Historic and Cultural Resources'' was developed based in all the credits remarked in grey in Table A-11, the sixth credit called ''Light Pollution'' was developed based in all the credits remarked in dark red in Table A-11, and the seventh credit called ''Heat Island Effect'' was developed based in all the credits remarked in browin in Table A-11. All the credits can be seen in Table A-12.

Table A-12. Ecology and Land Use Credits

Ecology and Land Use	
1. Site Selection 2. Soil Protection 3. Protection of Biodiversity 4. Lndscape Protection 5. Historic and Cultural Resources 6. Light Pollution 7. Heat Island Effect	

Management:

Table A-13. Credits from the literature to come up with Credits for Management.

	Management		
Sarachaga et al. (2016)	BREEAM infrastructure - BRE Group (2022)	Sustainable Infrastructure (2018)	Diaz-Sarachaga et al. (2017a)
sustainable management	principles of sustainable development	establish a sustainale management plan	Project sustainability management plan
	selection process for designers and contractors		
	environmental and social performance in contracts		
		plan for end of life	

Credits developed for this thesis:

The credits found from the literature in this category were related to the sustainability concept included in management, and to the plans for end of life of the project during the design phase. Therefore, two credits were developed. The ''Sustainable Management Plan'' was developed based in all the credits remarked in red in Table A-13, and the ''Plan for End-of-Life'' credit was developed based in the credit remarked in light blue in Table A-13. Both can be seen in Table A-14.

Table A-14. Management Credits.

Management	
1. Sustainable Management Plan 2. Plan for End-of-Life	

Innovation:

Table A-15. Credits from the literature to come up with Credits for Innovation.

	Innovation		
BREEAM infrastructure - BRE Group (2022)	Design and Construction - LEED (2023)	Gómez Comendador et al. (2019)	Ramakrishnan et al. (2022)
Exemplary level of performance in existing issues	Innovation	innovation	Innovation
Approved innovations			

Credits developed for this thesis:

All the credits in this category were related to the innovations that can be implemented in projects, that is why just one credit called ''Innovation'' was developed based in all the credits remarked in red in Table A-15, and it can be seen in Table A-16.

Table A-16. Innovation Credits.

Innovation
1. Innovation

B POINT ALLOCATION TO METRICS

The objective of this appendix is to explain how the point allocation of each metric within a credit was assigned.

As it was already mentioned in section 7.2 the studies used for this exercise are eight (8): four (4) of them related to rating systems for infrastructures in general (**CEEQUAL** analyzed by Diaz-Sarachaga et al. (2016), the Envision version 3 manual (Institute for Sustainable Infrastructure, 2018), the **BREEAM** infrastructure guide version 6 developed by BRE Group (2022) and a private rating system developed by Diaz-Sarachaga et al. (2017a)), two (2) of them related to rating systems for airport infrastructures specifically (private rating systems developed by Gómez Comendador et al. (2019), and Chao et al. (2017)), and two (2) of them related to rating systems for buildings in general (the **LEED** guide version 4.1 for Building Design and Constructions (LEED, 2023), and a private rating system developed by Yu et al. (2015)).

In section 7.2 it is explained how the structure of each main credit was given, and in this appendix every credit is show again but with the process of point allocation included. Now, going credit per credit, the point allocation process for the different questions is shown. It is important to highlight that it was decided to follow several rating systems published for this exercise, due to the impossibility of get involved in a stakeholder engagement for time reasons. It is trusted that published papers and rating systems have already done their corresponding studies on assigning weights.

Water Consumption in Operation:

The credit is shown below in Figure B-1 with the structure as presented in section 7.2, but the interesting topic to analyze in this appendix are the four columns to the right side of the figure. The first column called ''Points according to Rating Systems'', shows the weight of each question according to an average weight across all different authors that can be seen in Table B-1. The second column called ''%'', shows the values from the first column but converted to a 100% scale. The third column called ''According to **ARS**'', indicates the amount of points that each question should value according to the percentages from the second column and the total amount of points of the credit. The fourth column called ''Final'', shows the final values for each of the question after rounding. One thing to consider is that it was decided that each final number will be rounded to the nearest half (0.5, 1, 1.5, etc.). However, this is not always the case given that sometimes the rounding would give as a result a higher value than the total value of the credit, and in those special occasions other considerations were taken into account and will be also explained.

So, the first thing that was done in order to fill the four columns from Figure B-1, is the creation of Table B-1. In this table, the eight relevant studies were arranged in columns, and the questions for each credit were arranged in rows. A percentage was obtained per author per question, based on specific credits where they analyzed the same content that a specific question has. In order to keep reproducibility of this thesis, the credits considered from each author are shown in the table which is in the inferior part of Table B-1, and in order to get the percentages of those credits please refer to the tables presented per author in Appendix A, where the credits can be found next to their weights.

In the case of this credit is important to mention that the percentage and credit of question A, belonging to Envision in Table B-1, is highlighted in blue because that number is using just part of the credit were Envision tackles this question and not the whole weight of the credit.

Water Consumption in Operation					8 points
Intent	To reduce overall water consumption in an airports airside, with some consideration of the terminal.				
Applicability	The credit is applicable to all airports (airside and terminal) consuming water during operations. Airports not including operational water consumtpion may apply this credit deemed not applicable.				
Level of Achievement:		points according to Rating Systems	%	according to ARS	Final
Water consumption impact					
A	Was the water consumption from the airside during operation estimated?	0%	3%	0,24	0,5
Water consumption reduction measures					
B	Were measures to reduce water consumption in the terminal due to actions taken in the airside in operation included? To what extent has the airport reduced water use in the Terminal due toa ctions taken in the airside? 25% - 1 pt, 30% - 1,75 pts, 35% - 2,5pts, 40% - 3,25 pts, 45% - 4 pts, 50% - 5 pts	6%	63%	4,87	5
C	Were measures to reduce water consumption in the airside during operation included? To what extent has the airport reduced water use in the Airside? 20% - 0,5 pts, 30% - 0,75 pts, 40% - 1 pt, 50% - 1,5 pts	2%	24%	1,83	2
Water metering					
D	Were measures to meter water consumption in the airside implemented?	1%	11%	0,82	0,5
	TOTAL	10%	100%	8	8

Figure B-1. Point allocation for Water Consumption in Operation.

Another important thing to mention is that numbers that can be seen assigned with 0%, actually are not zero but close to it, and Microsoft Excel rounds it to zero when not showing the decimals. The true zero values are the dashes that can be seen in Table B-1, and this indicates that noncredit was used for the point allocation. Related to this last statement, is also important to mention that some authors do not present any value because it was difficult to exactly relate their credits to the different questions proposed in the rating system developed in this thesis. Therefore, those which were tackling exactly the same issue were used.

Table B-1. Point allocation across authors for Water Consumption in Operation.

sub credit	question	Gómez Comendador et al. (2019)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Envision - Institute for Sustainable Infrastructure (2018)	Yu et al. (2015)	LEED v4.1 Building Design and Construction - LEED (2023)	Average
Water consumption impact	A	-	-	-	-	0%	0%	-	-	0%
Water consumption reduction measures	B	2%	7%	-	-	-	-	10%	6%	6%
	C	3%	-	-	4%	1%	2%	-	2%	2%
Water metering	D	1%	-	-	-	-	1%	-	1%	1%

CREDITS USED	A					Water consumption in operation - consideration during desgin	Preserve water resources		
	B	Reducing water consumption indoor	Installation of water-saving devices Use of recycled water					Water-saving system Water-saving utensils and facilities Utilization of non-traditional water resources	Indoor water use reduction
	C	Reducing water consumption outdoor			Fresh water consumption reduction Runoff water stored	Capturing run-off beneficial use Water consumption in operation - reduction measures included in the design	Reduce operational water consumption		Outdoor water use reduction
	D	Water metering					Monitor water systems		Water metering

Other thing to give insight from this credit is that the rounding from the fourth column of Figure B-1 uses always the closest half. Thus, for instance it can be seen that question C receives a score of 1.83 in the third column, and question D receives a score of 0.82. While in a normal situation 1.83 would be rounded to 2 and 0.82 to 1, in this case it was decided to round them based on which number is closest to a half. This was done to keep the total number always equal to the value of the whole credit, which in this case is 8 points.

Last important comment to highlight from this credit is that it can be seen that the heaviest question is letter B, corresponding to the water consumption of the terminal, which is logic due to the effect that this have compared to that one from the airside, already mentioned in section 5.2.3 of this thesis.

Now proceeding with the next credits, please note that the process was the same for all of them, and thus, in the next credits just important remarks of each of them will be given, avoiding the repetition of the whole structure, as it was given for this credit.

Energy Consumption in Operation:

The credit can be seen in Figure B-2 and the point allocation from the different authors in Table B-2.

Energy Consumption in Operation					**11 points**
Intent	To reduce overall energy consumption and minimise carbon emissions and other pollutants associated with it in an airports airside.				
Applicability	The credit is applicable to all airport airsides consuming energy during operations. Airports not including operational energy consumtpion may apply this credit deemed not applicable.				
Level of Achievement:		points according to Rating Systems	%	according to ARS	Final
Energy and carbon emissions impact					
A	Were the energy consumption and carbon emissions related to it, from the airside during operation estimated?	1%	14%	1,58	1,5
Energy and carbon emissions reduction measures					
B	Were measures to reduce energy consumption and carbon emissions related to it, in the airside during operation included? To what extent has the airport reduced energy and carbon emissions in the airside? 10% - 2 pts, 30% - 4 pts, 50% - 6 pts, 70% - 8 pts	6%	72%	8,07	8
Energy Metering					
C	Were measures to meter energy consumption in the airside implmented?	1%	14%	1,60	1,5
	TOTAL	8%	100%	11	11

Figure B-2. Point allocation for Energy Consumption in Operation.

For this credit is important to remark that the credit called ''Energy savings rate'' from Diaz-Sarachaga et al. (2017a), was not considered with its full weight given that this credit weight was provided by Diaz-Sarachaga et al. (2017a) together with the weight for the credit for renewable energy. Hence, part of its weight was considered here and the rest of it for the renewable energy credit. Similar situation happens with the credit called ''Reduce Operational Energy Consumption'' from Envision version 3 manual (Institute for Sustainable Infrastructure, 2018). This credit was divided between questions A and B, because in the content of it, some little part of it was addressing the estimation of energy consumption, while the rest of the credit addresses the reduction measures.

From Figure B-2 it can be noted that the question with the highest value is that one of reduction measures for energy consumption and carbon emissions, which makes sense given the importance of these topics as already explained in section 3.1 and section 5.2.3. While the other questions are related to estimation and monitoring, with little impact on taking action to do something about it.

Table B-2. Point allocation across authors for Energy Consumption in Operation.

sub credit	question	Gómez Comendador et al. (2019)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Envision - Institute for Sustainable Infrastructure (2018)	Yu et al. (2015)	LEED v4.1 Building Design and Construction - LEED (2023)	Average
Energy and carbon emissions impact	A	-	-	2%	-	-	0%	-	-	1%
Energy and carbon emissions reduction measures	B	4%	12%	2%	2%	2%	2%	-	18%	6%
Energy metering	C	-	-	-	-	-	1%	-	1%	1%
CREDITS USED	A			Energy and carbon performance on site			Reduce operational energy consumption			
	B	Energy consumption and management	Energy-saving control	Design for reduced energy consumption and carbon emissions in use	Energy savings rate	Energy and carbon emissions reduction for operation Implementation of energy and carbon reductions for operation	Reduce operational energy consumption		Optimise energy performance	
	C						Comission and Monitor energy systems		Advanced energy metering	

Renewable Energy:

The credit can be seen in Figure B-3 and the point allocation from the different authors in Table B-3.

Renewable Energy					**4 points**
Intent	To reduce the environmental harms associated with fossil fuel energy and reduce greenhouse gas emissions by increasing the supply of renewable energy projects.				
Applicability	This credit is applicable to all airports that consume energy (fuel or electricity) during their operation.				
Level of Achievement:		points according to Rating Systems	%	according to ARS	Final
Opportunities for Renewable Energy					
A	Were opportunities for the incorporation of energy from renewable sources generated in the airside and/or off-site explored?	1%	14%	0,57	0,5
Incorporation of Renewable Energy					
B	Was energy from renewable sources in the project implemented? Which percentage of the consumed energy of the airport is met with renewable energy generated in the airside? 5% - 0,50 pts, 15% - 1 pts, 30% - 1,50 pts, 50% - 2 pts, net positive - 3 pts	3%	75%	3,09	3
Net Positive Impact					
C	Does the airports airside generates energy that can be used by the community?	0%	11%	0,45	0,5
	TOTAL	4%	100%	4	4

Figure B-3. Point allocation for Renewable Energy.

As it was mentioned in the previous credit, in this case is important to remark that the credit called ''Renewable energy use rate'' from Diaz-Sarachaga et al. (2017a), was not considered with its full weight given that this credit weight was provided by Diaz-Sarachaga et al. (2017a) together with the weight for the credit for energy savings rate. Hence, part of its weight was considered here and the rest of it for the energy consumption credit. Similar situation happens with the credit called ''Use Renewable Energy'' from Envision version 3 manual (Institute for Sustainable Infrastructure, 2018). This credit was divided between questions B and C, because in the content of it, some little part of it was addressing the net positive impact that can be generated, while the rest of the credit addresses the measures that can be implemented to get renewable energy sources.

From Figure B-3 it can be noted that the question with the highest value is that one of implementing measures to use energy from renewable sources, which makes sense given that these clean sources can help reducing the emissions from the aviation industry mentioned in section 3.1.

Table B-3. Point allocation across authors for Renewable Energy.

sub credit	question	Gómez Comendador et al. (2019)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Envision - Institute for Sustainable Infrastructure (2018)	Yu et al. (2015)	LEED v4.1 Building Design and Construction - LEED (2023)	Average
Opprotunities for renewable energy	A	-	-	-	-	1%	-	-	-	1%
Incorporation of renewable energy	B	2%	5%	-	1%	1%	2%	-	5%	3%
Net positive impact	C	-	-	-	-		0%	-	-	0%
CREDITS USED	A					Opportunities for renewable/low carbon/ zero carbon nergy witihn the operational scheme				
	B	Use of renewable energy	Use of renewable energies		Renewable energy use rate	Incorporating renewable/low carbon/ zero carbon nergy witihn the operational scheme	Use renewable Energy		Renewable energy	
	C						Use renewable Energy			

Environmental Impact of Materials:

The credit can be seen in Figure B-4.

Environmental Impact of Materials					6 points
Intent	To minimise the impacts on the environment from the construction materials of airside pavements and drainage system.				
Applicability	This credit is applicable to all airports airsides that consume physical materials in their design.				
Level of Achievement:		points according to Rating Systems	%	according to ARS	Final
Materials impact assessment					
A	Was a Life Cycle Assessment of the pavements and drainage system materials executed, and has this been used to select materials that can reduce environmental impacts? Complete Carbon footprint - 4 pts, Simplified LCA - 5 pts, Complete LCA - 6 pts				6
	TOTAL	0%	0%	0	6

Figure B-4. Point allocation for Environmental Impact of Materials.

In the case of this credit this is a single question and hence the point allocation from different authors is not needed. The whole 6 points from this credit goes to the only question that this credit contains.

Choice of Materials:

The credit can be seen in Figure B-5 and the point allocation from the different authors in Table B-4.

For this credit is important to remark that the credit called ''Choice of Building Materials'' from Gómez Comendador et al. (2019) was divided in questions A and B, because the content of this credit was analyzing both the durability of the material and the incorporation of recycled materials. Similar situation happens with the credit called ''Material Saving Design'' from Yu et al. (2015). This credit was also divided between questions A and B, because in the content of it, half of it was analyzing the durability of the material and the other half the inclusion of recycled material.

Choice of Materials					6 points
Intent	To ensure that material resources of airside pavements and drainage system remain in use for as long as possible, that maximum value is extracted whilst in use, and that can be recovered at the end of each service life.				
Applicability	This credit is applicable to all airports airsides that include the use or consumption of physical materials.				
Level of Achievement:					
		points according to Rating Systems	%	according to ARS	Final
Long term design					
A	Was durability and low maintenance considered and applied when designing the airside pavements and drainage system?	2%	50%	2,99	3
Materials recycle					
B	Were recycled materials included in the pavements and drainage structure design? at least xx% (by weight or volume) of recycled materials including materials with recycled content and/or reused existing structures or materials. 5% - 0,5 pts, 15% - 1 pt, 25% - 1,5 pts, 50% - 3 pts	2%	50%	3,00	3
	TOTAL	4%	100%	6	6

Figure B-5. Point allocation for Choice of Materials.

From Figure B-5 it can be noted that both questions receive the same weight. This can be logic given the importance of both of them. Question A aims to design for long term with low maintenance, which would save emissions in terms of maintenance activities, while question B saves emissions when it comes to the production of materials. Both questions are addressing important issues for materials topics, and thus, a 50% weight for each of the questions is considered to be fair for this thesis.

Table B-4. Point allocation across authors for Choice of Materials.

sub credit	question	Gómez Comendador et al. (2019)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Envision - Institute for Sustainable Infrastructure (2018)	Yu et al. (2015)	LEED v4.1 Building Design and Construction - LEED (2023)	Average
Long term design	A	3%	-	2%	-	0%	-	4%	-	2%
Recycled materials	B	3%	-	2%	-	1%	2%	4%	-	2%
CREDITS USED	A	Choice of building materials		Design for resource efficiency		durability and low maintenance		Material saving design		
	B	Choice of building materials		Responsible sourcing, reuse and recycling amterials		On-site use of demolition arisings Reclaimed or recycled materials Reclaimed or recycled bulk fill and	Use recycled materials	Material saving design		

Aircraft Carbon Management:

The credit can be seen in Figure B-6, and the point allocation in this case was done following different steps than the other credits, given that none of the topics addressed in this credit was found in the eight reviewed literature mentioned at the beginning of this appendix. Therefore, for this specific credit extra research was done in order to be able to assign points to the different questions.

First, literature research was conducted to allocate points to questions B, C and D which are the actual measures taken from an infrastructural perspective. Therefore, coming to question B and C, it was investigated the emissions from **SAF**, electricity and hydrogen as alternative fuels. It was found that **SAF** is a ''drop-in'' fuel and its able to reduce 85% of the emissions of **CO_2** associated with the lifecycle, but the tailpipe emissions from the aircrafts remains the same according to ACI & Aerospace Technology Institute, (2022) and NACO Aviation Academy (2023a). For electric aircrafts, a study conducted by Mukhopadhaya & Graver (2022), states that they can achieve 69% reduction of **CO_2e** emissions including the production process for the battery. It is also important to mention that electric aircrafts do not produce tailpipe emissions, but the main restriction for them is the range that they can fly, which currently technology enables to fly a maximum distance of 140 km with 9 passengers on board (Mukhopadhaya & Graver, 2022), and coming aircrafts can reach 500 km according to NACO Aviation Academy (2023a). In the case of hydrogen aircrafts the main advantage is that they can cover up to 2000 km (NACO Aviation Academy, 2023a), while not generating tailpipe emissions, with a potential of **CO_2** emissions reduction of 50% (Airbus, 2021). One disadvantage of this last technology is that the area covered by the contrails is expected to increase by 70% according to Gonzalez Sanchez (2023), but their life would be shorter due to larger ice crystals. All in all, with all these figures and the literature research conducted, together with the sustainability expert from **NACO** (fifth expert from Table C-1), it was decided that the benefits brought to the industry from an environmental perspective from hydrogen and electric flights compared to **SAF**, they can be 1.5 times higher, and this is reflected in the point allocation to questions B and C.

For question B specifically, it's important to remark that percentages were defined based on the information from European Council (2023). Where it states the RefuelEU Aviation mandates and defining that the minimum share of **SAF** by 2025 should be of 2%, by 2030 of 6%, by 2035 of 20%, by 2040 of 34%, by 2045 of 42% and by 2050 of 70%. Therefore, the percentages established in question B were established to follow the same trend with some modifications. Instead of 34% it was decided to round it to 35%, instead of 42% it was decided to round it to 40% and instead of 70% it was decided to opt for 55% of higher. Then, the 4.5 points were scaled to these percentages defined. In the case of question C, no academic information was yet found on mandates given the early stage of the electric and hydrogen technologies as defined by the sustainability expert from **NACO** (fifth expert from Table C-1). Hence, no percentage was defined for this question, and something that should definitely be considered for further research.

Moreover, when coming to question D, according to Di Mascio et al. (2022), the emissions during taxiing from carbon fuel aircrafts can be reduced up to 12% from a one minute save in taxiing times. As these emissions are just during taxiing, and also some other solutions can be proposed for them apart from the layout, as the restrictions in the use of engine ground or using special **GSE** to push the aicrafts till the runway, as the taxibot proposed in Schiphol (2020), the point allocation to this question was decided to have one third of the value from question B.

For questions A and B, one point was remaining for the allocation and, thus, it was decided to be divided in half and half for each of the questions.

Aircraft Carbon Management					**14 points**
Intent	To reduce the impacts of emissions from Aircrafts in the airports airsides and for the aviation industry in general.				
Applicability	Fixed				
Level of Achievement:		points according to Rating Systems	%	according to ARS	Final
Energy Estimation					
A	Was the energy consumption (fuel, biofuel, electricity or hydrogen) that the Aircraft requires estimated?				0,5
Aircraft Emissions					
B	Was infrastructure for Aircrafts using Sustainable Aviation Fuels incorporated? What percentage from the fuel consumption does biofuel meet? 2% - 0,5 pts, 6% - 1 pt, 20% - 2 pts, 35% - 3 pts, 40% - 3,5 pts , 55% - 4,5 pts				4,5
C	Was infrastructure for Aircrafts using electricity or hydrogen as fuel incorporated?				7
D	Were aircraft taxiing emissions considered when detailing the airport layout?				1,5
Monitoring					
E	Was a tracking system able to reveal the amount of charged fuel into the aircraft (fuel, electricity or hydrogen) incorporated?				0,5
	TOTAL	0	0%	0	14

Figure B-6. Point allocation for Aircraft Carbon Management.

Ecological Ground Support Equipment:

The credit can be seen in Figure B-7, and the point allocation in this case was done following the same trend as in the ''Aircraft Carbon Management'' credit. Where the point allocation was discussed with the sustainability expert from **NACO**. Therefore, question C related to electric and hydrogen **GSE** has 1.5 times higher value than that of question B related to **SAF**. The remaining score of 1.5 was distributed between question A and D, where it was decided to give a heavier weight to question A given that the outcome from this can be useful for the decision of which infrastructure to provide.

Ecological Ground Support Equipment					8 points
Intent	To reduce the impacts of emissions from Ground Support Equipment in the airside of airports.				
Applicability	Fixed				
Level of Achievement:		points according to Rating Systems	%	according to ARS	Final
Energy Estimation					
A	Was the energy consumption (fuel, biofuel, electricity or hydrogen) that the GSE requires estimated?				1
Infrastructure for Ecological Vehicles					
B	Was the corresponding infrastructure to cope with Ground Support Equipment using biofuels incorporated? What percentage from the fuel consumption does biofuel meet? 2% - 0,5 pts, 6% - 0,75 pts, 20% - 1,25 pts, 35% - 1,75 pts, 40% - 2 pts , 55% - 2,5 pts				2,5
C	Was the corresponding infrastructure to cope with electric/hydrogen Ground Support Equipment incorporated?				4
Monitoring					
D	Was a tracking system able to reveal the amount of charged fuel into the GSE (biofuel, electricity or hydrogen) incorporated?				0,5
	TOTAL	0	0%	0	8

Figure B-7. Point allocation for Ecological Ground Support Equipment.

Water Pollution:

The credit can be seen in Figure B-8 and the point allocation from the different authors in Table B-5.

Water Pollution					3 points
Intent	To protect the local water environment from pollution as the result of the operation of an airports airside.				
Applicability	This credit is applicable to all airsides that use polluting substances with the potential to contaminate water sources.				
Level of Achievement:		points according to Rating Systems	%	according to ARS	Final
Regulatory measures					
A	Were regulatory authorities consulted about water issues related to the airport's airside, and has the outcome been communicated to project team members?	0%	8%	0,27	0,5
Control of imapact on the water environment					
B	Has a plan to control the impacts on the water environment from the airside in operation been developed? And were elements of this plan incorporated on the final design?	2%	79%	2,56	2
Monitoring					
C	Were measures to track the water quality from the drainage systems so as to satisfy local regulatory requirements included?	0%	12%	0,40	0,5
	TOTAL	3%	100%	3	3

Figure B-8. Point allocation for Water Pollution.

First, from Figure B-8 it can be noted first that the rounding of questions A and C to the closest half, makes question B to round down to a value of 2, so as to keep the total amount of points of this credit equal to 3.

Also, from Figure B-8 it can be noted that question B is the one with the highest weight. This point allocation is logic given that question A refers to consultation with regulatory authorities, and question C refers to the monitoring of water quality. While question B, refers to the actual measures that should be implemented to control the water quality, and hence, it will have the greatest impact because is a question referred to taking action.

Table B-5. Point allocation across authors for Water Pollution.

sub credit	question	Gómez Comendador et al. (2019)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Envision - Institute for Sustainable Infrastructure (2018)	Yu et al. (2015)	LEED v4.1 Building Design and Construction - LEED (2023)	Average
Regulatory measures	A	-	-	-	-	0%	-	-	-	0%
Control of impacts on the water environment	B	1%	-	4%	-	1%	3%	-	-	2%
Monitoring	C	-	-	-	-	0%	-	-	-	0%
CREDITS USED	A					Consultation with regulatory authorities				
	B	Wastewater		Basic principles of the water environment Protection of the freshwater and marine environments		Preventing pollution in operation Control of impacts on the water environment from the completed project	Preserve water resources Protect surface and ground water quality			
	C					Long term monitoring of impacts on the water environment				

Management of Run-Off:

The credit can be seen in Figure B-9 and the point allocation from the different authors in Table B-6.

Management of Run-Off					3 points
Intent	Minimize the impact of the airside development on runoff quantity.				
Applicability	This credit is applicable to all airports airsides impacting on run-off water.				
Level of Achievement:		points according to Rating Systems	%	according to ARS	Final
Floodrisk					
A	Was the flood/draught risk of run-off as a consequence of the airside during operations assessed?	0%	11%	0,34	0,5
Control of run-off water					
B	Were systems in the design to manage water run-off considered and implemented?	2%	78%	2,33	2
Monitoring					
C	Were measures to track the quantity of run-off discharged to the environment in order to satisfy local regulatory requirements included?	0%	11%	0,34	0,5
	TOTAL	3%	100%	3	3

Figure B-9. Point allocation for Management of Run-Off.

First, from Table B-6, it can be seen that no numbers were found specifically for the monitoring of runoff water, from the eight studies mentioned in the beginning. Therefore, this number was assumed to be equal to the monitoring of water quality defined in Table B-5.

Then, from Figure B-9 it can be noted that the rounding of questions A and C to the closest half, makes question B to round down to a value of 2, so as to keep the total amount of points of this credit equal to 3.

Last, from Figure B-9 it can be noted that question B is the one with the highest weight. This point allocation is logic given that question A refers to the assessment of consequences, and question C refers to the monitoring of quantity of water discharged. While question B, refers to the actual measures that should be implemented to control the water runoff, and hence, it will have the greatest impact because is a question referred to taking action.

Table B-6. Point allocation across authors for Management of Run-Off.

sub credit	question	Gómez Comendador et al. (2019)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Envision - Institute for Sustainable Infrastructure (2018)	Yu et al. (2015)	LEED v4.1 Building Design and Construction - LEED (2023)	Average
Floodrisk	A	-	-	-	-	0%	-	-	-	0%
Control of run-off water	B	2%	-	-	-	3%	2%	-	3%	2%
Monitoring	C	-	-	-	-	-	-	-	-	0%
CREDITS USED	A					Flood risk assessment				
	B	Management of runoff				Flood risk based enhancements Sustainable Drainage Systems Implementation of flood risk based enhancements Implementation of sustainable drainage systems Managing runoff at source	Manage stormwater		Rainwater management	
	C									

<u>Site Selection:</u>

The credit can be seen in Figure B-10 and the point allocation from the different authors in Table B-7.

Site Selection					**6 points**
Intent	To avoid the development of the airports airside on environmentally sensitive lands that provide critical ecosystem services.				
Applicability	Fixed				
Level of Achievement:		points according to Rating Systems	%	according to ARS	Final
Planning for site selection					
A	Was sufficient relevant information collected about the alternatives for the airside location and were studies undertaken to assist with the suitability of the site selection of the airside?	3%	30%	1,90	2
Sensitive locations to be considered					
B	To what extent is the airside sited on previously developed land? 25% - 0,5 pts, 50% - 1pt , 75% - 1,5 pts , 100% - 2,5 pts	4%	40%	2,52	2,5
C	Were compensatory measures incorporated according to the site slection?	3%	30%	1,89	1,5
	TOTAL	10%	100%	6	6

Figure B-10. Point allocation for Site Selection.

From Table B-7, it can be seen that the credit called ''Land Use'' from Yu et al. (2015) is highlighted in green, because the weight of this credit was given together with other 2 credits. Therefore, one third of the weight of that full weight was considered for this credit.

Then, from Figure B-10 it can be noted that question C was rounded to 1.5, because question A was closest to 2, and this was done in order to keep the value of the whole credit equal to 6 points.

Also, from Figure B-10 it can be noted that question B is the one with the highest weight, while the other two questions are not that far from it. This point allocation is logic given that all three questions are relevant topics, but question B can be slightly more important given that is the actual siting of the airside, and hence, where the impact from its location happens. However, it's still important to conduct good studies for site suitability as mentioned in question A, or even good compensation measures as mentioned in question C.

Table B-7. Point allocation across authors for Site Selection.

sub credit	question	Gómez Comendador et al. (2019)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Envision - Institute for Sustainable Infrastructure (2018)	Yu et al. (2015)	LEED v4.1 Building Design and Construction - LEED (2023)	Average
Planning for site selection	A	-	-	5%	-	3%	-	4%	1%	3%
Sensitive Locations to be considered	B	-	-	-	9%	1%	5%	-	1%	4%
	C	3%	-	-	-	-	-	-	-	3%
CREDITS USED	A			Basic principles in the use of land		Project lcoation alternatives Consideration of project location alternatives Site suitability Justification of site suitability Land use efficiency		Land Use	Site assessment	
	B				Floodplains areas Farmland area impacted	Previous use of the site Conservation of soils and other on-site resources	Preserve prime farmland Preserve undeveloped land Maintain floodplain functions		Sensitive Land protection	
	C	Site selection								

Protection of Biodiversity:

The credit can be seen in Figure B-11 and the point allocation from the different authors in Table B-8.

Protection of Biodiversity					**5 points**
Intent	To minimize the possible interference to ecosystems and organisms present in the airport environment.				
Applicability	Fixed				
Level of Achievement:					
		points according to Rating Systems	%	according to ARS	Final
Ecosystem Assessment and control					
A	Was a qualified ecologist to conduct an appropriate study and evaluation of the site and its zone of influence appointed to determine the ecological impacts? And has the information been shared with the project team members?	2%	22%	1,02	1
B	Is the airside placement avoiding land identified as of high ecological value?	2%	24%	1,11	1
C	Were measures to control the bird impacts implemented on the airside?	2%	29%	1,36	1,5
Enhancement of Habitats					
D	Was a specialist appointed to identify opportunities for creating new wildlife habitats and have these been incorporated into the project?	2%	26%	1,23	1,5
	TOTAL	7%	100%	5	5

Figure B-11. Point allocation for Protection of Biodiversity.

From Table B-8, it can be seen that the credit called ''Protection of Biodiversity'' from Gómez Comendador et al. (2019) was divided in questions A and C, because the content of this credit was analyzing both, the studies from ecological impacts from the surroundings of the airside and measures to control the impact of birds in the airside. A similar situation happens with the credit called ''Impacted ecosystem area ratio'' from Diaz-Sarachaga et al. (2017a), that was divided in questions A and B, because the content of this credit was analyzing both, the studies from ecological impacts from the surroundings of the airside and the placement of the airside itself on land of high ecological value.

From Figure B-11 it can be noted that questions C and D have a higher weight than A and B, but these two lasts are not far from the others. The main difference was due to rounding procedures. The point allocation gotten for this credit is logic given that all four questions are relevant topics, but question C and D can be slightly more important. Question C due to the impact that birds can have not just in aircrafts but in passengers' safety. While question D, is also quite important to relocate and create new habitats for the wildlife that was interfered. However, it's still important to conduct good studies for ecological impacts as mentioned in question A, and avoiding as much as possible lands of high ecological value as mentioned in question B. The latter one can also be compensated with measures taken in question D.

Table B-8. Point allocation across authors for Protection of Biodiversity.

sub credit	question	Gómez Comendador et al. (2019)	Chao et al. (2017)	CEEQUAL - Diaz-Sarachaga et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Envision - Institute for Sustainable Infrastructure (2018)	Yu et al. (2015)	LEED v4.1 Building Design and Construction - LEED (2023)	Average
Ecosystem Assessment and control	A	2%	-	1%	2%	0%	-	-	-	2%
	B	-	-	2%	2%	0%	2%	-	-	2%
	C	2%	-	-	-	-	-	-	-	2%
Enhancement of Habitats	D	-	-	1%	-	0%	4%	-	2%	2%

CREDITS USED	A	Protection of biodiversity		Basic principles of ecology and biodiversity	Impacted ecosystem area ratio	Survey and evaluation of ecological valie			
	B			Conservation and enhancement of biodiversity	Impacted ecosystem area ratio	Land of high ecological value	Preserve sites of high ecological value		
	C	Protection of biodiversity							
	D			Habitat creation measures		New wildlife habitats Improving the water environment	Enhance functional habitats Enhance wetland and surface water functions		Protect or restore habitat

Innovation:

The credit can be seen in Figure B-12.

Innovation					9 points
Intent	To support innovation in the aviation industry, whether related to infrastructure or aircrafts and ground support equipment.				
Applicability	Extra credit apart				
Level of Achievement:		points according to Rating Systems	%	according to ARS	Final
A	Innovations can be suggested by the project team. Most considered ones are those achieving a demonstrable performance in reduction of carbon emissions.	-	-	-	9
	TOTAL	-	-	-	9

Figure B-12. Point allocation for Innovation.

In the case of this credit this is a single question and hence the point allocation from different authors is not needed. The whole 9 points from this credit goes to the only question that this credit contains.

C Interviews

As it was mentioned in section 2.2.8, face to face interviews were executed with experts within **NACO**.

As different disciplines and activities within an airport's airside are studied in this thesis, experts from these different fields were interviewed in an informal way. Information was asked to them mainly to complete or complement different information along the thesis.

In Table C-1, a list of interviewed experts can be seen with their corresponding field and date of interview. And in the following, a ''high-level'' description of each interview is given.

Table C-1. List of Experts interviewed in NACO.

No.	Field of expertise	Date of the interview
1	AGL Expert	27-06-2023
2	ATM Expert	28-06-2023
3	Utilities Expert	27-09-2023
4	AGL Expert	26-09-2023
5	Sustainability Expert	21-09-2023
6	Pavements Expert	27-09-2023
7	Drainage Expert	16-08-2023
8	Design Leader in the Civil Engineering Department	28-09-2023
9	Sustainability Consultant within Royal Haskoning DHV, Expert in Sustainable Rating Systems	05-10-2023

1- With the first interviewee from Table C-1, the topics discussed were about the impacts from **AGL** on energy consumption and best practices that are used nowadays in **AGL** to be able to reduce the energy consumption.
2- With the second interviewee from Table C-1, the topics discussed were about ways to reduce environmental impacts from different strategies used on the **ATM**.
3- With the third interviewee from Table C-1, the topics discussed were several. One of them was about the impacts from water consumption on the terminal building and in the airside. Other topic was about best practices to reduce water consumption in the airside and terminal buildings due to actions taken in the airside. The last topic was about best practices to tackle water pollution on discharged water from the airside.
4- With the fourth interviewee from Table C-1, the topic discussed was about best practices that are used nowadays in **AGL** to be able to reduce the energy consumption. Also, one best practice for the bird control on airside that he was aware of in one of the projects, was suggested.
5- With the fifth interviewee from Table C-1, the topics discussed were two. One topic was about best practices that are used nowadays to reduce emissions from aircrafts and **GSE**. Then, the rest of the interview was discussing the point allocation for the questions from the credits of ''Aircraft Carbon Management'' and ''Ecological Ground Support Equipment''.
6- With the sixth interviewee from Table C-1, the topic discussed was about best practices used nowadays to reduce environmental impacts from pavement design.
7- With the seventh interviewee from Table C-1, the topic discussed was about best practices used nowadays to reduce pollution on water effluents to be discharged to the environment.

8- With the eighth interviewee from Table C-1, the topic discussed was about best practices used nowadays for bird control on the airside.
9- The ninth interviewee from Table C-1 is not from **NACO**, but from Royal HaskoningDHV, the mother company of **NACO**. Given that **NACO** is a company that encompasses the Aviation Business Unit from Royal HaskoningDHV, also every employee from this company can be contacted easily with the same tools, via Microsoft Teams. A colleague from **NACO** recommended an expert in sustainable rating systems within Royal HaskoningDHV and thus, this was contacted. With this expert, the main topic discussed was about the different levels of certification to define for **ARS**. Also, a brief feedback on the developed rating system from this expert was provided.

D Scientific Paper

This appendix provides a scientific paper on the development of a sustainable rating system for airports airsides.

Developing a Sustainable Rating System for Airports Airsides

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Abstract

Airports and aviation in general play a crucial role in the transportation network of society. More than 2,500 airports support an annual traffic of 4 billion passengers. However, this number is expected to continue increasing to 8 billion passengers in 2040 according to International Air Transport Association (IATA). At the same time, the climate change phenomenon gained popularity in the society, in which the aviation industry is responsible for 3.5%, and 2% of the CO_2 emissions (major contributor to greenhouse gases (GHGs) emissions). If no change is made the share of CO_2 emissions are estimated to reach 20% by 2050. Specifically in airports, there is a lack of guidance on how to make the airport's airside more sustainable. Therefore, this study aims to develop a state-of-the-art sustainable rating system for airports airsides to be able to make the aviation industry more environmentally friendly. This is done based on research from the already existing rating systems for buildings and others considering infrastructures. The focus of the one developed in this study is on the environmental pillar of sustainability from an infrastructural point of view. The developed system was named as 'Airport Rating System' and it was found to be a technique that can be applied in a systematic way when designing airsides, making the word 'sustainability' tangible.

Keywords: Rating System, Sustainable Airport, Sustainable Infrastructure

1. Introduction

The aviation sector has shown a significant growth during the last decades all over the world; the International Air Transport Association (IATA) in the year 2019 measured an average yearly growth of 5.5% in Revenue Passenger Kilometers (RPK) and expected this growth to continue [1]. However, due to the recent COVID-19 pandemic the industry showed a contraction in air traffic in the year 2020. Nevertheless, the industry has proven to recover, and it is now forecasted to grow from 1.5 billion passengers in 2020 to 8 billion passengers in 2040 [2].

While the aviation sector is expected to continue growing, also during the last decades climate change and global warming have gained popularity within the population [3]. The aviation sector is responsible for a 3.5% of climate change [4], and for 2% of the global carbon dioxide (CO_2) emissions [5], and if no change is made, this share is predicted to increase to 20% in 2050 [6,7], hence, efforts in reducing these emissions should be made. Although CO_2 emissions are the greatest contributor to greenhouse gas (GHG) and climate change now, and main point of focus to every sector, all other sources of pollution can be mentioned from the aviation industry and are given later in this study.

From an organizational perspective, efforts are being carried out to help the aviation industry. Particularly, the International Civil Aviation Organization (ICAO) is seeking and pushing for a sustainable development in airports [8]. Sustainable development is defined in Bocchini et al. [9] and Kamalam [10] as *'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'*. This concept is mainly focused on three "pillars", namely the Social, Economic and Environmental ones which are known as the Triple-Bottom-Line (TBL) [11]. So, the TBL is based on the notion of achieving financial stability, minimizing environmental impacts, and aligning with the expectations of communities, employees and consumers.

Based on the concept of sustainable development, several practices and methods are being developed in the aviation industry to pursue a greener future. Some of them that can be mentioned are the Airport Carbon Accreditation (ACA) developed by Airports Council International (ACI) in 2009, Sustainable Rating Systems developed by private or governmental organizations, and other methodologies mainly developed by privates.

This study in particular focusses on tackling part of the 3.5% contribution from the aviation sector on climate change, plus the other environmental impacts previously mentioned, through the development of a Sustainable Rating System for airports airsides. This was chosen given that the already existing sustainable rating systems focus mainly on terminal buildings and there is a lack of guidance on how to make airports airsides more sustainable. This means there is a gap. Therefore, the objective of this research is to develop a rating system specifically for airport's airsides considering infrastructures and the influence of them to operations to close the gap. To achieve this some scope was defined and it's mentioned in the following:

- Just the airside of airports for green field projects and already existing projects that want to be certified are considered.
- The infrastructure and operations (from an infrastructural perspective) of an airport's airside are the focus of this thesis.
- The phases that are considered in the developed sustainable rating system are the planning and design phases. However, the sustainable approaches identified by the project teams using this framework (rating system) in the planning and design phases will be carried forward throughout the project's construction, operation, maintenance, and End-of-life phases. Hence, it can be said that decisions made in the planning and design phases are crucial because they can influence the whole life cycle of a product.
- The TBL is an important concept to be considered, and hence, from the three pillars (social, economic, and environmental), this rating system aims to consider just the environmental one, which is the main focus and key factor in all the rating systems existing nowadays [12].

This paper illustrates the methodology used to achieve a rating system in section 2. Then, in section 3 (also called Phase zero) a summary of the literature on environmental concerns for airports and rating systems is given. Next, in section 4 (also called Phase I), the main stakeholders for the development of such a rating system are provided. In section 5 (also called Phase II), the boundaries that the rating system englobes are defined. In section 6 (also called Phase III), the structuring and weighting of the system is provided. In section 7 (also called Phase IV), metrics and best practices for the rating system are provided. In section 8 (also called Phase V), the validation of the developed rating system is given. Finally, in section 9, conclusions and recommendations from the study are presented.

2. Methodology

As it was mentioned previously, this research was divided in six phases, namely Phase zero plus five phases. This was done in order to guide better the reader through the development process. In each phase different methodologies were used and are better explained in section 2.1.

2.1 Framework Overview

In Phase zero literature review is performed to collect background information of environmental concerns in airports and sustainable rating systems currently used in the construction sector.

To perform an efficient literature study and a good collection of articles, first, online electronic databases were used, namely, ASCE (American Society of Civil Engineers) library, Scopus, SpringerLink, TU Delft Library and Google Scholar. Scopus and SpringerLink are databases that contain peer-reviewed literature such as scientific journals, books and conference papers. The special thing about ASCE library is that it's specifically for civil engineering literature. While Google Scholar and TU Delft library are search engines that gathers scholarly literature from different disciplines and sources in one place. The main advantage of TU Delft library is that while some papers or books in a certain search engine as Google Scholar must be paid, in this library they are provided freely due to the license of Delft University. To execute the research of articles and reports relevant to "sustainable rating systems" and "airport sustainability", the keywords used were "rating system", "airports" and variations of "sustainability". Some of these variations include "green rating systems", "green airports", "sustainable development" and "environmental sustainability". Moreover, the snowballing method (forward and backward) [13] was used in order to find more relevant literature.

This method of literature review was also used in other phases in the same way, so it won't be repeated in each phase.

In Phase I to understand the stakeholders, literature review and stakeholder analysis are performed. This analysis is helpful to understand what the role of each stakeholder is, what is their perspective and their relevance in the system [14]. To make this clear, stakeholders then come arranged in a Power-Interest Grid.

In Phase II, three types of boundaries are defined for the rating system, namely spatial, component, and functional boundaries. With the spatial boundaries is intended to define the geographical demarcation that the rating system considers (mainly airside), which will be done with literature review.

With the component boundaries is intended to define specifically which activities and disciplines from the airside are considered for this rating system, based on which of those activities are related to infrastructure and pollute the most, this is done with literature review and Interviews. The interviews are unstructured interviews with different experts from Netherlands Airports Consultants (NACO – company where this study was developed) and they were organized informally, where the interviewees were asked for brief conversations during working hours. The different experts chosen for the interviews were selected according to the different fields touched upon on this thesis. A total of nine interviews were executed. Please see Table 1 to recognize the different interviewees for this thesis.

Finally, the functional boundaries are defined based on the main polluting activities. This means recognizing and defining the specific processes of each activity that pollutes the most and specifically naming per activity which environmental impact is considered. This is done with desk research and expert consulting, with experts from NACO.

In Phase III, for the structuring, the rating criteria is needed to be defined, meaning the indicators (credit categories and credits). These ones are defined based on the knowledge from already existing rating systems for buildings and infrastructures described in Phase zero, while also considering the functional boundaries and main polluting sources from Phase II. Therefore, for this it's important to use the desk research methodology, which is used to define the structure of the rating system developed in this thesis, based on research from other rating systems.

Then, the weighting takes place, mainly allocating points (weights) to credit categories and credits. This is done via direct rating methodology, because with this methodology it's possible to allocate weights based on the studied rating systems from Phase zero. Direct Rating means assigning scores based on expert opinions to different criteria in a numeric scale defined by him, and that is based on the importance of each criterion relative to the other ones [15]. In this study this was done via the different studies used, calculating averages values for the different indicators. After this, all the points are accommodated in a scorecard, with an expert consulting check.

Table 1. List of Experts interviewed within NACO.

No.	Field of expertise
1	AGL Expert
2	ATM Expert
3	Utilities Expert
4	AGL Expert
5	Sustainability Expert
6	Pavements Expert
7	Drainage Expert
8	Design Leader in the Civil Engineering Department
9	Sustainability Consultant within Royal HaskoningDHV, Expert in Sustainable Rating Systems

After this, the possible levels of certification that can be achieved are defined, and this is based on the points arranged in the scorecard, where breakpoint points are decided according to literature review from other systems and experts from rating systems within Royal HaskoningDHV (mother company of NACO).

In Phase IV first metrics are given to each credit, meaning how each credit is measured according to different practices. So basically, this step is saying how many points out of the total amount of points possible per credit, is a certain measure obtaining. To do this, also direct rating will be used based on desk research from the different rating systems studied. The metrics established are checked with experts within NACO so as to validate the results.

After giving the metrics, also best practices for those considered "main credits" (having the most weight) are given. This is done so as to recommend the users on how to achieve high levels of certification in an airside. To find the best practices, literature review is executed, complemented with interviews to experts within NACO. The interviewees in this case are also part of Table 1.

In Phase V, to validate the developed rating system in this thesis, a case study with experts from NACO in an existing airport is applied in sort of a workshop. Then, the performance of the system is reviewed by the experts. In this phase, the main goal is to have a practical and validated rating system, and in this way this is obtainable. The chosen airport for this phase is the 'Aeropuerto Internacional Del Pacífico' in El Salvador, designed by NACO where all the data is provided by NACO.

3. Literature Review (Phase zero)

The purpose of this literature review is to collect background information of environmental concerns in airports and sustainable rating systems currently used in the construction sector. With this information is possible to understand the importance of the environmental concerns nowadays in the aviation industry and more specifically in airports. Moreover, it is possible to briefly analyze the most widely used rating systems in the construction sector and use their components and structure as a guide to develop the proposed rating system in this thesis. Lastly, this literature review sets the reader in the context of this research. In section 3.1 a description of the current environmental concerns at a global scale are given, with focus on the aviation industry. Then in section 3.2 a description of sustainable rating systems are given. Finally, in section 3.3 a brief description of the most used rating system in the constructions sector is provided.

3.1 Environmental Concerns at a global scale and for the Aviation Industry

Climate change and global warming have gained popularity within the population creating a sense of concern. Global temperatures have been significantly rising after the industrial revolution and even more in the last two decades [16]. This rise in temperatures is due to the increasing GHG emissions produced by human activity, and more especially due to CO_2 emissions (which is the major source of GHG, responsible for 80% of them according to US EPA [17]) and concentration in the atmosphere [3].

Although CO_2 is the main source of GHG emissions, is not the only one. Other contributors are methane (CH_4) (responsible for a 11.5% of GHG), nitrous oxides (N_2O) (responsible for 6.2% of GHG), and less than 3% of GHG emissions come from fluorinated gases, such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) [17].

While the transportation sector accounts for 23% of the global CO_2 emissions [18], a 2% of that share corresponds to the aviation sector [5]. However, most importantly, the aviation sector is responsible for 3.5% of climate change [4]. This share on climate change accounts for factors as CO_2 and NO_x emissions, and the effect of condensation trails (a.k.a. contrails) [4]. These contrails have a significant impact on climate change according to Yin [19]. He stated that the effect of contrails in climate change is twice greater than that of CO_2.

It is also interesting to see the distribution of CO_2 emissions within the aviation sector to have a better illustration. So, from the 2% CO_2 emissions of the aviation industry, airports are responsible for a 2% share of that percentage, while airlines take a 94% of responsibility and other sources accounts for a 4% [6].

Although CO_2 emissions are the greatest contributor to GHG and climate change now, and main point of focus to every sector, all other sources of pollution can be mentioned. Especially in airports, some of them that can be mentioned are the conservation of biodiversity, water consumption, waste management, the treatment of water effluents, and health effects to workers in airsides, such as NO_x emissions and PM (among others), mainly due to jet engine and GSE emissions [6]. The last two (NOx and PM), are of great importance to workers in airsides because these kinds of emissions are linked to carcinogenic effects, high risk of disease and lung problems [20]. Given all these sources of pollution, the ICAO is pushing for more sustainable development in airports to pursue an eco-friendly and carbon-neutral industry [8]. To this end, several standards and tools have been developed during the last decades, and the focus in this study is given to sustainable rating systems which will be further explained in the next section.

3.2 Sustainable Rating Systems

Sustainable Rating Systems are based in the concepts of sustainability and the TBL. These are defined in Diaz-Sarachaga et al. [21] as a collection of best practices which assess sustainability by assigning scores to a series of specific indicators. These frameworks permit using different indicators measured in different units that are integrated with the objective to rate certain product (infrastructure projects in this case) [21]. For infrastructures and buildings, these frameworks provide guidance in the whole life-cycle or part of it, so they are decision-making tools [22]. In this way, they can measure to which extent the project contributes to the sustainability conditions defined in the TBL (social, economic and environmental indicators) [23]. Therefore, with the sustainable rating systems, designers, owners and other stakeholders are able to make more informed decisions about the sustainability of buildings and infrastructure.

So, to state it clearly, the purpose of these frameworks is to foster an improvement in the sustainable performance of buildings and infrastructure (in the case of the transportation and construction sector but it is analogous for the other sectors) [24]. The need for these state-of-the-art decision-making tools is to help users and experts from different sectors from all over the world to tackle the environmental, social and economic issues to pursue a more sustainable future. From the perspective of the aviation sector users of these tools are contractors, experts from the aviation industry, airport operators, aviation consultancies, airlines and other stakeholders (a better and more in-depth description of them is provided in section 4 of this paper).

The sustainable rating systems are based on different sustainability indicators (usually called credits) and are grouped in different categories which are basically several sustainability criteria (usually called credit categories). Each of the credits has different possible levels of achievement given in points, representing the performance goal of each of the credits, the more points the more sustainable the project is in that credit. By assessing the total achievement for all the credits (summing all points), a final score is given to the project with the corresponding certification, depending on the level of sustainability achieved by the project. In the next section a brief description of main rating systems currently used for buildings and infrastructures is given.

3.3 Sustainable Rating Systems for Infrastructures and Buildings

The main rating systems widely used nowadays in the construction sector are BREEAM and LEED, with some relevant mention for this study to Envision and BREEAM infrastructure.

BREEAM stands for Building Research Establishment´s Environmental Assessment Method, its focus its on buildings [25], and the environmental pillar from sustainability is predominant [12].

LEED stands for Leadership in Energy and Environmental Design and Envision. It's mainly used for buildings, and from the three pillars of sustainability, LEED is mostly focused on the environmental one [12].

Envision is a rating system that is mainly focused on horizontal infrastructures, and from the three pillars of sustainability, its mostly focused on the environmental one [22].

BREEAM infrastructure its part of Building Research Establishment (BRE) group and is used for the assessment of civil engineering, infrastructure, landscaping, and public realm projects and contracts. As an example, it is used for several projects like roads, bridges, tunnels, utilities and water projects [25].

In **Error! Reference source not found.** a brief overview of the four systems described above can be found.

As it was said before, these tools can help tackling environmental impacts through different indicators, guiding the users, and triggering them on which measures they should apply to be more sustainable. Hence, this literature review its relevant for this thesis because the information from the environmental impacts from the aviation industry is useful to see what are the issues that the rating system to be developed in this thesis should focus on. Also, the analysis of the different existing rating systems is of utmost importance, given that these are used as a guide to set the sustainable rating system in this thesis, mainly considering their structure in categories, indicators, and rating levels.

Now, section 4 starts with the development of a rating system for this master thesis, and it starts by analyzing who the main and secondary stakeholders of such a rating system are.

4. Stakeholders (Phase I)

The stakeholders were divided in Main stakeholders and Secondary Stakeholders according to their

Table 2. Overview of the most used rating systems in the construction sector.

	BREEAM	BREEAM Infrastructures	LEED	Envision
Country	UK	UK	US	US
Organizations	BRE	BRE	USGBC	ISI
Flexibility	77 countries	Mainly UK	160 countries	7 countries
First Version	1990	2003 (as CEEQUAL)	1998	2012
Main categories	Management	Management	Integrative process	Quality of Life
	Health & Wellbeing	Resilience	Indoor Environment	Leadership
	Energy	Communities & Stakeholders	Quality	Resource Allocation
	Transport	Land Use & Ecology	Energy & Atmosphere	Natural World
	Water	Landscape & Historic Environment	Location & Transportation	Climate & Resilience
	Material	Pollution	Water Efficiency	
	Waste	Transport	Material & Resources	
	Land Use & Ecology		Sustainable Sites	
	Pollution		Regional Priority	
	Innovation		Innovation	
Rating approach	Pre-weighted categories	Pre-weighted categories	Additive credits	Additive credits
Rating level	Outstanding ≥ 85	Outstanding ≥ 90	Platinum ≥ 80	Platinum ≥ 50
	Excellent ≥ 70	Excellent ≥ 75	Gold ≥ 60	Gold ≥ 40
	Very Good ≥ 55	Very Good ≥ 60	Silver ≥ 50	Silver ≥ 30
	Good ≥ 45	Good ≥ 45	Certified ≥ 40	Verified ≥ 20
	Pass ≥ 30	Pass ≥ 30		
	Unclassified < 30	Unclassified < 30		
Number of certified buildings	over 560,000	over 900	over 100,000	142

interest and power, and then they were arranged in a Power-Interest Grid. The main stakeholders to be considered for an environmentally friendly rating system for airports airsides identified in this study are aviation regulators, governmental bodies, Airport Operators (AOs), ACI, staff on airside, airlines, service providers (airport consulting firms and GSE providers) and local communities. The secondary stakeholders are environmental groups, passengers, local governments (municipalities) and construction firms. All the stakeholders can be seen in the P/I grid denoting their power and interest in Figure 1.

Stakeholders are usually consulted when developing a sustainable rating system, they are usually involved in the weight of the different credits. This is done through questionnaires prepared for them comparing the different credits, where they have to assign a rating to them [26]. Then, their ratings are transformed into points using different methodologies and techniques, as an Analytical Hierarchy Process (AHP) [21, 26, 27]. In this thesis, due to the objective and time reasons, this approach was not followed, but the weight its mainly done with desk research. Nevertheless, the stakeholders are used in the conclusion of this master thesis, to give an insight on what would change if the stakeholders were involved in the weight decision.

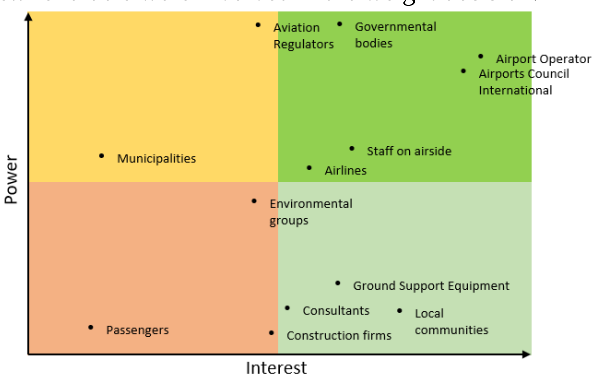

Figure 1. Stakeholder P/I grid.

Now, in section 5, the boundaries that the developed rating systems considers are given.

5. Boundaries (Phase II)

The focus of this section is to define the boundaries of the rating system that is developed in this study. This means defining the limits within which the rating system operates. In this way, elements, processes, and interactions to be included or excluded when designing the rating system are determined. Three types of boundaries are defined, namely spatial boundaries (section 5.1), component boundaries (section 5.2) and functional boundaries (section 5.3).

5.1 Spatial Boundaries

An airport has several components, and it is common to classify them in two or three major categories, depending on the source. Horonjeff [28] classifies them in two categories: landside facilities (with the terminal building included) and airside facilities and can be seen in Figure 2. This study defines as spatial boundary the airside of an airport. This means from the black dashed line to the right in Figure 2.

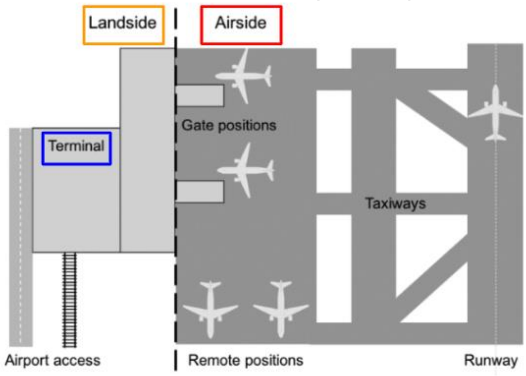

Figure 2. Bipartite classification of airports [31].

The airside englobes the runways (RWYs) where an aircraft takes off and lands, the taxiways (TWYs) that connects and permits the movements of aircrafts between the runway and the terminal, and the apron and gate areas where aircrafts park and passengers embark and disembark [29].

5.2 Component Boundaries

Different disciplines and activities can be found on the airside of an airport. On the one hand, by disciplines is intended to define all the different main sources of work that need to be carried out before an airport's airside is operational. On the other hand, by activities is intended to define the different tasks that are being executed every day in an operational airport's airside. Figure 3 shows an illustration of all the disciplines and activities that can be found on an airside.

From all the different disciplines and activities, those that are relevant for this thesis are those that are related to infrastructure and are the main pollutants. Through research it was found that the main ones related to infrastructures and pollutants are those shown in Table 3, together with its relevant elements.

Pavements are considered relevant given that are large areas that can be flexible or rigid, this means made from asphalt or concrete respectively, which are main sources of GHG emissions [30]. The concrete industry contributes to 8.6% of global CO_2 emissions [31], which on average the production of 1m^3 of concrete generates from 240 to 320 kg CO_2eq/m^3. While for the asphalt, the emissions generated are almost half, reaching 150 kg CO_2eq/m^3

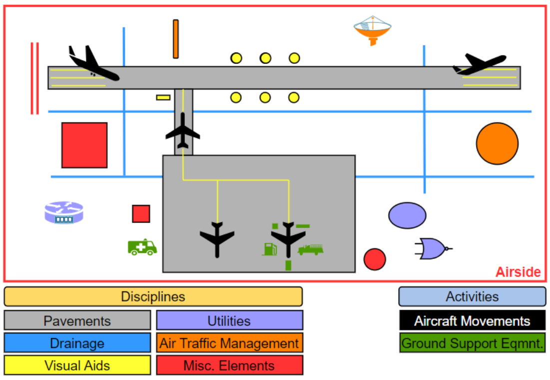

Figure 3. Disciplines and activities on airside.

[32]. Therefore, is key to take them into account in the analysis. Furthermore, these large, paved surfaces should be located somewhere thus, site selection is a crucial aspect to consider given the environmental impacts that airports can create to the surrounding ecosystem and biodiversity as stated in Belant et al. [33] and Zhao et al. [34]. Impacts to soil, water, air and animal species, among others, are one of the main effects that site selection can have [30].

Drainage structure its relevant mainly due to the function of conveying water and the effects that this can have. Large airports consume a large amount of water, compared to that of a small and medium sized city [35]. Not just in the terminal building but also in the airside for different activities, like irrigation and infrastructure or aircraft washing [30]. The water consumption in the terminal building is estimated to be 85%, while that one consumed in airsides 15%, according to the utility expert from NACO (third expert from Table 1). Moreover, some water conveyed in the airside can be contaminated due to different activities such as de-icing or fueling (among others), which then discharge to the

Table 3. Main disciplines and activities considered for the rating system.

Discipline/Activity	Relevant elements to consider for the development of a rating system
Pavements	Runway, Taxiway, Apron and Service Roads
Drainage	Pipes, Culverts, Channels, Ditches, Oil-Water separators, Grated and Slotted drains and Ponds, water collection systems
Visual Aids	Airfield Ground Lighting
Utilities	-
Air Traffic Management	-
Miscellaneous Elements	Infrastructure for alternative power sources
Aircraft Movements	Taxiing
Ground Support Equipment	water trucks, sewage/lavatory trucks, GPU, fuel bowsers, pallet tractor, pallet mover, pallet loader, baggage conveyor belt, baggage tractor, catering truck, push/pull tractor, follow me car passenger buses and vehicles for people with reduced mobility, cleaning and emergency vehicles

environment can create significant environmental impacts to the ecosystem [36]. Last, but not least, drainage systems have a great impact on the flood risk of airports, aiding to manage the amount of surface run-off [37]. Hence, a drainage system with solutions able to reduce water consumption in terminal buildings and airside, able to prevent pollutants to water bodies, and able to manage run-off water is needed [36]. That is why all the elements conforming the drainage system in this case are considered relevant.

From visual aids the Airfield Ground Lighting (AGL) component is the one considered relevant, given that they are responsible for a 50% of the energy consumption in the airside according to the AGL expert from NACO (first expert from Table 1), while the signage elements are negligible compared to the AGL.

In the case of buildings for utilities (like the fire station or substation) and air traffic management (like the control tower) are left out of the analysis given that their impacts from an infrastructural perspective are negligible. In the case of air traffic management (ATM) more relevant things can be done from an operational perspective according to the ATM expert from NACO (second expert from Table 1).

In the case of miscellaneous elements (as the infrastructure for alternative power sources), this are relevant because they are futuristic solutions for the aviation industry that can help reducing the GHG emissions from the aviation sector, where now the most common ones are solar panels for electricity generation, hydrogen production or Sustainable Aviation Fuels (SAF) [6].

Coming to aircraft movements, just the taxiing movements are considered relevant for this study, while the landing and take-off not. The latter ones are not considered relevant because the length of the runway depends on other factors mainly attached to the critical aircraft characteristics [38] rather than the design of the airport itself. Moreover, it is fair to mention that around 10% of aircraft emissions are produced during ground operations [39], hence, considering taxiing is crucial for this thesis. Some of the main pollutants that are generated by aircraft engines during operation due to combustion are NO_x, Carbon Monoxide (CO), PM and Volatile Organic Compounds (VOCs) contributing to air pollution, and CO_2 contributing to GHG [39].

Finally, coming to GSE several vehicles can be found in this category, but not all of them are considered relevant for this study. The most relevant impact from GSE is about emissions due to fuel burning, given that all vehicles are largely diesel, and therefore very polluting [6]. According to Bao et al.

[40], GSE consumes about 13% of the total energy consumption of gasoline and diesel fuel and produces 15% of the airport carbon emissions. Hence, those that are considered relevant are the ones that make the longer distances in an airport during the day, meaning those GSE operating between aircrafts stands and logistic stations, and those operating between aircraft stands, or those that are polluting the most.

5.3 Functional Boundaries

The different elements of activities and disciplines defined in section 5.2, pollute in different way through their life cycle. Therefore, it is important to define per discipline and activity, which are the most important part of the process that should be considered from their life cycle from a planning and design perspective and can be seen in Figure 4.

For pavements and drainage structures the whole life cycle is considered given that with different decisions taken from a planning and design perspective several advantages can be taken from sustainability. This can be done through material selection, geometrical properties, and considering durability and low maintenance [41]. However, the construction and maintenance of the infrastructures itself are not considered inside the scope of this research. Also, the end-of-life stage is also influenced by the design, given that professionals can choose to use the old material to recycle in a new pavement or to send all the old material to landfill [31].

For the drainage system the most interesting environmental impacts that can be improved from the design, are related to the operational phase rather than the material production phase. This is because the amount of material needed for the drainage system is negligible compared to that of pavements, while the operation phase is important because is when water runs through the infrastructure and should be managed correctly. Hence, professionals should do their best with the designs in airports airside so as to convey, conserve and treat water in the best possible way, avoiding pollution of water bodies or creating problems downstream, and conserving the resource.

In the case of visual aids, and more specifically in the AGL system, the most interesting stage is the operational phase due to the energy consumption of the lights, which is the main environmental impact related to them as stated in section 5.2.

In the case of the infrastructure for alternative power sources, the relevance for this element has more to do with the operational phase rather than the construction of it. This is because, as said before, airlines are the most polluting activity in the aviation industry, and new sources are being developed to reduce their percentage of CO_2 emissions. These developments have to do with hydrogen flights, electric flights and flights powered by SAF [6, 42, 43]. Moreover, the same technologies are considered to reduce the emissions from GSE [44]. Hence, the focus of this discipline for this research is more related to the extent of which airports consider providing this type of infrastructure for an improvement in operations phase, reducing GHG emissions.

When considering the taxiing movements emissions as already described in section 5.2, these are related clearly to the operation phase of an aircraft and the infrastructure. Therefore, it is important to consider this phase, and from a planning and design perspective, try to design an airport where the taxiing movements pollutes as less as possible with different solutions.

In the case of the different GSE, the emissions are clearly related to the operation phase from the vehicles and the infrastructure. Hence, from a planner and designer perspective different solutions should be proposed in an airport to reduce the emissions from the GSE, these can be related to the planning and design of the infrastructure or the vehicles.

Please see Figure 4 for an illustration of the phases that are considered in this rating system from a planning and design perspective, for the different elements.

6. Structuring and Weighting (Phase III)

In this section the credit categories and credits are defined. Also, their weights are given and the different possible levels of certifications that a project can get, are provided.

6.1 Credit Categories

The different categories defined for this rating system are based on the Sustainable Development Goals (SDGs) defined by the United Nations (UN) in the Agenda 2030 [45]. All the seventeen SDGs were linked to airports based on the ACI report from 2021 [46], while just six of them are relevant for this study, considering the environmental pillar from sustainability. The six relevant goals for this study are number 6 (Clean Water and Sanitation), 7 (Affordable and Clean Energy), 12 (Responsible Consumption and Production), 13 (Climate Action), 14 (Life Below Water) and 15 (Life on Land), given the impacts defined in Phase II. For more details, please refer to the complete thesis [47]. Based on these six SDGs, six different categories were defined. However, their names were modified to

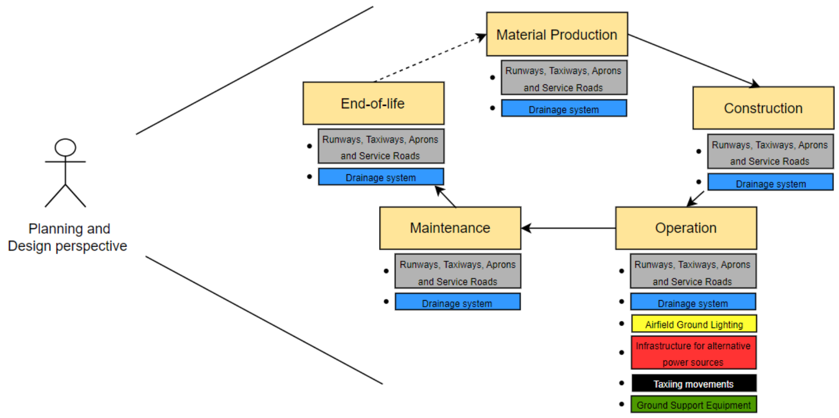

Figure 4. Part of process to be considered per activity and discipline in the rating system.

keep it more related to the disciplines and activities on an airside. Moreover, two categories are added: one to represent aspects of the managerial perspective and one to include innovations that are not covered in the rest of the categories. In this way rendering a total of eight categories. The different categories are shown in Figure 5 under number 1 – Credit Categories.

6.2 Credits per Category

The credits were defined based on different studies, where relevant credits were extracted and allocated to the corresponding eight categories. To highlight the relevant credits, it was important to keep in mind the boundaries and environmental impacts of each discipline and activity, defined in Phase II. Then, to allocate the relevant credits to the categories, the paper from Wen et al. [48], Ramakrishnan et al. [8], and the Agenda 2030 from United Nations [45] were useful. Wen et al. [48] analyzes how the different SDGs are tackled by the rating systems and their credits, Ramakrishnan et al. [8] develops an airport-specific green rating framework and the Agenda 2030 from United Nations [45] explains each SDG deeply.

The main papers and manuals from existing rating systems used to extract credits were ten (10): four (4) of them related to rating systems for infrastructures in general (CEEQUAL analyzed by Diaz-Sarachaga et al. [49], the Envision version 3 manual [22], the BREEAM infrastructure guide version 6 developed by BRE Group [50] and a private rating system developed by Diaz-Sarachaga et al. [51]), four (4) of them related to rating systems for airport infrastructures specifically (private rating systems developed by Gómez Comendador et al. [37] and Chao et al. [52], a sustainability ranking of airports index to benchmark the performance of airports across multiple factors developed by Kılkış & Kılkış [53], and the study from Ramakrishnan et al. [8]), and two (2) of them related to rating systems for buildings in general (the LEED guide version 4.1 for Building Design and Constructions [54], and a private rating system developed by Yu et al. [27]).

With all these studies, eight different tables (one per credit category) were made comparing the relevant credits from each of the papers. After this, credits analyzing the same topic were grouped into one general credit and given a name according to the developed rating system in this master thesis. In this way, a total of twenty-two (22) credits were obtained and can be seen in Figure 5 under number 2 – Credits per category and Weights (W). With all these credits, it will be possible to assess different airports airsides, considering all their impacts mentioned in Phase II.

6.3 Weight Allocation to Credits

To assign weights to the different credits its first important to highlight that normally in rating systems this is done via stakeholder engagement. Where different stakeholders with different points of view and area of expertise, are required to rate the different indicators and get involved in an iterative process. However, in the case of this thesis, due to a different time availability, it was decided that the background information to obtain weights will be obtained from the desk research mainstream information. To this end, several different rating systems and studies developing rating systems were carefully analyzed and used as input for this section. This means that the ‘rating method’ is done following the current practices from different experts from the different sources.

The main studies involved in the weight and point allocation process for credits and credit categories were eight (8), namely the same as those used for credit selection except for those studies from Kılkış & Kılkış [53], and Ramakrishnan et al. [8], given that these two did not provide information on weights. With all these studies, weights were assigned to those credits already specified as relevant in section 6.2. The relevant credits from the different authors with its weights were grouped according to the credits developed in this thesis

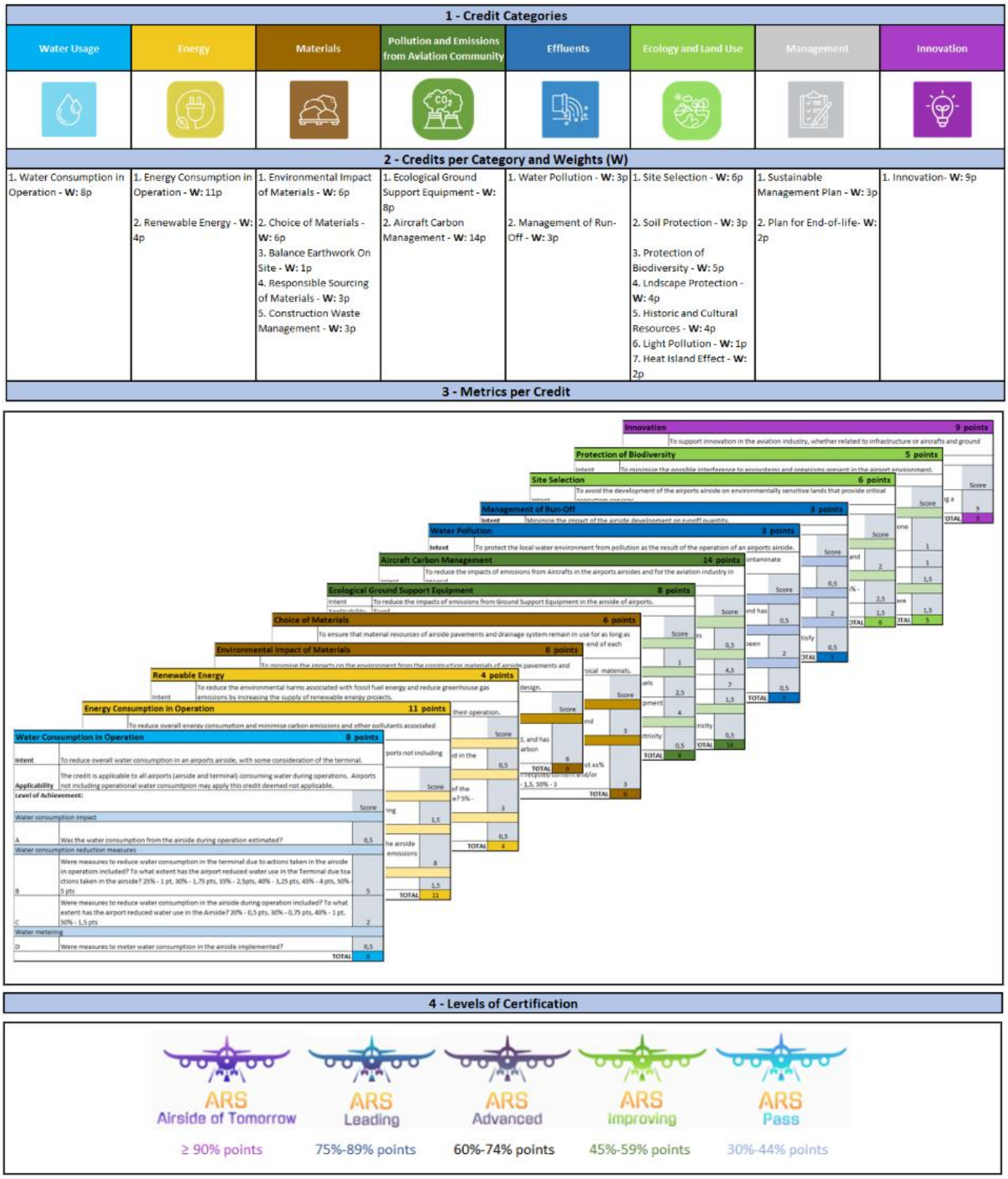

Figure 5. Summary of the developed rating system in this master thesis.

obtaining a weight per author and were arranged in a table as shown in Appendix A. To finally obtain the weights per credit, an average value was obtained across all the authors, where a 75% of weight was given to the authors related airport and infrastructure studies, while a 25% weight to the building authors. This is done to underscore the importance of infrastructure and airports related aspects when developing specifically a rating system for airports airsides from an infrastructural perspective (scope of this thesis). Once having the weight per credit, this summed up to 75% across all the credits. In order to make a rating system with a hundred points as total amount of points, all the percentages from the final average were scaled to sum 100%. And to get points, the percentages were converted in a 1:1 scale to points. The final weights of the credits can be seen in Figure 5 under number 2 – Credits per category and Weights (W).

6.4 Levels of Certification

To define the different levels of certification, literature review was used. Therefore, different rating systems were analyzed, namely LEED guide version 4.1 for Building Design and Constructions [54], BREEAM infrastructure guide version 6 developed by BRE Group [50], BREEAM for buildings also developed by BRE Group, Envision version 3 manual [22] and Green Star NZ analyzed by Doan et al. [12]. From all of them, similar definitions of levels were found. Normally, the base level for the minimum certification is with 30% of the points obtained, with an incremental of 10-15% for the next level of certification. In the case of this thesis, it was decided to follow these common practices, assigning a 30% for the minimum level of certification, and with an incremental of 15% for the following categories, rendering a total of 5 levels of certification, plus one level without certification below 30%. The different levels defined in this study can be seen in Figure 5 under number 4 – Levels of Certification, together with different stamps created in order to recognize the level obtained by each airport airside.

Having finished with this section it's important to mention that the developed rating system was named as 'Airports Rating System' (ARS), with a slogan defined as *Airports of Tomorrow*, and its logo can be seen in Figure 6. The slogan is aimed to show the intention of a state-of-the-art rating system and looking into the future of the aviation industry regarding airports infrastructures.

7 Metrics and Best Practices (Phase IV)

In this section is where metrics are defined for the different credits. In this way, it will be possible to assess a whole airport's airside against all the corresponding credits, and at the end get a total amount of points for it. Then, this total amount of points gives the corresponding level of certification to the project. Also, best practices to achieve the highest levels of certifications are given.

7.1 Metrics for main credits

For this study metrics are given just to main credits which are the ones for which the weights are 5 points or higher. This is because when defining this threshold, 41% of the credits are given metrics, which is the closest to 50%, number from which is considered to be fair to give metrics in this study. But also, three more credits are added because are important from a civil engineering perspective, which are the credits called 'Renewable Energy', 'Water Pollution' and 'Management of Run-Off'. In this way, a total of 12 credits out of 22 are given metrics (55% of credits, more than 50%).

To be able to define the metrics in this section, also an extensive desk research was followed, where the different studies were used as a guide and source

Figure 6. Logo for ARS.

of point allocation. Also, for the assessment of each credit, it is of utmost importance to consider the effects from the different disciplines in airports as defined in Phase II. The main studies used for this aim are the same that were used for weight allocation in section 6.3.

The first thing to define for each of the main credits, is the structure. It was decided that each of the credits will contain the 'Intent', the 'Applicability' and the 'Level of Achievement' as it is done in BREEAM, LEED and Envision rating systems. The 'Intent' refers to the intention of each of the credits, the purpose of them. The 'Applicability' refers to the condition of when to apply each credit, and a project team should evaluate this condition to know if a certain credit should be considered for their airside or not. Finally, the 'Level of Achievement' is the set of questions defined to assess the projects against the credits. Hence, the 'Level of Achievement' defines the score that a certain airside gets in each of the credits, based on the answers to the different questions.

Moreover, it is important to highlight that some of the credits are defined 'continuous' and other 'fixed'. The 'continuous' ones mean that their effect considered in the design phase of the airside can vary after the airport airside is already in operation. While the 'fixed' ones, are a one-time decision that will not vary after the airport airside is in operation. Therefore, for those credits considered as 'continuous', three types of assessment questions were prepared: one question related to the current situation that they are designing for, one question related to what can be done to improve the current situation that they are designing for, and a last question related to the monitoring of their designs. All the main credits with its metrics can be seen in Figure 5 under number 3 – Metrics per Credit. Due to a space reason its difficult to define all the metrics in this current paper, but one of them is explained. To see the explanation of the metrics of all the credits please refer to the complete thesis [47].

The credit to be explained is called 'Water Consumption in Operation' and it can be seen in Figure 7. The intent of it, is to reduce water consumption in the airside and terminal due to actions taken in the airside. This credit is applicable to all airports consuming water during their operations, and hence, it's difficult to deem it not

Water Consumption in Operation		8 points
Intent	To reduce overall water consumption in an airports airside, with some consideration of the terminal.	
Applicability	The credit is applicable to all airports (airside and terminal) consuming water during operations. Airports not including operational water consumtpion may apply this credit deemed not applicable.	
Level of Achievement:		Score
Water consumption impact		
A	Was the water consumption from the airside during operation estimated?	0,5
Water consumption reduction measures		
B	Were measures to reduce water consumption in the terminal due to actions taken in the airside in operation included? To what extent has the airport reduced water use in the Terminal due toa ctions taken in the airside? 25% - 1 pt, 30% - 1,75 pts, 35% - 2,5pts, 40% - 3,25 pts, 45% - 4 pts, 50% - 5 pts	5
C	Were measures to reduce water consumption in the airside during operation included? To what extent has the airport reduced water use in the Airside? 20% - 0,5 pts, 30% - 0,75 pts, 40% - 1 pt, 50% - 1,5 pts	2
Water metering		
D	Were measures to meter water consumption in the airside implemented?	0,5
	TOTAL	8

Figure 7. Metrics for Water Consumption in Operation Credit.

applicable. The first question (indicated with letter A) is related to the impact of water consumption and if the consumption of this resource was estimated. Then, if it was estimated, the next logical question is if measures were applied to reduce the water consumption and to what extent it was reduced, both in the terminal (due to actions taken in the airside so as to still comply with the scope defined in section 1) and in the airside (questions indicated with letter B and C respectively). Specially in this type of questions is important to highlight that the reduction is measured against a baseline that should be calculated by the project team, and in the case of this thesis the baseline is defined as a seriously considered alternative or the industry standard practice, whichever is more favorable to the team.

For this case, the percentages that can be seen in question B were taken from the credit of Water Consumption Indoor in LEED guide version 4.1 for Building Design and Constructions [55], given that the question refers to the terminal building and this credit is related to it, and the 5 points were gradually divided between these percentages. In the case of question C, the percentages were extracted from the credit called 'Reduce Operational Water Consumption' in Envision version 3 manual [22] due to its focus on infrastructures, and the 1.5 points were gradually divided between these percentages. The last question, namely letter D, refers more to the monitoring of the water consumption, to incentivize project teams to keep track and control of the resource consumption.

7.2 Best Practices

In order to recommend best practices to the users of ARS, literature research was conducted on current practices in different airports in the world. Also, experts at NACO were consulted for recommendations in each of the disciplines. Again here, due to a space reason it's difficult to define the best practices for all the credits in this current paper, but those for the credit explained in section 7.1, are given. To see the recommended best practices for all the credits please refer to the complete thesis [47]. Furthermore, it is important to highlight that not all the questions receive best practices but just those that are considered more relevant per credit.

So, in the case of the 'Water Consumption in Operation' credit, best practices are given for questions B and C, where implemented measures permit the reduction of water consumption in the terminal (due to actions taken in the airside) and the airside. According to ICAO [55] and NACO Aviation Academy [6], to be able to reduce water consumption in the terminal due to actions in the airside, what can be done is to collect rainwater, groundwater, seawater and greywater to use it for toilet flushing, which consumes a large amount of water, even reaching 50% of the water consumed in the terminal, according to the utility expert from NACO (third expert from Table 1). Therefore, these practices can achieve a significant reduction of water consumption in the terminal.

For the airside, according to Gómez Comendador et al. [37] and ICAO [55], to be able to reduce water consumption a good practice is also to collect and reuse rainwater, groundwater, seawater and grey water as an alternative to non-potable water supply that can be used for maintenance activities. One of the possible practices is to reuse greywater for irrigation [6]. Also, water collected from different sources can be used for aircraft washing, GSE washing, firefighting or harvesting [6]. Finally, an interesting approach mentioned by Gómez Comendador et al. [37] is to reuse the water from de-icing activities, given that to defrost aircrafts in winter, a mix of water and glycol is used.

Having finished with recommendations for best practices for the main credits, in the next section, the validation of the rating system created takes place.

8 Validation (Phase V)

In this section, the validation of ARS takes place. For this, the organization of the workshop is explained in section 8.1. Then, the case study applied on the workshop is further described in section 8.2. Finally, an expert review from the case study and the performance of ARS is given in section 8.3.

8.1 Workshop Organization

The workshop was carried out at the offices of NACO in the city of The Hague, in The Netherlands. The experts invited from NACO where five, and the case study used was the new airport for the 'Bitcoin City' in La Unión, El Salvador, called Aeropuerto Internacional Del Pacífico. This airport was chosen given that is relatively a small airport compared to other projects, and hence, a 'simple' case that fits the validation purpose of this thesis. Moreover, this airport was chosen because it's a greenfield project and NACO was highly involved in every design aspect, so a large part of the information was available.

The five professionals invited to the workshop were chosen considering their involvement in El Salvador project and their field of expertise. As this rating system considers different disciplines from an airport (pavements, drainage, AGL, siting of the project and design in general), it was decided to include in the project the leading professionals involved in El Salvador project for their specific areas, and the supervisor of this thesis. The different professionals are the experts' number 4, 6 and 8 from Table 1 plus the leader for design in El Salvador (which was also highly involved in the drainage design for it), and a modelling and layout design expert. Hence, the team was a complete team of professionals from different fields, with a high level of understanding of the case study.

To do the workshop, first of all a presentation was given to the experts to familiarize them with the objective of this study. After this, the rating system with its credits and metrics was presented and the activity kicked-off. It was decided that the best way to face this workshop was going credit per credit, analyzing all the questions contained on them. Now the case study is shown in section 8.2.

8.2 Workshop Case Study

To start with, it's important to mention first that the development of Aeropuerto Internacional Del Pacífico is part of a bigger project launched by the current president of El Salvador, Nayib Bukele. The plan is creating a smart city called 'Bitocin City' where the official currency used is the cryptocurrency known as bitcoin [56].

In this paper, detailed results for the 'Water Consumption in Operation' credit are given, while for the rest of the credits these are just named. This is because this credit was already described and explained in the previous sections. For more details on the rest of the credits please refer to the complete thesis [47].

<u>Water Consumption in Operation (answers to questions)</u>

A- According to the professionals from NACO, the water consumption from the airside was estimated, but no further detail could be given in figures for this question, given that a company from Uruguay was the one in charge of utilities. However, as NACO was in constant contact with them and different information was shared, they know that the water consumption was estimated. Therefore, the whole 0.5 possible points for this question were assigned to El Salvador project.

B- According to the professionals from NACO, no measures from the airside were taken to reduce the water consumption in the terminal. Therefore, 0 points were allocated to El Salvador in this question.

C- According to the professionals from NACO, no measures from the airside were taken to reduce the water consumption in the airside. Therefore, 0 points were allocated to El Salvador in this question.

D- According to the professionals from NACO, measures to meter the water consumption in the airside were implemented. Therefore, 0.5 points were awarded for this question.

The total points obtained for this credit is equal to 1 point out of 8 possible.

For the rest of the main credits the points obtained can be seen in Table 4, together with the level of certification obtained for El Salvador.

Table 4. Results for the main credits on the case study.

Credit	Points obtained
Energy Consumption in Operation	3.5 out of 11
Renewable Energy	0.5 out of 4
Environmental Impact of Materials	0 out of 6
Choice of Materials	3 out of 6
Ecological Ground Support Equipment	5.5 out of 8
Aircraft Carbon Management	1.5 out of 14
Water Pollution	2.5 out of 3
Management of Run-Off	2.5 out of 3
Site Selection	2 out of 6
Protection of Biodiversity	3.5 out of 5
TOTAL standard points obtained	25.5 out of 74
Innovation	0 out of 9
TOTAL	25.5 out of 74
Percentage	34%
Level of Certification	Pass

As it can be seen from Table 4, El Salvador got a 'Pass' level according to ARS. In the next section the expert feedback on ARS is presented.

8.3 Expert Review

Once the round of credits was finished, the experts were asked for feedback on the rating system. Hence, one by one each of the experts gave their feedback. To make it easier and in a summarized way, the main feedback is given in bullet points below.

• *'The rating system is a good tool to have conversations with clients, where the framework can* *be used to trigger solutions that can be applied from a sustainability perspective'* common point between expert 8 from Table 1 and the modelling and layout design expert.

• *'This framework is good to have a structure that we can apply in a systematic way, when approaching the projects'* leader for design in El Salvador.

• *'It's a good way to detect where the weaknesses are and to see where we can improve from a sustainability perspective in every project'* expert number 4 from Table 1.

• *'The tool gives us a framework to understand what the sustainability word really entails. It helps us to see where to focus on and where to put our efforts'* expert number 6 from Table 1.

• *'It's a tool that can make airports become more sustainable and compete between them, wanting to have a better certification than the rest of the airports'* modelling and layout design expert.

All in all, it can be said that the mainstream of comments from the experts is that they see it as a useful tool, that can make sustainability (the environmental pillar of it in the case of this study) in airports airsides tangible. It's a way to trigger stakeholders and think about possible solutions to implement, that can make the project more sustainable.

However, they also provided a critical opinion in some credits. Specifically for the Ecological Ground Support Equipment and Aircraft Carbon Management credits, where some questions were defined as binary options, while these should be studied further on how to give them different point allocation according to a specific percentage achieved, as done in some of the other credits. This was a relevant point where the rating system can be improved. These percentages are important to avoid the concept of 'green washing' as defined by Zych et al. [57].

Overall, the tool was well received, and the experts recognized it as useful, and with a real opportunity to continue developing it inside NACO, with contribution from other stakeholders. Moreover, the experts agreed that the 'Pass' level achieved by Aeropuerto Internacional Del Pacífico, was fair. This is because they recognized that several environmentally friendly measures are still missing, and there is a lot of space to improve. Therefore, it can be concluded that the tool as it was presented performed 'correctly' or 'good', given that the result from the case study was expected.

9 Conclusions and Recommendations

First a conclusion for the study is given in section 9.1, then in section 9.2 a discussion is provided and finally, in section 9.3 recommendations for data and for further research are given.

9.1 Conclusion

Overall, it can be concluded that ARS it's a tool that can be used by AOs in collaboration with airport consulting firms (as NACO) and other stakeholders, to design airsides infrastructures certified with different levels of environmentally friendliness. An important point is that ARS is able to influence final decisions because users are able to analyze which are the different measures that should be applied to achieve the highest levels of certification and thus, a more environmentally friendly airside.

Furthermore, it can be said that ARS it's a tool that its feasible to be applied as it was shown in the case study conducted in this thesis, with some limitations. The main risks of using ARS as it is right now, is the lack of precise definition in some questions within credits risking ending up on 'green washing'. However, the tool performed correctly in the case study. Hence, some more applications are also recommended in the future to have a bigger spectrum of the main weaknesses. On the other hand, the main advantage of the tool, is the structure that it contains (with different credits and credit categories), where every important environmental issue can be tackled in a systematic way, developing kind of a 'checklist', triggering and incentivizing users to think about the environmental pillar of sustainability from every angle, while also providing recommendations for best practices that can be used in their airside designs. Another advantage that can be mentioned is that ARS is a tool that can make the different AOs compete one with each other, striving to have higher levels of certification than their competitors, making the whole industry more sustainable, and changing the image of the airports and aviation industry in general.

All in all, it can be said that ARS can be seen as a state-of-the-art methodology that could help the aviation industry to tackle the environmental issues from the TBL, with infrastructural solutions applied on airsides. The name given to the system with its slogan ('Airports of Tomorrow') denotes this intention from the rating system to think in solutions to make airside more sustainable in the coming future. As it was mentioned at the beginning of this master thesis, no rating system is officially developed yet for airports airsides to make it more sustainable or environmentally friendly, and this study has achieved the objective of providing one of them. This can be considered as a first step to tackle part of the 3.5% of the climate change that the aviation industry is responsible for, including the 2% of CO_2 emissions and different environmental impacts as conservation of biodiversity, water resources and treatment of water effluents.

9.2 Discussion

This study provided the development of a sustainable rating system for airports airsides. Academically, this thesis is able to bridge the gap given that there is no specific rating system for airports' airside in existence yet. Hence, this thesis contributes to the academy given that it can be seen as a model to follow to create analog sustainable rating systems in different industries as a first step. This could be of significant importance because with sustainable rating systems reaching the Agenda set by the UN could be easier, given that every stakeholder from every industry would know exactly where to focus on, and apply best practices for it.

The practicalities of this master thesis are that ARS could be useful for main stakeholders (as ICAO) to learn from it, and maybe push to make sustainable rating system mandatories always that an airport has to be designed. Also, ARS could be a useful way to make the aviation industry more environmentally friendly, where AOs could decide to use them in collaboration with different stakeholders, while communities around airports could get benefits from it. Last important point from practicalities, is that the image from airports could substantially change, attracting more passengers due to the provision of a more sustainable mode of transport/industry.

9.3 Recommendations

The first most important limitation is regarding data, more specifically, that weight allocations to credits and questions for metrics were based on mainstream data from different building, infrastructure, and studies from airports rating systems. However, this is a limitation given that this is an expedited approach to develop a whole rating system. It is important to remind that rating systems are developed in teams of a considerable amount of people and time (years), with stakeholders' engagement. Those in charge of doing these kinds of systems are whole associations, where they develop and update every time the versions of their rating systems. Therefore, to comply with the objective of this thesis, the 'mainstream' procedure was followed. Nevertheless, it is highly recommended to involve all the stakeholders mentioned in this thesis for an iterative process, complementing them with a depth research per credit, conducted by a whole team of sustainability experts on airports, for a more precise allocation of weights to credits and metrics. By doing this, is expected that weights could slightly variate with respect to those defined in this study.

In the case of recommendations for further research, several things can be said. The first and most important one is that is highly suggested to include the two other pillars from the TBL, namely the social and economic pillars. In this way, new credits would be obtained and given weights. Two important credits that can be included are regarding air quality and noise for instance, that are of high importance [58]. Furthermore, in this thesis just the airside was analyzed, while its also recommended to consider landside and terminal, given that some interfaces are generated and it's good to have the complete spectrum of them. In this line, one possible thing to be done in future research is to create analogically rating systems for landside and terminal building, complementing the airside one, and obtaining a rating system for the whole airport, giving a level of certification to the entire airport. Coming to the credits from this thesis, it is recommended to define the metrics for all the credits developed in this thesis and not just the 'main' ones, and to apply a case study to the whole package, to analyze the performance of the entire rating system. Finally, another recommendation would be to include with a more in-depth analysis the effect of new technologies in contrails, given that these can have a great impact in climate change as mentioned in section 3.1.

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Appendix

A. Weight Allocation for the different Credits

Table 5. Weights from different authors to the credits developed.

	Airports		Infrastructure					Buildings					
Credits	Gómez Comendador et al. (2019)	Chao et al. (2017)	Diaz-Sarachaga et al. (2016)	Diaz-Sarachaga et al. (2017a)	BREEAM infrastructure - BRE Group (2022)	Institute for Sustainable Infrastructure (2018)	**Average INFRA**	Building Design and Construction - LEED (2023)	Yu et al. (2015)	**Average BUILDINGS**	**TOTAL Average**	**Weight in 100%**	**Final Point**
Water Usage													
Water Consumption in Operation	6%	7%	6%	4%	1%	3%	5%	9%	10%	10%	6%	8%	8
										SUB-TOTAL	6%	8%	8
Energy													
Energy Consumption in Operation	4%	15%	4%	1%	2%	4%	5%	19%	18%	18%	8%	11%	11
Renewable Energy	2%	5%		1%	2%	2%	2%	5%		5%	3%	4%	4
										SUB-TOTAL	11%	15%	15
Materials													
Environmental Impact of Materials	4%	4%	3%		2%	2%	3%	7%	8%	7%	5%	6%	6
Choice of Materials	5%		5%	1%	1%	2%	3%		8%	8%	5%	6%	6
Balance Earthwork On Site					1%	1%	1%			-	1%	1%	1
Responsible Sourcing of Materials			2%	4%	1%		2%	2%		2%	2%	3%	3
Construction Waste Management			4%	1%	1%	2%	2%	2%		2%	2%	3%	3
										SUB-TOTAL	15%	19%	19
Pollution and Emissions from Aviation Com.													
Ecological Ground Support Equipment	4%	9%					6%			-	6%	8%	8
Aircraft Carbon Management	6%	15%					10%			-	10%	14%	14
										SUB-TOTAL	16%	22%	22
Effluents													
Water Pollution	1%		4%		1%	3%	2%			-	2%	3%	3
Management of Run-off	2%			0%	3%	2%	2%	3%		3%	2%	3%	3
										SUB-TOTAL	4%	6%	6
Ecology and Land Use													
Site Selection	3%		5%	9%	3%	5%	5%	2%	6%	4%	5%	6%	6
Soil Protection	3%		5%		2%	1%	3%			-	3%	3%	3
Protection of Biodiversity	4%	4%	5%	5%	1%	6%	4%	2%	2%	2%	4%	5%	5
Lndscape Protection	4%	4%	1%		3%	1%	3%		4%	4%	3%	4%	4
Historic and Cultural Resources			3%	6%	1%	2%	3%			-	3%	4%	4
Light Pollution	1%				2%	1%	1%	1%		1%	1%	1%	1
Heat Island Effect	1%						1%	2%		2%	1%	2%	2
										SUB-TOTAL	20%	25%	25
Management													
Sustainable Management Plan			3%	3%	2%	2%	3%			-	3%	3%	3
Plan for End-of-life						1%	1%			-	1%	2%	2
										SUB-TOTAL	4%	5%	5
										TOTAL	75%	100%	100
Innovation													
Innovation	1%				10%		6%	10%		10%	7%	9%	9
TOTAL	51%	62%	51%	36%	39%	41%		64%	54%	SUB-TOTAL	7%	9%	9