Project no. FP7-AAT-2011-RTD-1-284529-2050AP

2050AP

"The 2050+ Airport"

Collaborative Project

Small or medium-scale focused research project

Area 7.1.6.2. – Step changes in air transportation operation

AAT.2011.6.2-3.Airports

D4-2 The Ultra-Green Airport Concept

An operational concept for 2050 and beyond

Due date of deliverable: September 30th 2013

Actual submission date: September 27th 2013

Start date of project: September 1st 2011 Duration: 30 months

Organisation name of leader for this deliverable: NLR Revision: V1.0

DOCUMENT CONTROL SHEET

Title of document:	The Ultra-Green Airport Concept – An operational concept for 2050 and beyond
Authors of document:	NLR, DLR, and INECO
Deliverable number:	D4-2
Classification:	Public
Project acronym:	2050AP
Project title:	The 2050+ Airport
Project no.:	FP7-AAT-2011-RTD-1-284529-2050AP
Instrument:	Collaborative Project Small or medium-scale focused research project
Theme:	Area 7.1.6.2 – Step changes in air transport operation AAT.2011.6.2.-3.Airports

DOCUMENT CHANGE LOG

Revision	Issue Date	Sections affected	Relevant information
0.1	19-April-2012	All	Initial draft of deliverable D4.1
0.2	02-May-2012	All	To complete initial draft of concept template
0.3	11-May-2012	All	To apply template and complet the background of the concept (chapter 3)
0.4	18-July-2012	Chapter 4 and 5	To draft the airport concept, including proposed solutions
0.5	01-Sep-2012	Chapter 4/5 + section 3.4	Draft concept updated, contributions partners included
0.6	04-Dec-2012	All	Consolidation of chapters 1-5 after WP3 gaming workshop in Budapest, 11/Sep/2012
0.7	14-Jan-2013	All	Consolidating advanced concept, chapter 5
0.8	11-April-2013	All	Comments and brainstorming Feb-April 2013
0.9	07-June-2013	All	Major update
0.92	29-July-2013	All	Update after review + results from workshop
0.96	21-Aug-2013	All	Update for review by UG partners
0.98	29-Aug-2013	All	Update after review of UG partners
0.99	30-Aug-2013	All	Final draft ready for consortium review
0.991	17-Sep-2013	All	Update based on consortium review
0.992	20-Sep-2013	All	Update including input from UG partners INECO and DLR on chapters 1-5
0.993	25-Sep-2013	All	Update including Vilnius meeting comments
0.994	26-Sep-2013	All	Pre-final version
1.0	27-Sep-2013	All	Final version including last comments INECO

Revision 1		**Organisation**	**Signature/Date**
Authors	Hugo de Jonge, Pim van Leeuwen	NLR	
	René Verbeek, Ab Hoolhorst	NLR	
	Thorsten Mühlhausen	DLR	
	Peter Lubrani, Maria Sánchez Sampedro	INECO	
Internal reviewers	Hugo de Jonge, René Verbeek, Ab Hoolhorst, Pim van Leeuwen	NLR	
	Paul Roling	TUD	
	Laura Serrano, Peter Lubrani	INECO	
	Jaime Pérez	CRIDA	
	Roland Guraly	SLOT	
	Thorsten Mühlhausen	DLR	
	Rosa Arnaldo	UPM	
	Andrius Jarzemskis	Smart Continent	
	Peter van de Brink	Schiphol Airport	
External reviewers	Ivan Konaktchiev	EC DG – Research & Innovation	

Executive Summary

The main task of the Airport-2050+ project is to develop three advanced airport concepts in support of the future development of airports in Europe: the Ultra-Green, Time-Efficient and Cost-Effective and airport concept. These three concepts are complementary, all three aiming to allow airports improving seamless connectivity of transport operations, to perform their operations in a Cost-Effective and Time-Efficient way and to perform these operations in an environmentally sustainable way. This report describes the Ultra-Green (UG) airport concept, focusing on improved sustainability and reduced pollution at and around airports.

The Ultra-Green airport concept does not describe a major redesign of the airport, but rather a set of step-change solutions to improve the environmental performance of airport operations, intermodal transport operations to and from airports, and the airport's infrastructure. Another premise is that Ultra-Green improvements should go hand in hand with – and should even contribute to – time-efficiency and Cost-Effectiveness. If not, the airport would not be able to compete with other airports in the fierce, global competition of 2050 and beyond. As a result, the Ultra-Green concept elaborated in this document yields a set of solutions – alternatively called concept ideas – that reduces the impact on the environment whilst offering enhanced operations.

To this end, solutions are selected that offer airports a reference frame for enhanced operations as a node in the future European Transport Network. However, the implementation of these solutions is often not the sole responsibility of the airport authorities since these solutions may also involve stakeholders outside the airport. For such cases broad public support and buy-in is required (e.g. development of regional transport plans rather than merely an airport development plan, etc.).

The selected solutions are structured around the following set of application areas:

- **Airport services**: Evidently, there are good opportunities at the airside to improve the green character of ground operations by reducing aircraft's use of engines as much as possible. In addition, several more subtle environmental management strategies are envisaged to reduce pollution, waste, water use and energy consumption and to promulgate a comprehensive environmental strategy.
- **Intermodal Transport services**: For greening transport operations it is important to offer the passengers a broad network for direct connectivity and shortest routes by public transport to reach their destinations. This supports Flightpath-2050's 4-hours door-to-door transport in Europe, but also relates to the aim to save fossil fuels and reduce emissions. Airports are crucial nodes in the European Transport Network, offering both airport-to-airport connectivity and, through seamless "door-to-airport" and "airport-to-door" transport, intermodal connectivity. Therefore, high quality, dense network connectivity within the catchment area of the airport is key to the success of seamless door-to-door transport services.
- **Infrastructure in support of airport services**: The infrastructure offers the context and determines the conditions under which seamless and environmentally friendly service provision takes place. Initiatives to green air transport operations should therefore not be limited to airport or intermodal transport services, but should also focus on the buildings, the landscape and the supporting road- and rail transport system around the airport For long-term development this yields a policy focusing on the recovery of resources and the avoidance of unrecyclable waste.

These solutions or concept ideas offer a view on how operations are enhanced by improving airport sustainability, whilst never ignoring the need to be competitive at the same time, offering the best service possible against a competitive price and time efficiency. The selected solutions are ranging from state-of-the-art now, even if likely not implemented European-wide yet, to radical but not yet achievable solutions. An overview of the selected Ultra-Green solutions can be found in Table 1 below.

These solutions can be regarded as building blocks for the Ultra-Green airport of 2050+. The modular approach taken implies that not all ideas should be regarded as mandatory for a sustainable airport; instead, interested airport managers and stakeholders are given the choice to combine only those ideas that fit their specific airport, business plans, target groups and local community. Together with the Time-Efficient and Cost-Effective concept ideas, these solutions may offer the benefits to enable small, medium and large airports in Europe to become seamlessly integrated as nodes in the European Transport Network. With the development of these solutions and overarching concepts, the AP2050+ consortium hopes to contribute to the long-term development of European airports meeting the challenges of the far future.

Table 1: List of most promising solutions of the Ultra-Green airport concept

Application Area	Purpose	Applicability and Benefits
Airside services		
Electric engine accelerators for take-off	Reduce aircraft main engine size	Reduce local noise nuisance, local emissions and flight fuel consumption. Applicability of (partial) alternative energy sources for take-off
Electric ground movement	Introduction of electrical towing and gear systems	Reduce local noise nuisance and emissions, improving local air quality, improved punctuality through better aircraft ground guidance and control
Cleaning & De-Icing robot	Reduce airframe drag, support closed-loop de-icing process	Reduce fuel consumption and less pollution due to de-icing process
Parafoil landing	Reduce aircraft landing speed	Shorter runway needed for landing and decrease of noise nuisance during approach
Landside services		
City & Single Central Terminal	Provide passenger-friendly check-in and security procedures in the city and efficient green transport to and from the airport. Concise building of airport itself.	Reduce noise nuisance by locating airports further from the city centre. Less energy, emissions, waste and water usage at the airport.
Intermodal transport services		
Automated Seats from curbside/train to aircraft	Minimise time spent between security and gate. Decrease the surface needed for the processes.	Since the number of seats in the aircraft exactly matches the number of passengers and can be optimally balanced, aircraft emissions and noise nuisance are decreased.
Infrastructure		
Dual Threshold Runway / Split Runway	Increase runway capacity.	Less runway incursions as aircraft are more physically separated. Due to a more central terminal location less taxiing time and therefore less noise nuisance and emissions.
Magnetic Levitation (MAGLEV) for Take-off and Landing (M-TOL)	Assist aircraft during take-off and after touch-down.	Less noise, less aircraft fuel consumption, and the possibility to also use alternative energy sources for take-off. System needing the implication of aircraft manufacturer, airport and AC handling.

Automated Apron Services	Automation of the turnaround processes increases predictability, control, and efficiency, and most of all leads to an uncluttered apron	Radical reduction in fuel consumption, noise and emissions due to the increased use of electrical systems.
High pier turnaround (passenger/baggage access from above)	Reduce turnaround time and allow for smaller-sized airport	Noise levels will be reduced since ground handling operations are performed in more enclosed infrastructure. Emissions are reduced due to the elimination of servicing vehicles on the platform.
Weather protected turnaround	Protected turnaround by permeable roofs.	Beneficial to high throughput airport operations in adverse weather conditions. Acceptability depends on light constructions, operating under safe conditions. Expected benefits by operating independently from external climate conditions.
Shielding landing and take-off operation by landscape design	Forest, located next to the runways with beneficial effects on noise, cross-winds and bird risks during take-off and landing operations	When cross-winds, birds and noise are a problem, improvement of operations can be achieved with secondary benefits to the environment. (Must comply with obstacle regulations of ICAO.)

Table of Content

Executive Summary **5**

List of Figures **11**

List of Tables **13**

1 Introduction **15**
1.1 Purpose of the document 15
1.2 Intended Audience 15
1.3 Document structure 15
1.4 Background and Context 16
1.5 Why develop an airport concept for 2050 Europe? 17

2 Summary of the Concept Development Methodology **20**
2.1 Background of the concept: vision and objectives 20
2.2 Reference airport 20
2.3 Solutions and advanced airport concept 20
2.4 Change-Impact and Value assessment 21

3 The Ultra-Green Airport concept and its Context **22**
3.1 Understanding of the UG concept 22
3.1.1 Conceptual definitions and the Scope of operations 22
3.1.2 Definition of an airport within the project 22
3.1.3 Focus 23
3.1.4 Classification of airports 23
3.2 Global trends, key focus areas and stakeholders interests 24
3.3 Boundary conditions and requirements 29
3.4 Summary of scope, context and objectives 33

4 A Reference for the Ultra-Green airport concept **36**
4.1 Baseline concept for present airport operations 36
4.1.1 Airside 37
4.1.2 Landside 37
4.1.3 Airport support facilities 38
4.2 Baseline for current airport processes 40
4.2.1 Landing and Take-off operations 41
4.2.2 Airfield Ground operations 41
4.2.3 Apron and Turnaround management 43
4.2.4 Maintenance and repairing the aircraft 44
4.2.5 FOD control, recovery and clearance 44
4.2.6 Water and Waste management 44
4.2.7 Anti-icing and de-icing operations 45
4.3 Environmental impacts and management associated with current airport operations 45
4.3.1 Noise, nuisance and management. 46
4.3.2 Local air quality (LAQ) in the vicinity of the airport. 47
4.3.3 GHG emissions from energy consumption and vehicle use 49
4.3.4 Use of resources 51
4.3.5 Waste prevention and management including the management of solid and liquid waste 53

4.3.6 Soil contamination, groundwater and surface water pollution 55
4.3.7 Habitat and biodiversity losses 55
4.4 Summary of the reference airport context and key challenges 55

5 The advanced Ultra-Green airport concept 58
5.1 Overview of the concept 58
5.2 State-of-the-art airport operations in 2050 58
5.3 Airport concept development following the invariant processes 62
5.4 Airside services 64
5.4.1 Electric engine accelerators for take-off 64
5.4.2 Electric ground movement 65
5.4.3 Cleaning & De-Icing robot 67
5.4.4 Parafoil landing 68
5.5 Landside services 70
5.5.1 City & Single Central Terminal 70
5.6 Intermodal transport services 72
5.6.1 Automated Seats 72
5.7 Infrastructure 76
5.7.1 Dual Threshold Runway 76
5.7.2 Magnetic Levitation (MAGLEV) for Take-off and Landing (M-TOL) 78
5.7.3 Automated Apron Services 80
5.7.4 High pier turnaround 87
5.7.5 Weather protected turnaround 90
5.7.6 Shielding landing and take-off operation by landscape design 91
5.8 Summary of the advanced Ultra-Green concept 93

6 Value assessment of the Ultra-green airport concept 96
6.1 Identification of operational changes in the Ultra-Green concept 96
6.2 Composing a value function to evaluate the concept 97
6.2.1 Determination of the value function 97
6.2.2 Determination of the weight factors 98
6.3 Expert judgment of the Ultra-Green concept solutions 99
6.3.1 Set-up of the validation workshop 99
6.3.2 Results of expert brainstorm session 100
6.3.3 Improvements to the Ultra-Green concept solutions 102
6.4 Value analysis of the Ultra-Green concept solutions 102
6.4.1 Most value-adding ideas 102
6.4.2 Validation of the Ultra-Green specific ideas 103
6.4.3 Limitations to the analysis 106
6.5 Summary, perspective, and potential of the Ultra-Green concept 106
6.5.1 Best ideas for the Ultra-Green concept 107
6.5.2 Expert’s most promising combinations of ideas 108

7 Conclusions and recommendations 109

Acronyms and Definitions 112

References 115

List of Figures

Figure 1: The Ultra-Green airport 16
Figure 2: The Time-Efficient airport 16
Figure 3: The Cost-Effective airport 16
Figure 4: Infrastructure associated with current airport description. 36
Figure 5: Invariant processes framework for which solutions are developed. See: [13]. 41
Figure 6: LTO cycle, source: [40]. 41
Figure 7: Proposed decomposition of airside airport processes 43
Figure 8: Airport operations environmental impacts. 45
Figure 9: Airport carbon scopes and levels of accreditation, source: [61] 49
Figure 10: European Union Waste Hierarchy, source: [21]. 53
Figure 11: Confederation of Europe Waste-to-Energy Plants, source: [51]. 54
Figure 12: SESAR Key Features at Step 3 - ATM Masterplan, source: [55]. 59
Figure 13: The autonomous vehicle driving from door-to-airport and vice versa, source: [44]. 61
Figure 14: Development of the UG airport concept of 2050+ 63
Figure 15: Example radar plot indicating how solutions contribute to the objectives. 64
Figure 16: Example of an aircraft with take-off assistance by a drone, source: [17]. 65
Figure 17: Expected impact of electric engine accelerators on the UG KPIs. 65
Figure 18: Nose gear with electrical engine, source: [62], © DLR. 66
Figure 19: Expected impact of electric ground movement on the UG KPIs. 67
Figure 20: A cleaning robot, source: [50] 68
Figure 21: Expected impact of cleaning / de-icing robots on the UG KPIs. 68
Figure 22: a. Banshee air vehicle under parafoil canopy. b. Winching technology being applied to (gliders and) parafoils for assisted (take-off and) climb. Source: [66]. 69
Figure 23: Expected impact of parafoil operations on the UG KPIs. 70
Figure 24: City terminal connected through high speed rail to a single lean airport terminal with security in the city (2) or at the airport (1). 70
Figure 25: Expected impact of the city and single central terminal on the UG KPIs. 72
Figure 26: Automated moving seat system - changes in future processing of passenger flows. 73
Figure 27: Scheme of passenger flows by moving seats 74
Figure 28: Expected impact of Automated Seats on the UG KPIs. 75
Figure 29: Example of Door-to-door use of the Automated Seat Concept. 76
Figure 30: a. Displaced threshold landing with raised initial approach altitude, source: [59]. b. Reduced taxi distances for medium type aircraft. 77
Figure 31: Expected impact of dual threshold runway on the UG KPIs. 78
Figure 32: Maglev concept for TOL: a) NASA, source [63]; b) AIRBUS, source [64]. 79
Figure 33: Aided Take-off and Touch-down retention systems conceptual design, source: [52] 79
Figure 34: Expected impact of Maglev runway operations on the UG KPIs. 80
Figure 35: Automated Apron Services split into decentralised robot based, telescopic centralized and a hybrid of the two. 81
Figure 36: Re-fuelling and fire system tower. 82
Figure 37: Moving towers (dynamic apron) and Fixed towers (static apron), A320 image: © Airbus. 83
Figure 38: Warehouse robots, source: [42], © Kiva Systems. 83
Figure 39: Equipment (blue) is moved by multiple transport robots (purple) 84
Figure 40: Luggage (grey) is handled individually by transport robots (purple). 84
Figure 41: Security equipment can be transported to the needed location for screening. 84
Figure 42: Transport of luggage between a central terminal and aircraft using transporters. 84
Figure 43: Expected impact of transport robots on the UG KPIs. 85
Figure 44: Automated de-icing bots, when finished the bots return underground. 86
Figure 45: Expected impact of Anti-icing and De-icing services and Pads on the UG KPIs. 87
Figure 46: The High Pier disposition. 87
Figure 47: Deployment of elevators/towers for the boarding/de-boarding of passengers, A380 image: © Airbus 88

Figure 48: Expected impact of high pier turnaround on the UG KPIs. 89
Figure 49: Integration of train to the high pier (intermodality), A320, A350, A380 images: © Airbus 90
Figure 50: A semi-permeable roof allows heat and gases to pass, but no precipitation. 90
Figure 51: Expected impact of weather protected turnaround on the UG KPIs. 91
Figure 52: Shielding of runway operations through landscape design. 92
Figure 53: Expected impact of the shielding of runway operations on the UG KPIs. 93
Figure 54: Weight distribution of the three KPAs for the UG airport concept. 98
Figure 55: Ideas chosen by experts and placed on the invariant processes chart. 101
Figure 56: Impact of electric ground movement on UG attributes. 103
Figure 57: Impact of electric ground movement on KPAs. 103
Figure 58: Impact of dual/split runway on UG attributes. 104
Figure 59: Impact of dual/split runway on KPAs. 104
Figure 60: Impact of cleaning and de-icing robot on UG attributes. 104
Figure 61: Impact of cleaning and de-icing robot on KPAs. 104
Figure 62: Impact of city & single central terminal on UG attributes. 105
Figure 63: Impact of city & single central terminal on KPAs. 105
Figure 64: Impact of electric engine accelerators for take-off on UG attributes. 105
Figure 65: Impact of electric engine accelerators for take-off on KPAs. 105
Figure 66: Impact of magnetic levitation for take-off and landing on UG attributes. 106
Figure 67: Impact of magnetic levitation for take-off and landing on KPAs. 106
Figure 68: Impact of automated apron services on UG attributes. 106
Figure 69: Impact of automated apron services on KPAs. 106
Figure 70: Best ideas for UG according to value assessment and expert judgment, and combined. .. 108

List of Tables

Table 1: List of most promising solutions of the Ultra-Green airport concept....................................... 6
Table 2: Airport layouts, source: [10]. 24
Table 3: Relevant Vision 2050 aspects for the UG airport.. 24
Table 4: High level interests of Stakeholders in Air Transport for their future operations.................. 27
Table 5: External requirements as boundary conditions per KFA 29
Table 6: List of applicable performance parameters and their attributes 34
Table 7: List of applicable LAQ improvement measures.. 48
Table 8: GHG emission management measures.. 50
Table 9: Energy consumption management measures... 52
Table 10: Summary of environmental aspects, existing objectives and current practices.................... 56
Table 11: Overview of solutions in the UG airport concept presented in this chapter......................... 64
Table 12: Weight distribution of all low-level attributes for the UG airport concept 99
Table 13: Ranking of ideas from expert's gaming session. 100
Table 14: Suggested improvements to some of the ideas.. 102
Table 15: Expert's value assessment of ideas for the UG airport concept... 102
Table 16: 10 best ideas for UG based on expert judgment and value assessment.............................. 107
Table 17: Expert’s judgement on the best three idea combinations for the UG airport concept......... 108

1 Introduction

1.1 Purpose of the document

The 2050+ Airport project develops three airport concepts for 2050 and beyond: the Ultra-Green airport concept (UG), the Time-Efficient airport concept (TE), and the Cost-Effective airport concept (CE). These concepts are elaborated as part of WP4 (Work Package), Concept Development. In WP2, a Concept Development Methodology has been developed to provide structured guidance to the development of these three airport concepts. In WP3, a validation framework has been constructed to validate the airport concepts and to increase their maturity level.

This report describes the Ultra-Green airport concept. Starting point has been the Concept Development Methodology developed in WP2 [9]. First, this report summarizes the most important global trends in Europe and the world as identified in the WP2 "Vision 2050" document [8]. Next, the trends, bottlenecks and future developments related to sustainability are analysed and the scope, context and objectives of the Ultra-Green airport concept is formulated. In the following, a reference airport of today is described to investigate current-day environmental challenges and adopted mitigating measures. Subsequently, the Ultra-Green concept is elaborated, distinguishing between solutions assumed to be in place by 2050 (state of the art), and solutions proposed by the 2050+ Airport project consortium to meet the environmental challenges of 2050 and beyond. Finally, the results of the second project validation workshop, held on June 19 2013 at the Polytechnic University Madrid as part of WP3, are presented as a means to validate the quality of the overall Ultra-Green concept and its constituent concept ideas.

1.2 Intended Audience

The intended audience is:

- The EU-Commission (European Union), DG Research (Directorate General), which commissioned the 2050+ Airport Project and which will assess project results;
- All European airports, the main stakeholders, which receive an operational concept that is intended to give guidance to the planning and decision making involved in developing towards the future;
- All other stakeholders (e.g. airlines, ANSPs (Aeronautical Navigation Service Provider), industry, passengers) with an interest in long-term development of the air transport system; and
- The 2050+ Airport consortium partners who will use the document to perform a high-level validation and give directions for further research.

1.3 Document structure

This document is structured as follows:

- The purpose and background of the Airport 2050+ concepts is explained in Chapter 1.
- The essentials of the Concept Development Methodology are summarized in Chapter 2.
- Based on the WP2 "Vision 2050" document, Chapter 3 develops a vision on the sustainable airport of the future taking relevant Key Focus Areas (KFAs), stakeholder interests and operational requirements into account. A description of global trends sets the scene for the scope, context and objectives of the Ultra-Green airport concept; in addition, a list with applicable performance parameters and their attributes is derived to support quantification of the Ultra-Green concept.
- Chapter 4 describes a current-day reference for the Ultra-Green Airport, starting with a baseline airport infrastructure and process design, followed by an analysis of the environmental impact of current-day airport operations and impact management strategies.
- Chapter 5 then elaborates the Ultra-Green airport concept itself in detail. A distinction is made between solutions assumed to be in place by 2050 (state of the art), and solutions proposed by the 2050+ Airport project consortium to meet the environmental challenges of 2050 and beyond.

- In Chapter 6, the results of the second validation workshop are presented as a means to validate the quality of the overall Ultra-Green concept and its constituent concept ideas. Two main methods have been employed to measure the ‘value’ of each concept idea: expert judgement and direct value assessment. The overall result is a list of best Ultra-Green ideas.
- Chapter 7, finally, draws conclusions on the scope and limitations of the Ultra-Green airport concept.

1.4 Background and Context

The 2050+ Airport project is commissioned by the EU-Commission in order to investigate the perspective of far future development of airports in Europe. The project explores new airport concepts with novel solutions to support and give direction to the development of the airport of 2050 and beyond.

The project develops three different airport concepts. These three concepts address time efficiency, environment and Cost-Effectiveness. The objectives of the three concepts are:

- **The Ultra-Green airport concept:** to make the airport as much as possible self-sufficient regarding its energy needs, to operate in a climate-neutral way and to limit noise exposure to municipalities surrounding the airport (See Figure 1).
- **The Time-Efficient airport concept:** to maximise the efficiency and effectiveness of air transport operations (See Figure 2)
- **The Cost-Effective airport concept:** to create an airport with extremely low operating cost and high revenues (See Figure 3).

Figure 1: The Ultra-Green airport

Figure 2: The Time-Efficient airport

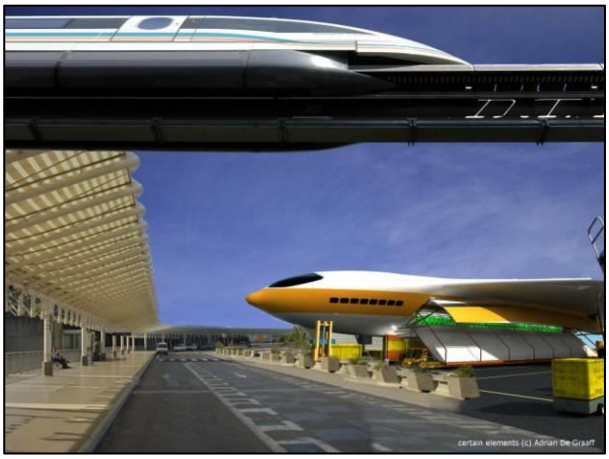


Figure 3: The Cost-Effective airport

These concepts show what the future airport could look like and which level of performance can be expected. They describe the interface between aircraft and ground, passenger/baggage related processes, new airport operations management principles and how the application of new principles of airport layout can improve integration of future intermodal connections.

The 2050+ Airport aims to provide the seeds to feed the long-term development of airports in Europe. The project’s main activities focus on the development and partial validation of the three innovative airport concepts for 2050. These activities comprise:

- **Building a Methodology for airport concept development:**
  In order to find a structured approach in the development of an airport concept, a uniform methodology is developed. This methodology, based on value theory, assesses the different stakeholder relations and interests, and provides a high-level set of objectives and attributes to set the focus of each concept. This makes it possible to rate the concepts' designs and make trade-offs between different proposed solutions.
- **Delivery of three airport concepts building upon user contributions:**
  Several ideas are captured mainly through workshops and brainstorm sessions. The most promising ideas are used to develop an initial version of the concept, which is further refined by validation activities. The concepts are updated and the process continues following a spiral life cycle until they are considered sufficiently mature (E-OCVM - V1 at project end, [25]) (European Operational Concept Validation Methodology).
- **Partial validation of these concepts:**
  The validation activities increase the maturity level of the concepts and enable performance assessments to be done. The validation activities gather the needs, generate ideas to fulfil these needs, and identify the best solutions for the further refinement of the concepts. This task ensures the coherence of the maturity level achieved by each concept.
- **Delivery of three airport concepts building upon user contributions:**
  Several ideas are captured mainly through workshops and brainstorming sessions. The most promising ideas are used to develop an initial version of the concept, which is further refined by validation activities. The concepts are updated and the process continues following a spiral life cycle until they are considered sufficiently mature (E-OCVM - V1 is expected at project end, [25]).
- **Partial validation of these concepts:**
  The validation activities increase the maturity level of the concepts and enable performance assessments to be done. The validation activities assess the feasibility of each solution allowing for the further refinement of the concepts. This task ensures the coherence of the maturity level achieved by each concept.

The current document reports on the Ultra-Green airport concept for the Airport of 2050 and beyond.

1.5 Why develop an airport concept for 2050 Europe?

The world is changing and towards 2050 a strong increase of air traffic demand is expected due to an increase in population and consumption rates world-wide, as well as a strongly growing economy in the BRIC (Brazil, Russia, India, and China) countries and other emerging markets. In Europe, air traffic demand is expected to grow as well, although at a more moderate pace and under heavily constraining conditions of scarcity of resources, increased prices of fossil fuels and the need to limit environmental pollution, in particular CO_2 emissions (see the 2050 Vision Document [8]).

The increase in European air travel demand is a result of the growing desire and ability of people within and outside of Europe to travel. This increased demand can only be accommodated if the European air transport industry is able to meet its targets to significantly enhance mobility, cost-efficiency and sustainability for door-to-door travelling. This is no easy task, but fortunately a number of Time-Efficient, Cost-Effective and Ultra-Green improvements have already been initiated within the European SESAR and CLEANSKY research programmes and can be expected to be in place by 2025 – 2030. For 2050 and beyond, however, a much more radical set of solutions may be required. It is here that the AP2050+ project steps in, developing airport concepts for the far future.

The Flightpath 2050 report [26] sets the objective to allow 90% of European travellers to be able to complete their intra-European door-to-door journey within four hours. Europe will only meet this objective if the European Transport Network improves significantly, meaning that:

- The connectivity between the critical nodes (hubs) of the Air Transport network has to improve

- The connectivity between the Air Transport Network and other modes of transportation has to improve
- The network of nodes has to expand to offer full coverage
- A seamless service provision has to improve door-to-door travel time and meet the requirements for user-friendliness, sustainability and undisturbed service provision

Airports are the major nodes of this European Transport Network and, even though parts of the network are functioning well already today, the network itself is far from complete and far away from providing full network connectivity and door-to-door transport services against the most competitive prices, centred towards the passenger, and in the most environmentally friendly way.

This justifies the development of advanced airport concepts, reflecting the need to improve the airport's performance as the critical nodes in the European Transport Network. In a competitive world, constrained by several limitations, European airports have to develop to enhance their operations, strengthening their role in the network:

- Airports have to improve connectivity between airports and connectivity in their catchment area offering seamless service provision to their passengers. This justifies the development of a Time-Efficient airport concept for 2050, improving seamless operations and removing delays and other hurdles in travelling whenever possible.
- Airports have to reduce their costs and increase revenues in a world that becomes ever more competitive. This justifies the development of a Cost-Effective airport concept for 2050, reducing costs and improving efficiency and revenues whenever possible.
- Air Transport has to reduce its impact on the environment by reducing not only emissions and noise, but also its overall consumption of resources and its production of waste. This justifies an Ultra-Green airport concept for 2050, reducing the burden on the environment as much as possible. Ultra-Green relates to all operations at and around the airport, comprising also transport services to and from the airport as well as all other activities to build, maintain and operate the airport.

In the 2050+ Airport project, the European Transport Network of 2050 is assumed to consist mainly of already existing, yet upgraded airports, with limited possibilities for the construction of brand new airports. Existing airports shall have to expand and modernise their operations to cover full 4-hour door-to-door services throughout Europe, even though some airports already provide at present an elaborate network of transport services within their catchment areas. The focus of the 2050+ Airport project is on civil commercial air transport operations, excluding military air transport or general aviation but including, to a limited extent, other modes of transportation linking airports to their catchment areas. Very specific and dedicated service provision such as airships and/or cargo drones operating from dedicated airfields, and/or dedicated cargo rail transport lines are considered less relevant for the network of interest.

In order to be beneficial to airport development, the three 2050 airport concepts of the 2050+ Airport project are complementary to one another. The airport concepts aim to provide the airports as main stakeholders with new views and new ways to initiate implementation plans to meet the demands of the far future. The concepts are constructed by analysing a baseline reference airport and identifying processes, operations or infrastructural bottlenecks that can be significantly improved - each time with its specific focus on Ultra-Green, Time-Efficient or Cost-Effective improvements. (See the Definition of the Ultra-Green concept in the green box). Airports may ultimately choose their own specific solutions from

Definition of the concept of the Ultra-Green airport:
The "Ultra-Green airport" is the airport that has been designed and is operated and managed in such a way that environmental impacts are minimized or made sustainable. Based on new forthcoming technology it aims to make sure all the resources are used and managed in the most efficient way possible in order to give the least environmental footprint and the best service to all stakeholders. To do this the airport applies intelligent, collaborative, dynamic and automated systems capable of reacting to the daily needs of its stakeholders

each concept, benefiting from what suits their purpose and their vision to improve their competitive position within the European Transport Network.

2 Summary of the Concept Development Methodology

This chapter summarizes the Concept Development Methodology (CDM), which is used to develop the Ultra-Green (UG) airport. The methodology, as developed during WP2, essentially consists of four steps that should be followed: (1) description of the background of the concept, (2) analysis of a reference airport, (3) solution generation, and (4) initial value assessment. This chapter will describe these four steps in the subsequent sections and forms the basis for the rest of the document.

2.1 Background of the concept: vision and objectives

The goal of the first step is to create a clear background on the development of the concept, how it is interpreted (definitions), what is in/out of scope and which requirements are derived. In this step the Vision 2050-document [8] is re-examined to find which parts of it are key for the concept in terms of future forecasts, boundary conditions and pre-set performance goals.

Furthermore the Value Operations Methodology (VOM) [9] is applied by laying down the value structure that will be used for concept development. Working from the high-level value structure presented in the VOM framework, more detailed objectives and associated attributes are added to the value lever that is the primary focus of this report: sustainability. In this step also low-level weights can be assigned to all attributes. This part of the VOM has been applied in an early stage of the project, yielding a clear focus beforehand on what the concept should achieve (based on the expected environmental needs of 2050) and which attributes are needed to measure this. Such focus will help direct the effort in the context analysis and solution finding phase.

2.2 Reference airport

When the background of the concept, its goals and objectives are clear, an analysis of the current airport operational context is then conducted. To make the final concept as widely applicable as possible, a generic, medium-sized airport is chosen and described in terms of processes, infrastructure and/or services as the baseline situation (or ‘reference’).

After this, the baseline airport is analysed in detail using the tools and method presented in the first part of the Context and Architecture Description (CAD) method [10]. This analysis will point out where the key bottlenecks or challenges in airport operations are currently located. The view taken here is concept-specific: what aspects in current airports are already bottlenecks that need to be overcome to achieve the required Ultra-Green levels (as derived from the concept background)?

Finally, taking the identified bottlenecks as a starting point, these are translated to a 2050 situation. What will it mean if current bottlenecks are not solved? Also, are there problems to be expected from other airport areas that are currently not a challenge for the concept, but will become so if no changes are made from now to 2050? This step ‘distils’ the challenges the Ultra-Green concept absolutely needs to solve in light of the 2050 goals, as derived from the first step of the methodology (background).

2.3 Solutions and advanced airport concept

The foregoing analyses will have created a clear argumentation for the goals to be met by the Ultra-Green airport concept, and the aspects of current airport operations that need to be radically improved to achieve these goals. Using creative tools such as morphological analysis, design-option trees, brainstorming or any other means presented in the second part of the Context and Architecture Description [10], innovative solutions (directions) to the challenges of 2050 are now developed. This is the creative phase of concept development, guided by the findings of the previous two steps. Solutions will be developed for specific airport areas (landside, airside, intermodal links – or a combination/integration of those), together with an outline of their expected benefits to 2050 goals. The development is followed by a check to prevent incompatibility between solutions. The end result is a draft concept of Ultra-Green airport operations, consisting of a number of selected solutions (concept ideas) for 2050 and their expected benefits.

2.4 Change-Impact and Value assessment

Following the steps outlined in the Change-Impact (C-I) methodology [11], the changes proposed by the concept solutions (or concept ideas) are mapped to concrete operational processes/services/infrastructure. The information obtained from the context analysis provides the framework for this. The specific operational metrics attributes which are expected to be affected are also listed.

Then, using the quantification scheme outlined in the C-I method, the different impacts expected from these changes are estimated. This is initially done by the consortium partners (see Chapter 5), but subsequently the input of the various airport operational and industry experts present at the second validation workshop of WP3 has been used to assess the impact of the proposed solutions on the value attributes (see Chapter 6). Specifically, the expert's C-I analyses will be used as input for the Value Operations Methodology and value structures, which in turn are used to calculate the value contribution (i.e. the ΔV score) for each solution. Apart from the C-I method, an expert judgment gaming session is used to provide an alternative way of evaluating the several concept's ideas. Both methods aim to determine the most promising Ultra-Green solutions/concept ideas and are further detailed in Chapter 6.

The results of the four steps of the CDM as discussed in this chapter will be elaborated in Chapters 3-6 respectively.

3 The Ultra-Green Airport concept and its Context

The vision, developed within WP2 [8], has defined the goals and boundaries of the future world for which the three airport concepts are to be developed. This chapter takes this high level global scale vision and picks out those parts which are considered to be most relevant for the development of airports between now and the year 2050. First, the scope of the Ultra-Green airport concept is discussed in section 3.1, thereafter each Key Focus Area and the stakeholder interests are assessed in section 3.2. Section 3.3 uses this 'expanded' vision to derive requirements specific to the UG airport concept. The outcome, in terms of scope, context and objectives, is summarised and concluded in section 3.4.

3.1 Understanding of the UG concept

The UG concept aims to be climate-neutral regarding its airport specific operations and to be as environmental-friendly as possible where traffic to and from the airport is concerned (see also section 1.5). The UG concept is described here in relationship with the two other concepts of the 2050+ Airport project: the Time-Efficient and the Cost-Effective concept. Aspects of scope, definitions, focus and classification are as much as possible uniform among the three concepts.

3.1.1 Conceptual definitions and the Scope of operations

All three concepts of the 2050+ Airport project are addressing daily operational issues, in first instance. However, the concern of airports is not only to address daily operations: design, development, and constructions are considered very important as well. Most relevant for the Ultra-Green concept is therefore, to develop a concept enabling the airports to process their daily operations in an environmentally friendly and sustainable way, whilst paying attention to airport development and expansion as well. Chapter 3 of the Methodology Framework, WP2, [9], describes what is inside and what is outside the scope of the airport concept development of the 2050+ Airport project. By focussing on airport operations, aspects like airborne Air Traffic Management (ATM) procedures are outside the scope, whereas platform operations, and thus also that part of aircraft operations related to ground movements, are within scope. That said, new aircraft design, e.g. the blended wing body (BWB), may have an impact on airport design, airport operations, and airport deployment and might become an essential part of the concept as such.

In the definition of the airport concept, the Ultra-Green airport concept assumes operations by aircraft types which will be increasingly sustainable, marking an extended legislative process towards sustainable and environmentally friendly operations.

This definition is necessary in order to describe a credible and in itself consistent scope of operations. Not only the airport itself is assumed to optimise its operations towards one of the selected optimisation parameters, but also the world around it and its operations have to be aligned with the main theme of the airport concept. Nevertheless, the main driver is still leading, to foster Ultra-Green operations at the airport.

In summary, 'Ultra Green' means that operations at the airport have minimal or even no impact on the environment. It is essential, that any airport is built and operated in an environmentally friendly way. Still sustainability must be in balance with the economic factors for the airport and the time factor for the passenger. That the airlines operate in a climate friendly manner is not the focus of this project.

3.1.2 Definition of an airport within the project

In the context of this project, 'airport' is understood as the geographical territory of the aerodrome comprising[1]:

[1] At an actual airport the division into services can be sometimes different, but for further development of the concept ideas this division into service areas is arbitrary.

1. **Airside:** the part of an airport directly involved in the arrival and departure of aircraft. It comprises a tract of levelled land where aircraft can take off and land, usually equipped with paved runways, taxiways, platforms and buildings for maintenance of aircraft and provision of airport services like marshalling.
2. **Landside:** the facilities for passengers, comprising all areas and buildings accommodated to provide services to departing and arriving passengers, transferring between their specific flight and other modes of transport. Also for cargo there are facilities to ensure storage and sorting.
3. **Intermodality:** The areas dedicated to the transfer of passengers between different modes of transport at the airport, i.e. railway, underground, bus station, pickup/drop off and car parking.
4. **Commercial/Industrial areas:** The areas for industrial activities, hotels, retail and community activities, important to the commercial success of the airport, but not belonging to the deployment of the airport as such.

The airport is the start-, transfer-, and end-point of air travel. And its scope of operations is essentially linked to its terrain limits. Flight operations are also out of the scope of the concept. Further details of the airport scope are outlined in D2-1-2 of the WP2 methodology.

3.1.3 Focus

Like the other two concepts, Time-efficient and Cost-effective, the Ultra-Green concept focuses on future changes of the airport regarding design, the associated services and the apron traffic management. Intermodal connections are not elaborated specifically, but the design of the terminal building should support seamless intermodal access by facilitating the change from one transportation mode to another whilst minimizing transfer time and costs for the passengers. Furthermore, it should allow passengers to choose for an environmentally acceptable mode of transport. As the focus of this concept is Ultra-Green, green intermodal connectivity is considered to be a critical element of the door-to-door transport. This is especially valid with regard to the need to enable 90% of travellers within Europe to complete their journey (door-to-door) within four hours [8].

The Ultra-Green concept does not detail any ATM procedures; it only gives an overview of those possible future ATM developments that may influence the airport’s service structure in the forthcoming period. Finally, within the 2050+ Airport context, cargo operations are not elaborated in detail but rather treated as sub-flows of air transport executed in parallel with passenger transport.

3.1.4 Classification of airports

According to the methodology framework, all three concepts have to look at three possible airport layouts: the small, medium and large size airports, which are characterised by the parameters depicted in Table 2. Small airports may have a high potential for growth. Due to their limited size this type of airport will probably not require radical new solutions though they may benefit from certain new ideas applied to medium-sized airports. Medium size airports may have a potential for growth and may have the need for radical new solutions, as they already experience congestion and growth limitations due to environmental constraints. Congestion and growth limitations also apply to large (hub) airports. Within Europe, existing large airports will probably have reached their spatial limits and may therefore only be able to implement a reduced number of solutions. Each of these airport layouts has its specific characteristics, which may lead to a different implementation of the concept.

Table 2: Airport layouts, source: [10].

General characteristics	Large airport	Medium airport	Small airport
Type of airport	Large (hub)	Large regional / small hub	Regional
Operations type	Scheduled	Scheduled	Scheduled / charter
Connecting pax	>50% transfer	Limited transfer, or only self-connecting	No transfer
Fleet mix	WB+NB, hardly any GA[2]	Mainly NB, some GA	Regional with NB, fair share GA
A/C movements [x1000/yr]	> 150	75-150	10-75
Pax numbers [millions]	>15	10 – 15	< 10
Runways	2 or more	1-2	1
Catchment area (120 min.) [millions]	>10	5-10	<5
Example airport	Schiphol, Frankfurt, Barajas	Las Palmas, Warsaw, Nice, Düsseldorf	Eindhoven, Targu-Mures, Kaunas

3.2 Global trends, key focus areas and stakeholders interests

The Vision 2050 document [8] provided a global view of the world in 2050. This vision is further detailed to describe the impact on the environment. In this section, the main conclusions of the vision 2050 document are summarised and, if necessary, expanded with consequences for the aims of the aviation industry in 2050. This vision provides the context and a set of constraining boundary conditions for the development of each airport concept, as discussed in the following section.

Table 3: Relevant Vision 2050 aspects for the UG airport.

Key Focus Areas	Most relevant aspects of the Vision for airports in 2050
Demography	• The world population is expected to grow quickly, with most of its growth in Asia and other developing regions. Compared with this growth, the population of Europe is expected to remain quite stable with only a slight increase of about 12%. • Dense populated urbanised areas will become even more crowded, on the one hand worsening local environmental issues such as noise and local air quality, but on the other hand accommodating increased connectivity between destinations. • Peoples' life expectancy will increase, changing demand patterns for air transport. • All these changes will impact the ability of the world and the European population to participate in global and European mobility. This means that the services at the airport have to be adopted accordingly and be more differentiated.

[2] Note: WB stands for wide body, NB for narrow body, GA for General Aviation

Key Focus Areas	Most relevant aspects of the Vision for airports in 2050
Society	• Environmental awareness will increase industries' concern towards mitigating its effects on the environment. • Scarcity of resources may affect the balance of wealth in the world, creating differences in demand patterns for air transport. • There will be an increased frequency, scale and size of events like political, societal, sport and cultural events resulting in an increase of associated travelling.
Politics	The European-wide and global scale of societal integration and exchange of people and goods will impact the trends of travelling at European and global scale: • Due to the requirement of the public to act on environmental issues, governments will impose more strict and severe environmental regulations. • The regulatory framework for access to countries, globally and within Europe, will become more open. This relates for example to measures to guide migration and immigration trends. • Global security will remain a key issue.
Economics	Development and growth of the economy within Europe and at global level will directly impact travelling: • Travel costs will increase with respect to the level of welfare, specifically within Europe, probably reducing the number of travels per citizen. • The relative costs for travelling, which depend amongst others on oil pricing, environmental issues, emission rights and costs of labour and other resources, are expected to increase, driving the need for alternative fuels and cleaner, more efficiently operating aircraft and airports. • The competition between Air Transport and other modes of transport operations will increase. This competition will impact the volumes of Air Transport, being dependent on infrastructure and local conditions. • It is expected that stricter economic regulation will be in place in the future, limiting access to funds and ability to recuperate costs. This will be especially hard for the aviation sector, where development costs are high and lead times long. This will limit the ability to innovate.

Key Focus Areas	Most relevant aspects of the Vision for airports in 2050
Environment	The growing population outside Europe and the welfare of the people in Europe and at global level, following a more or less intensive consumption pattern, determine the load on society and determine the need to protect nature against environmental impacts: • Scarcity of resources determines the need to restrict consumption and to limit acceptable growth levels. In particular, oil will become much scarcer, driving up energy costs. This will increase the drive for new, sustainable sources of energy. • Emissions determine much of the damage at local and global level caused amongst others by Air Transport operations. • Air Transport operations are causing environmental effects, also at local level, by increasing noise levels, by air pollution, by noise, by use of sometimes scarce ground resources and by the impact of Air Transport on mobility at a local level (roads and trains). In some cases, this limits airport's and airlines' ability to expand and it creates an incentive for the design of e.g. quiet aircraft and optimized operations. • In 2050, climate change will have occurred very likely and will be perceivable. The public will be steadily less tolerant of any forms of pollution, so clean(er) alternatives to fossil-based air transport/ airports need to be developed.
Mobility	• Transport modalities within Europe will change due to changing transport requirements and offered services. • Air Transport between Europe and other parts of the world will grow due to a larger participation of other regions in economic global activities. • Net demand for air travel will increase. • With the EU goals of higher punctuality and efficiency, coupled with a relatively extensive system integration, air transport will be more expeditious in 2050 (in terms of processes), and more Time-Efficient, 'just-in-time', than before. • Personal forms of air transport are still likely to exist in 2050, but in Europe it will constitute only a small part of the total volume of traffic. • People demand for ever-increasing levels of safety and security, as air transport will become more and more mature. However, this will increase cost and inconvenience (for security reasons) during travel.

Key Focus Areas	Most relevant aspects of the Vision for airports in 2050
Technology	• Due to the long development processes and the long legislative process, Air Transport will not change significantly within the next 40 years. • Due to environmental pressure, the need for environmentally sustainable operations will increase and will constitute constraining conditions on technological development. • Due to competition, the need for cost-efficient operations will increase and will form constraining conditions on technological development. • Innovative technology will enhance the capability for safety/security-checks. • There will be increased use of non-oil technologies such as solar, hydrogen and perhaps even nuclear power for non-aeronautical applications (primarily for ground operations, but for aircraft operations as much as feasible). • Kerosene will still be used at a high and costly level, but complementation by biofuels will be prevalent (see also the section on environment). • There will be increased use of automated machines, such as unmanned transport vehicles on the airport and Remotely Piloted Aircraft Systems (RPAS)

General Stakeholder's interests

The Vision 2050 document [8] also presents an overview of stakeholders' interests in the development of future air transport operations and associated airport operations. The main interests and challenges of relevant stakeholders in future air transport (not limited to Ultra-Green operations) are listed below, in Table 4.

Table 4: High level interests of Stakeholders in Air Transport for their future operations

No.	Stakeholder	Main Interests
01	**Governments (central)**	• Setting rules and legislation (environment, economics, safety, etc.) • Protecting economic interest (perhaps more so than currently, due to foreign competitors) • Increasing competitiveness • Increasing innovation • Responsible for population and environment
02	**Governments (local)**	• Enforce rules and legislation (environment, safety, security, etc..) • Want to generate local economic activity • Want to protect local communities (noise, pollution)
03	**Public**	• Wants to have seamless access to mobility and a seamless trip • Wants to have a pleasant trip without stress • Wants to have access to jobs • Wants clean/sustainable and efficient air transport • Wants cheap, air transport

No.	Stakeholder	Main Interests
04	**Local community members**	• Want to have access to jobs • Want to have access to mobility • Want cheap air transport • Want to have lowest/acceptable amounts of noise, pollution, construction/expansion (esp. environment) • Want to benefit (as region) from an airport's activity
05	**Airports**	• Want to make profit or at least break even • Want to serve all possible demand for air transport without becoming congested • Want to be as efficient as possible (time, cost, sustainability) • Want to provide safe, multimodal transport
06	**Airlines**	• Want to make profit • Want to serve all demand for air transport • Want to be as efficient as possible (time, cost, sustainability)
07	**ATM/ATC**	• Want to make profit / break-even (depends on organisation) • Want to provide maximum airspace capacity to all users • Want to protect 'status quo' (jobs, ways of working, equipment) • Want to provide safe air transport
08	**Others (3rd party to airports)**	• Want to make profit • Want to be 'preferred partner'
09	**Air Transport Users**	Origin/Destination passengers • Want very quick and seamless access to mobility (inc. easy connection with non-aircraft transport) • Want a seamless experience regarding the purchase, ticketing, planning and point-of-contact for the complete door-to-door trip • Pragmatic to travelling/connection: road, rail, air, ICT • Open to/preferring sustainable air transport/mobility • Want cheap air transport • Want to stay connected all the time • Want enhanced and guaranteed rights w.r.t. delay, information, luggage Transfer passengers • Want efficient, fast connection (no waiting) • Want to stay connected all the time • Want cheap air transport • Open to/preferring sustainable air transport / mobility • Want enhanced and guaranteed rights w.r.t. delay, information, luggage Freight transporters • Want to have cheap prices • Want quick and efficient transport • Want seamless connection to road/rail/water

No.	Stakeholder	Main Interests
10	**Aerospace manufacturers**	• Want to make profit • Want to be market leader • Interest in high growth and demand for aircraft
11	**Lobbies/pressure groups**	• Want to further interests of public or industry • Want to influence policies to their favor
12	**Aviation organisations**	• Want to further interests of aviation industry • Wank to promote cooperations • Want to improve standardisation • Want to gather and disseminate data

The Vision 2050 document [8] concludes that by 2050 and beyond the economy is expanding in spite of major challenges, and as a consequence the demand for air transport will grow significantly. These trends will put extra pressure on the need to accommodate growth in a sustainable manner. The global growth will urge the need to find environmental-friendly and climate-neutral solutions at a European and global scale. The boundary conditions and resulting requirements for the Ultra-Green airport concept are elaborated in more detail in the following section.

3.3 Boundary conditions and requirements

The global trends and stakeholder's interests detailed above have been leading in the establishment of the boundary conditions relevant to the UG-airport concept. These boundary conditions specify both (1) the *conditions* expected to apply to the world of 2050+ and (2) the *boundaries* that need to be taken into account, or overcome, to establish the Ultra-Green airport of the far future. As such, boundary conditions can be regarded as opportunities for future development. Table 5 below lists the boundaries conditions applicable to green air transport per Key Focus Area, supporting the external requirements formulation for the Ultra-Green airport concept.

Table 5: External requirements as boundary conditions per KFA

Key Focus Areas	Boundary conditions to determine external requirements

Demography	• **Growing world population**: The growing world population (9 billion, +28.6% from 2011, see [8]) will ask for increased volumes of air transport, but the pressure on resources and climate will be a driver to stimulate climate-neutral operations and to make these operations (artificially) attractive.
	• **Urbanisation**: The increased urbanisation in the world (>70%, see [8]) and in Europe, on the one hand, will be attractive on the one hand for beneficial deployment of airports, on the other hand, will impose even more strict environmental requirements:
	  ○ Low (local) emission levels,
	  ○ Low levels of noise pollution, and
	  ○ Minimal use of resources (land, landscape, and airport feeding traffic).
	• **Catchment area**: Dense populated areas and appropriate transport means, determine the catchment area of the airport. Airports have to promote and accommodate environmentally friendly connectivity within this area to reach the airport, offering local public in a wide area unrestricted connecting services to the outside world.

Key Focus Areas	Boundary conditions to determine external requirements
Society	• **Pressure on climate**: The public pressure to protect the climate will ask for climate-neutral, or at least minimal environmentally polluting operations. It will form a constraint on the foreseen volumes of air traffic, likely putting pressure on ground travel more than at present, i.e. in 2013. The effectiveness of public pressure depends on local differences in welfare within countries and regions. • **Pressure by local environment**: People in the neighbourhood of the airport will firmly insist on protecting the environment and reducing emissions and noise at a local level.
Politics	• **European integration**: The continuing trend towards further European integration leads to more intense traffic flows within Europe. This will ask for growth of existing airports and if required and feasible to add new airports while closing others to get a better spatial arrangement, but also for a more seamless network, combining and integrating for example air transport and rail networks. This has a natural tension on our scarce resources and must be addressed by closing the resource cycle. • **Budgetary policies regarding incomes, debts and GDPs (Gross Domestic Product)**: Local, regional and world-wide agreements to stimulate or to restrict unlimited air transport operations will impact the air traffic flows and the evolution of airport development. A "green" concept for Air Transport may provide the answer as far as constraining the consumption of resources and fuel, and the Ultra-Green airport concept will be part of it. • **Local issues, LAQ (Local Air Quality), emissions and noise**: Governments are in charge of protecting the population against environmental pollution and noise. Airports will be monitored and controlled on implementing a pollution mitigation strategy, comprising Local Air Quality measures, emission reductions and noise abatement measures.
Economics	• **Price of energy**: Traditional fossil fuels will become scarce and will rise in price. This is the most direct driver for Air Transport industry to reduce energy consumption. This reduction is obtained by energy-efficient, renewed design and by energy-efficient operations, and at the same time, this will benefit the attractiveness to deploy the Ultra-Green concept. The airport is less bound to fossil fuels than aircraft operations, and has a wider scope for energy-efficient applications. • **Competition and limiting conditions**: The relative costs and environmental effects of different travelling modes will impact the development of Air Transport operations. On the one hand, this will be solved by competition; on the other hand, this will create a ceiling level of expansion by increased mobility. The competition will make train connections dominant for example when the infrastructure is affordable and the distance acceptable. The ceiling levels will be reached for example if serious deficiencies of available resources will become prohibitive (price balancing), or if environmental damage becomes prohibitive.

Key Focus Areas	Boundary conditions to determine external requirements
Environment	• **Long air transport operation change lead times**: The environmental effects of air transport operations is dependent on the ability to perform flight operations with low environmental impact in the first place. This is dependent on solutions to improve the environmental performance of aircraft during flight operations. The development of airports is dependent on accommodating changed aircraft constructions, but aircraft design has long lead times, and in addition there is a legacy problem. The traditional design can be further optimised towards minimal energy consumption and minimal noise production, and future changes will very likely not lead to deviate too much from traditional aircraft shapes. Future airport design has just to take into account these anticipated modest changes. • **Low environmental impact procedures at airport level**: Significant emission and noise reductions around the airport are dependent on advanced start and landing procedures. SESAR (Single European Sky ATM Research) will be the implementation programme to deliver operational acceptance for these procedures, and this will generate acceptance for further growth. • **Noise restrictions**: Given the importance placed on noise in the current situation it is perceivable, given the expected increase of air traffic in the future that this issue will set stricter limits. Current airports will have difficulty to expand. In addition to a reduction of engine noise by the manufacturers, airports must think of innovative solutions to reduce the noise load on the surrounding tenants, or face restrictions in growth. • **Local air quality**: Local environmental problems around the airport are dependent on different transport flows feeding the airport at the ground-side. This relates to emissions, noise and possible visual pollution . Different solutions may play a role in mitigating or solving such problems, such as: o New technology for cars, railways and other transport modalities, o Distribution of passenger and freight transport over different modalities, and o Local infrastructure and other conditions, such as e.g. filter screens. • **Low energy building, waste reduction and water management:** Enhanced isolation and/or closed heating systems can help to reduce energy consumption of the airport itself. Furthermore, waste reduction and water management have to be applied to reduce the environmental impact.
Mobility	• **Intermodal connectivity limitations**: Mobility, but also the environment, may profit from seamless integration of transport modalities. Seamless transport networks may better than today facilitate destination traffic with onward connectivity by rail. The benefits come from economically beneficial flows of air traffic covering a higher catchment area. Schiphol, for example, has a catchment area that will easily grow to cover also Antwerp, Maastricht, and the North of the Netherlands. Its ultimate reach depends on expansion of the high-speed rail network, connectivity by other trains and the road network. The future hub airports need to be not only the centre of an Air Transport network but to be the centre of a train and road network as well [26]. • **Relative costs of travelling**: The rising living costs and lack of resources will urge for low-cost and cost-efficient air transport operations. Regarding energy consumption, this coincides with environmentally friendly operations.

Key Focus Areas	Boundary conditions to determine external requirements
Technology	• **Optimised aircraft design restrictions on the airport**: Fuel costs and environmental constraints are forcing solutions that make optimal use of lift and drag conditions. The Blended Wing design is a possible option (See Vision document), but all "Out-of-the-box" designs for fast, easy, flexible or revolutionary access to airspace seem unrealistic for mass transportation[3].

In addition to these external boundary conditions and derived requirements, a number of internal requirements to Ultra-Green air transport can be drawn up as well. These conditions, internal to the field of air transport and its stakeholders, have been listed in the Vision 2050 Report [8]. The requirements that are relevant to the Ultra-Green airport concept are listed below.

Stakeholder requirements regarding the UG airport concept

In section 3.2 above, an overview of the stakeholders' interests in the development of future air transport operations has been given. Specific to the Ultra-Green airport concept, the main challenges are:

- **External stakeholders**, like government and the public, require extension of regulation and legislation to mitigate the challenges raised by the anticipated growth of air transport operations. This will put pressure both the environment and the population. On the other hand, these transport activities are profitable and beneficial, requiring a fair balance of economic and environmental interests.
- **Airports** want to satisfy their customers by ensuring seamless and customer friendly service provision. To allow this, they need unconstrained access to their airports through airspace and to their catchment area through other transport modes. Moreover, an increased volume of operations is often also a requirement to remain competitive. At the same time, any expansion has to be balanced by proportional measures to limit environmental impacts and satisfy the basic aim (imposed, proposed or committed) to operate the airport in a climate-neutral way.
- **Airlines** are competitive and profitable by offering air transport services against lowest costs and in agreement with air transport requirements of their customers. Ultra-green operations are considered as a primary opportunity to be fulfilled for reasons of acceptability.
- **ANSPs** find their mission in providing safe, orderly and expeditious ATM/ATC (Air Traffic Control) services, including also ground operations on taxiways and aprons if applicable. Severe environmental constraints are not directly profitable and may lead to a drastic increase in workload of Air Traffic Controllers. Therefore, climate-neutral and environmental sustainable operations can be fostered only by extending their mission with performance criteria to meet sustainable conditions. Safety cannot be compromised, but it can be part of the ATM mission statement to optimise towards a proper balance between Capacity, Efficiency and Environmental sustainable operations.
- **The Users of Air Transport operations** have an interest in unlimited, low-cost, easy, comfortable, reliable and punctual air transport operations. However, these very high requirements are balanced at all times with the requirements of users in their role of third parties defending the interests of e.g. local municipalities around the airport, or our global interest in a sustainable deployment of the earth, its environment as well as its resources.

It may be concluded that environment is still insufficiently present as an external cost factor[4] in operations. Therefore, local, national and supra-national policy makers increasingly develop and even impose regulations (ranging from e.g. local airport taxes to the EU Emission Trading System) to improve sustainability. Local and even European initiatives obviously run the risk of leading to unfair

[3] The Blended Wing design may impose extra constraints on airside airport design, i.e. on taxi routing, gate handling, and docking

[4] "External" stems from EU-terminology: internalization of external costs. External costs: the costs caused by (in this case) air transport users incurred by a third party (e.g., residents near airports) that have not been taken into account (i.e., in the ticket price).

competition, however. A level playing field in respect to sustainability at the airport is therefore essential.

As there will be an increasing need to promulgate climate-neutral operations the government, as committed stakeholder, is expected to come with more constraining conditions, requiring innovative concepts and technologies to enforce climate-neutral operations. This may change the balance between costs and benefits in future operations for air transport operations and thus also for airport operations, and may impact the profitability of air transport.

3.4 Summary of scope, context and objectives

The UG airport concept focuses on the boundary conditions applicable to the world of 2050+ that provide the most promising opportunity for sustainable improvements. As detailed in the previous sections, the most interesting opportunities for growth are constrained by scarcity of resources and environmental threats. Travelling will not disappear due to environmental constraints but the urgency and the pressure to change these operations into sustainable operations, saving fuel and emissions to the utmost extent, is likely to become the most dominant driver for change of air transport operations. Given the expected increase in demand, there are good opportunities to further develop airports and to accommodate air traffic demand in a sustainable and environmentally friendly way.

The main themes driving the Ultra-Green airport concept are:

- Climate changes becoming more visible, urging the need for air transport to operate in an Ultra-Green way, and whenever possible to operate in a climate-neutral way. The airport is the most visible part of the air transport industry and should not miss the opportunity to change to more sustainable and more climate-neutral operations.
- People becoming increasingly aware of the negative impact of our way of life on climate and ecology. This relates also to travelling and air transport operations, urging the need for airports to change their way of operation.
- Governments reacting on climate changes at different levels: national, European and sometimes at a global level. Governments may stimulate research and development and modernization, may give incentives for more environmentally friendly operations and may impose penalties and taxes for less environmentally friendly activities. The airports are part of the target group of actors aimed to be motivated to implement changes for environmentally friendly operations. The airport is responsible for only a small part of these threats, but is in a relatively good position to improve its operations accordingly.
- It is expected that energy, and in particular fossil fuels, will rise steeply in price. Moreover, fuel consumption is the most expensive and most environment-challenging element of today’s air transport operations already. This makes it urgent to give priority to further reduce energy consumption. The direct economic interests and the environmental interests are going hand in hand, and any improvement is welcome for the sector as well as for airport operations.
- The wish and the need for travelling is high today and will be high, or even increasing, in 2050. There is no other option than being prepared for increased demand by reducing the impact of travelling on the environment.

In summary, the airport in 2050 has to operate sustainably in daily operations as well as in its development, constructions and sometimes also dismantling of old and obsolete parts or buildings. The Ultra-Green concept aims for savings in all areas that are within the sphere of influence of airports:

- Fuel savings are possible by reducing movements and fuel consumption per movement at the airside, but also by saving energy inside the buildings and by improving efficiency in movements within the catchment area of the airport.
- Energy savings are possible whenever heat or cold can be balanced, either by saving disseminated heat from overheated areas, by storing heat/cold energy in the ground and retrieving it at the right time, or by avoiding creating heat through enhanced isolation. Also closed systems of heating and air conditioning will help to improve the energy balance of the airport.

- Waste reduction can be achieved for daily operations and long-term developments by following EU policies of waste management and life-cycle analysis, or by following a waste management strategy such as cradle-to-cradle [16][5].
- Water management is important at any airport in Europe. Improved water management systems aim to monitor water treatment and consumption; regulate flows of storm water, drainage, residues, aquifer levels, etcc....while also managing the use of drinkingwater.
- Local air quality can be improved by emission-free aircraft ground movement operations and by reducing exhaust by-products.
- Noise is one of the most important topics for acceptance of airport operations by the community living in the proximity of the airport. In reality, the majority of the noise is produced by departure/arrival operations which fall partially under the responsibility of the airport. However, the airport will be the first point-of-contact for the community regarding noise.
  Other sources of noise pollution are ground movements and engine test procedures. These will be anyhow the subject of improvement.
- Finally, the impact of the airport on the landscape (i.e. visual appearance) is for most airports not a major issue, because industrial areas are located next to it, and/or are in the proximity of cities feeding the airport. Moreover, the buildings are limited in height for safety reasons. Most beneficial is to keep the airport infrastructure designed and built as compact as possible, which is attractive also for reasons of efficiency and climate-neutral operations.

Whatever the savings in support of environmentally friendly operations at airport level are, the modern Ultra-Green airport concept must be aware of the need to improve seamless service provision for passengers and freight, and must propose to provide these services at the same speed against the lowest possible costs. Therefore, the other two airport concepts central to the 2050+ Airport project, focusing on Time-Efficient (see the Time-Efficient concept, WP4-D4.1, [14]) and Cost-Effective operations (see the Cost-Effective concept, WP4-D4.3, [15], are complementary but also overlapping. with the Ultra-Green airport concept and the. The advanced airport of 2050 should be an airport that scores ultra-high on sustainability whilst being competitive at the same time. This should lead to performance benefits in terms of environment, capacity, and efficiency, whilst preserving safety at all times. The following Table 6 lists the measurable performance parameters and their attributes relevant to all three areas of interest.

Table 6: List of applicable performance parameters and their attributes

Area	Objective	Proposed attribute	Metric
Sustainability	Keep Noise ≤legal limit	Total annual noise	[L_{den}, EPNdB]
	Reduce energy use	Energy consumed	[KWh/yr] or [GJ/yr]
	Reduce emissions	Airport emissions (NO_x, CO_2, Heavy Metals, particulate matter, etc)	[kg/yr]
	Optimal use of resources (recycling)	Volumes of waste (incidental/periodical)	[kg/yr]
	Optimal use of water	Water consumption (consumed-recycled)	[m^3/yr]

[5] "Cradle to Cradle: *refers to sustainable development [ref. 16], which* is defined in 1987 in the Brundtland-report as the development by which the present generation will obtain and realize its needs and resources without constraining future generations.

Economics	Reduce Aeronautical Cost	Aeronautical cost	[€/WLU]
	Reduce Non-aeronautical cost	Non-aeronautical cost	[€/pax]
	Increase Aeronautical income	Aeronautical revenues	[€/WLU]
	Increase Non-aeronautical income	Non-aeronautical revenues	[€/pax]
Mobility	Min. throughput time – airlines	Avg. Taxi time	[min.]
		Avg. Turn-around time	[min.]
		Avg. Delay level	[min.]
	Min. throughput time – passengers	Avg. Travel time from curb to gate	[min.]
		Avg. Queue time	[min.]
		Avg. Process time	[min.]
	Seamless Intermodality	Avg. connecting time/Total time	[-]

4 A Reference for the Ultra-Green airport concept

This chapter describes the infrastructure (section 4.1) and processes (section 4.2) that are present at an airport today to establish a reference for the Ultra-Green Concept. The airport's infrastructure and airport processes described form the baseline or reference for the Ultra-Green airport concept. This chapter also identifies the typical impact current airport operations have on the environment and the mitigation measures taken by airports today (section 4.3). Section 4.4 closes with a summary of current airport references and key challenges.

4.1 Baseline concept for present airport operations

The generic infrastructure that comprises the present day airport is depicted in Figure 4. It is important to stress that there are airport associated infrastructures that although in place at present day airports are not in the scope of the UG Concept (i.e. cargo associated infrastructure and operations), see also subsection 3.1.3.

Figure 4: Infrastructure associated with current airport description.

The main elements of the baseline airport infrastructure, subdivided in airside, landside and airport support facilities, are described below. This description follows ICAO's Airport Planning Manual [47].

4.1.1 Airside

Runways and taxiways
A medium size airport bears 1 or 2 runways (preferably in parallel) which are connected with the apron by several taxiways and rapid exit taxiways. In case of parallel runways with sufficient spacing, or non-parallel but also non-crossing runways, an airport may be able to operate independent take-offs and landings in both directions. It is assumed that for the design of the runway, the airport has followed the recommendations set at ICAO's (International civil Aviation Organization) Annex 14 [36]: "*The sitting and orientation of runways at an aerodrome should, where possible, be such that the arrival and departure tracks minimize the interference with areas approved for residential use and other noise sensitive areas close to the aerodrome".*

Apron
ICAO's Annex 14 defines the apron as an area intended to accommodate aircraft for purposes of loading and unloading passengers, mail or cargo, fuelling, parking and maintenance. These activities are known as turnaround. The processes and operations that are carried out at the apron are explained in section 4.2.

Air and ground navigation and traffic control
The airport has facilities to support the air traffic control system, navigation aids for aircraft approaching the airport and facilities to control aircraft and vehicles on the surface of the airport. In order to give service to IFR (Instrument Flying Rules) flights, the airport will have installed an Instrument Landing System (ILS), a combination of VHF (Very High Frequency) Omnidirectional radio ranges (VOR)/ distance measuring equipment facilities (DME) together with secondary, multilateration and/or surveillance type radars.

According to ICAO's 9184 document, aids to navigation, approach and landing are an essential element of the air transport system. Non-visual (electronic) aids for guidance, especially under low cloud ceiling and restricted visibility conditions, are more significant from an airport siting viewpoint because of the clearances required from the objects (power lines, large buildings, moving vehicles, etc.) which can affect their reliability of operation. They have to be located relatively close to the airport, airspace and served aircraft flight paths; potential locations should also include suitable areas for their installations [37].

In controlled European airspace and recognised as state-of-the-art airports by 2020, advanced A-SMGCS[6] (Advanced Surface Management Ground Control System) services will be available. All ATM services for access to busy airports will be supported by advanced ATM service provision at the level defined by SESAR in 2030 and beyond [53].

4.1.2 Landside

Terminal buildings (passenger)
The generic airport passenger terminal serves about 10-15 million passengers per year (Table 3), consisting mainly of Origin-Destination (O/D) passengers, with a limited amount of transfers. The terminal is capable to accommodate international and domestic flights (and Schengen and non-Schengen operations for European purposes). The terminal offers both jet bridges (fingers) and remote stands (for size definition see Table 1).

Ground transport and parking
The definition of ground transport at the landside area includes all the means of transport used internally between the curbside and the airside. Even transport from the intermodal stations located at

[6] A system providing routing, guidance and surveillance for the control of aircraft and vehicles in order to maintain the declared surface movement rate under all weather conditions within the aerodrome visibility operational level (AVOL) while maintaining the required level of safety.

the premises of the airport and/or the airport parking area can be included as such: e.g. Automatic People Movers between Heathrow parking and Terminal 5; internal trains communicating the main terminal with the satellites; buses communicating the different terminals.

4.1.3 Airport support facilities

This section describes a number of facilities and buildings for special purposes that are necessary to support the operation of an airport. The need for the building and facilities described will vary from airport to airport, as will the specific space requirements. The baseline airport is composed of the following facilities:

Rescue and Fire Fighting facilities

The airport fire station provides facilities for housing the rescue and fire fighting equipment and personnel. The equipment, amounts of extinguishing agents and number of vehicles and personnel is determined by the category which in turn is primarily determined by the number and length of the airplanes.

The fire fighting and emergency control centre is comprised of an office with a storage warehouse and parking area and may or may not have a vehicle maintenance area for the rescue and fire fighting vehicles.

Airport staff buildings

The airport staff facilities are built preferably independently from the terminal building. The baseline airport has an office block where administration, financial, operation, engineering, aviation safety, information system, and security departments are located. Handling agents and other companies working at the airport may occupy separate office buildings.

Aircraft maintenance facilities

Hangars are used to provide maintenance and repair services to aircraft. Aircraft maintenance facilities are hard covered and they consist of a workshop with a separate waste management area. They are located compatibly with taxiway systems to avoid aircraft having to cross runways and the furthest away possible from residential areas.

Ground support equipment facilities

The ground support equipment (GSE) are vehicles whose function is loading and unloading of goods, loading and unloading of passenger, water supply, airport waste water drainage, fuelling, maintenance and review of airframe.

Fauna control

Birds can seriously damage engines and aircraft windows and present an extreme hazard that needs to be prevented. Airports have used different methods to prevent bird strikes, such as broadcasting the cries of birds of prey or using fireworks. These are good as temporary measures however, since birds get used to living with these so-called threats leading to a return of the danger of collision. For small airports, falconry has been found to be effective to prevent this hazard. Such airports use a falconry service consisting of falconers, tracking dogs and a team of falcons and hawks. Larger airports (e.g. Amsterdam Airport Schiphol) may also employ – apart from sonic devices and the use of border collies - a so-called bird controller shooting in the air to scare birds away. The building that hosts the animals is of the size of a small warehouse.

Waste management facilities

The disposal of environmentally harmful materials used in aircraft servicing and maintenance and of waste from airport operations should be managed effectively. Although airports are not usually considered industrial complexes as such, waste management facilities have to be suitable to store and manage a significant amount of hazardous and non-hazardous waste. The waste storage area is a hard-covered area with containers suitable for the types of waste generated at the airport. Other devices, such as compactors and shredders, could be also in place to decrease waste volume.

Water management facilities
The airport must be supplied with adequate water and a sewage disposal system for handling and treating waste. Water supply is usually purchased off site, although in areas with water scarcity, airports may have desalination plants on site. A separated waste water and rainwater network is usually present at airports, where oil separators and other measures are in place to avoid water and soil contamination. Depending on the amount of sewage and rainwater discharge, the airport could have a sewage treatment plant on site.

De-icing and anti-icing facilities
According to ICAO's manual of aircraft ground de-icing and anti-icing operations [41], de-icing is the process which removes ice, snow, slush or frost from aeroplane surfaces. This may be accomplished by mechanical methods, or by pneumatic methods or through the use of heated fluids. Mechanical methods may be preferred under extremely cold conditions or when it has been determined that the frozen contaminant is not adhering to the aeroplane surfaces. When using heated fluids and optimum heat transfer is desired, fluids should be applied at a distance from the aeroplane surfaces in accordance with the approved operator procedure and fluid manufacterer recommendations.

On the other hand anti-icing is a precautionary procedure by which clean aeroplane surfaces are protected against the formation of ice and frost accumulation of snow and slush for a limited period of time by spraying fluids on these surfaces.

In some airports where icy and snowy weather conditions are constant, underground heating may also be used to make sure the operational surfaces are always kept operational. In addition, different tarmacs and asphalts may be in use, mitigating the forming/sticking of ice and the wear and tear due to sharp changes in temperature.

De-icing / anti-icing facilities have the following components [41]:

- De-icing / anti-icing pads for the manoeuvring of aeroplanes
- De-icing / anti-icing system comprising mobile and / or fixed equipment
- Bypass taxiing capability
- Environmental run-off mitigation measures
- Permanent or portable night-time lighting system and
- Support facilities such as storage tanks and transfer systems for de-icing / anti-icing fluids and de-icing crew shelter.

Ground vehicle fuel stations and aircraft fuel facilities.
Aircraft fuel supply and storage at the baseline airport consists of underground and/or above ground storage tanks and a well distributed network of fuel lines and pumps to offer fuel readily on the platform to the aircraft. Fuel trucks could be used for refuelling purposes at remote stands.

A separate station for airport vehicles fuelling purposes could also be present at the airport. This service can be either at the airside or landside. The facility has underground fuel tanks, fuel lines and pumps just like the typical petrol filling station. Wherever the petrol filling is carried out, oil separators are in place to avoid rainwater contamination.

Lighting (airfield)
The lighting on runways, taxiways, at stop-bars and at other crossing points is in operation when the services are made available. This is costly, consumes energy, and may have an impact on the natural habitat during the night, but due to safety reasons a reduction of light is hardly possible. Lighting should meet the requirements of the Directive 2005/32/EC of the European Parliament and of the Council and Commission Regulation (EC) 245/2009 [22] and in particular ICAO's Annex 14 [36].

Power generating stations

The energy consumed at an airport comes from the electricity grid or is generated locally through self-contained power stations based on hydrocarbon fuel or renewables. Electricity can be purchased from off-site producers or produced on-site, however, the airport has emergency energy generation facilities, which are hydrocarbon fuelled.

General aviation facilities
General aviation is defined as all civil flying not classified as commercial air carrier and includes many different type and use of categories of aircraft. General aviation includes such diverse activities as personal flying, transportation of personnel and cargo by privately owned aircraft, air taxi and agricultural flying, search and rescue flying, governmental flights, and instructional flying. General aviation facilities could comprise a separate terminal building and apron [37].

Control tower
The provision of airport control service requires a clear and unobstructed view of the entire movement area of the airport and of air traffic in the vicinity of the airport. The airport control tower is located and of such height that aprons, taxiways, runways and airspace surrounding the airport, particularly approach and departure areas, are clearly visible from the control room.

Intermodal infrastructure
Airports are increasingly offering connectivity for railway systems and other public means of transport:

- High-speed train connections
- National and regional connections by train
- Local connections by Train, Underground and Light-rail systems
- Busses, taxis, shuttle services

4.2 Baseline for current airport processes

With regard to the airport operations, there are processes that are present today that are not foreseen to change in the future. These so-called invariant processes are shown in Figure 5.

Four main areas can be identified. The intermodal area comprises the process of getting passengers from and to the airport. Airport services can be grouped in two categories: airside and landside. Airside services include landing, take-off, and aircraft turnaround. Landside services include the various passenger services and deboarding and boarding facilities. Air Traffic Management (ATM) is also included as one of the processes. Changes to any of the discussed areas may also imply changes to the infrastructure of the airport. Below, the processes most suited for sustainability improvement are described in some detail.

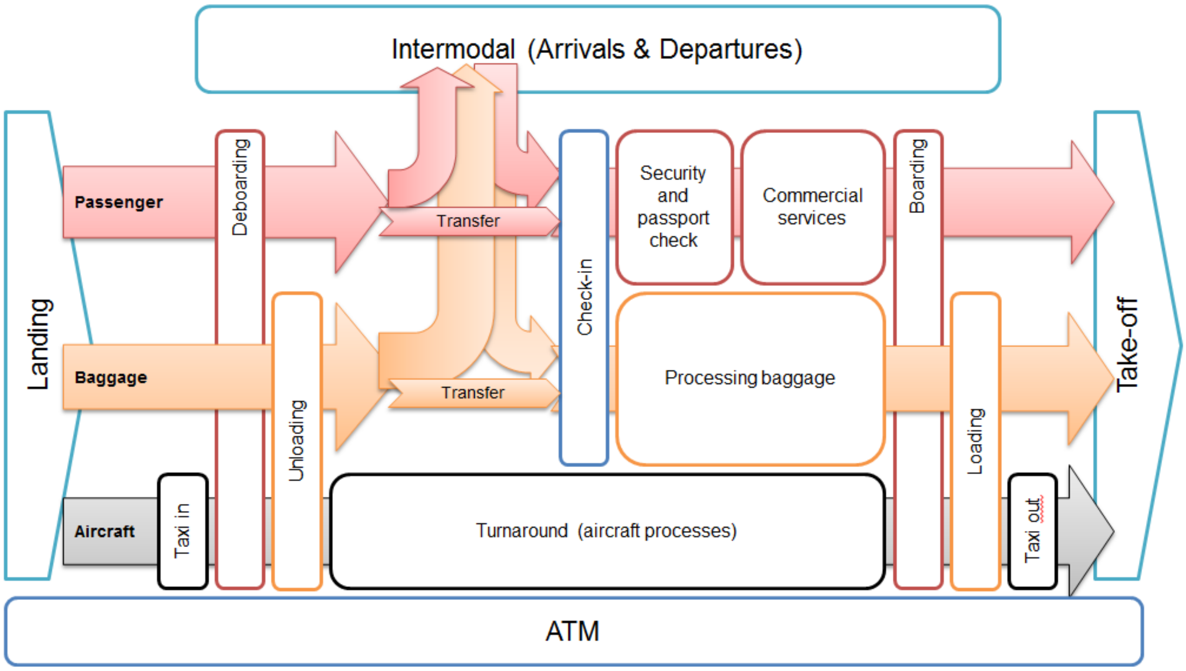


Figure 5: Invariant processes framework for which solutions are developed. See: [13].

4.2.1 Landing and Take-off operations

Strictly speaking, landing and take-off procedures are ATM related but they have been considered under the UG concept as the start and end points of the processes that occur at the airport.

The standard LTO (Landing/Take-Off) Cycle begins when the aircraft crosses into the mixing zone (or 3000 ft) as it approaches the airport on its descent from cruising altitude, lands and taxis to the gate. The cycle continues after turnaround when the aircraft taxis to the runway for take-off and climb-out as it heads out for the mixing zone (or 3,000 ft) and back up to cruising altitude. Figure 6 bellow illustrates this cycle.

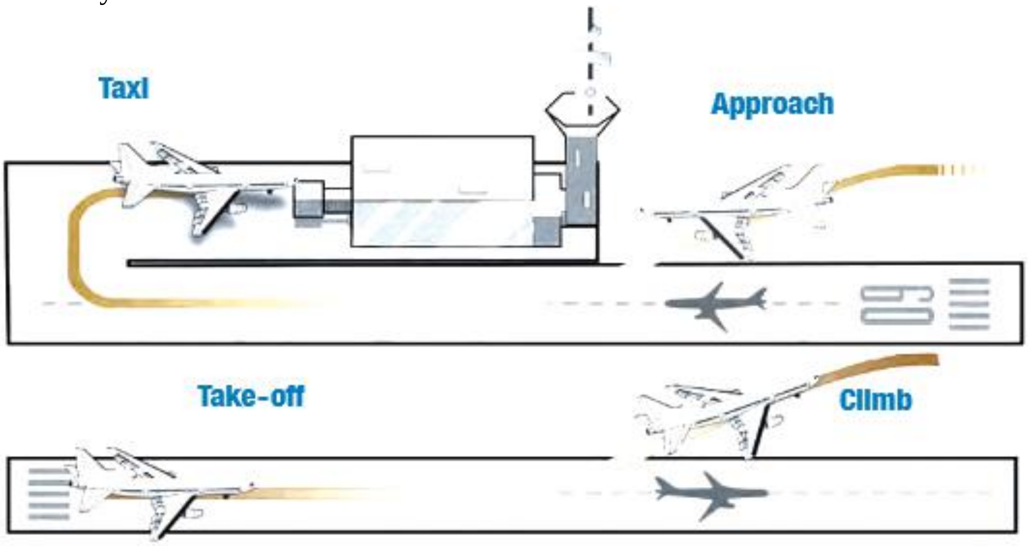


Figure 6: LTO cycle, source: [40].

4.2.2 Airfield Ground operations

Ground operations, in particular taxiing if not accurately planned, could lead to waste of fuel and to congestion at aprons and taxiways, as well as at the holding point. Aircraft engines are used at present to execute the movements over apron and taxiways under control of the pilot; the aircraft turbofan engines have however a low efficiency at the (near) idle power settings used in ground movement operations.

The handling of aircraft on the manoeuvring areas and the aprons of an airport during taxi and turnaround are to be made as efficient as possible. The soaring environmental awareness of the public in combination with the increased airlines' need to economise today, force aircraft operators as well as airports to consider new technology and procedures such as e.g. the use of an electrically driven nose wheel.

In the absence of a particular drive system for ground movements, aircraft today depend on their engines or towing vehicles during ground operation. On departure usually a pushback is required first for nose-in stands, followed by the start-up of the engines. Depending on the procedures of the respective airport, these two steps can either be executed successively or simultaneously. When the pushback is completed, the towing vehicle has to be detached and driven to a safe distance from the aircraft, where the pilot is notified by a hand signal that the plane is correctly prepared for its taxi. Depending on the size of the aircraft and the total idle thrust of the engines, the pilot either simply releases the brakes to start moving or applies additional thrust to overcome the breakaway torque. Afterwards, the produced thrust of all engines, even in idle, is sufficient in most cases to slightly accelerate the aircraft once it is moving. The last step, besides pushback, engine start and taxi, is the warm-up of the main engines. Depending on the specifications of the manufacturer, jet engines have to be warmed-up for a certain period of time to reduce thermal stress during take-off, when the highest thrust settings are required, in order to reduce the expenses for maintenance. Since the taxi-out is usually performed with all engines running, the complete time needed to taxi to the departure runway can be considered as warm-up period. Only on extremely short distances some additional time for this step is needed.

On arrival there are only three relevant steps to complete before parking the aircraft at the stand: taxi-in, engine cool-down and shutdown. The taxi phase begins in principle after landing when the aircraft has decelerated to taxi speed and vacated the runway, and lasts until arrival at the parking position. Simultaneously, the cool-down phase of the engines takes place, which again lasts for a specified period of time according to the specifications of the manufacturer. When the engine cool-down time has elapsed and the aircraft has arrived at the parking stand, the engines are switched off.

Sometimes there are variations in the aforementioned procedures. If an aircraft can leave the parking position on its own, e.g. by using reverse thrust of its variable-pitch propellers or in case of a drive-through position, the pushback step is not required and the engines are started-up right at the gate. Furthermore, the taxi phases can be performed as single-engine taxi if the prevailing conditions permit (in case of twin-engine aircraft or a subset of engines if more than two are installed). Conditions such as icing, rain or slush on taxiways disallow taxiing on a reduced number of engines but also company procedures often prohibit single-engine taxiing. Experience shows that this procedure is mainly used on taxi-in, especially in case of twin-jets.

Furthermore, the Auxiliary Power Unit is used for several functions at an aircraft in parking position. It provides the necessary energy for cockpit, cabin and air condition as well as the power for engine start.

By providing 400 Hz energy supply and preheated air at all stands, an airport can reduce the need for APU (Auxiliary power unit) use and therefore, the impact on the environment. Some airports have air start units (ASUs) and ground power units to provide the energy and compressed air required for the aircraft to avoid the use of the APU.

Figure 7 below shows the different processes that occur at the airport.

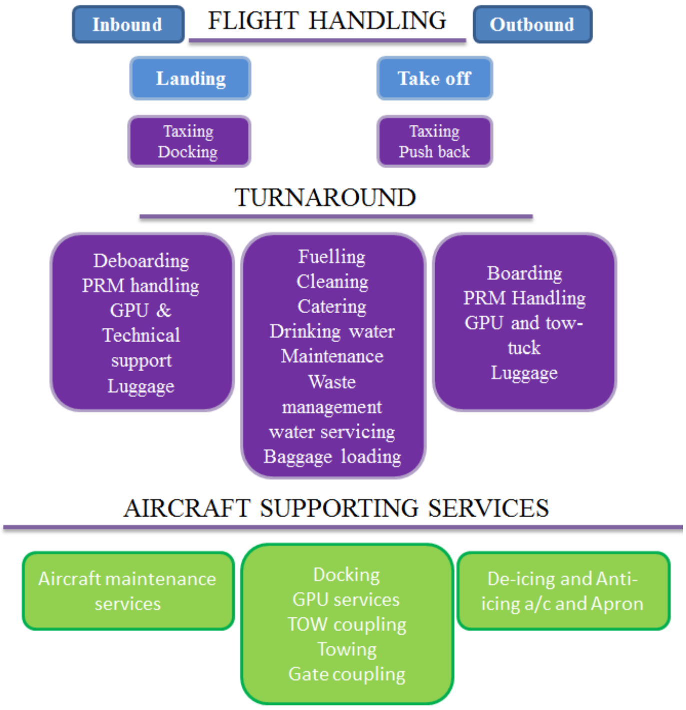


Figure 7: Proposed decomposition of airside airport processes

4.2.3 Apron and Turnaround management

Once aircraft arrive at the gate or parking spot the turnaround services are started. The turnaround prepares the aircraft for the next flight [43]. During the turnaround a number of services are performed in parallel or in sequence. According to the IATA (International Air Transport Association) Airport Handling Manual [35] the following activities are relevant in the turnaround process:

- Load control.
- Passenger handling during arrival and departure, including the checking of travel documentation, registering carry-on luggage, and the transport of passengers between the aircraft and the terminal building and vice versa.
- Baggage handling including loading and unloading, and transporting baggage between the aircraft and the baggage handling system.
- Freight handling including loading and unloading, and transporting freight between the aircraft and the freight handling system/area.
- Consumables/waste handling including loading and unloading, and transporting between the aircraft and the appropriate handling area.
- Marshalling the aircraft on the apron during arrival and departure.
- Aircraft parking assistance.
- Provision and operation of systems for electricity, engine start assistance, and cooling and heating of the cabin.
- The movement of aircraft in between arrival and departure at the gate or parking.
- External and internal cleaning of the aircraft.
- De-icing of the aircraft at the gate or parking spot.
- Fuelling operations and storage.
- Minor maintenance activities.
- Engine start.

Whenever possible the tasks of the turnaround process are done in parallel to shorten the turnaround time, but some tasks need to be done sequentially. In general, the following three sequential activities are on the critical path in the turnaround process and determine the bulk of the turnaround duration:

1. De-boarding passengers,
2. Fuelling, and
3. Boarding passengers.

These activities are quite often sequential because, for example, regulations require precautionary measures when refuelling is done with passengers still on board

4.2.4 Maintenance and repairing the aircraft

Hangars are used to provide maintenance and repair services to aircraft. This work is diverse and complicated in many respects, involving qualified labour to ensure safe aircraft operations. Related to this work, there are many issues concerning safety aspects, environmental aspects (such as waste production and management and noise nuisance).

4.2.5 FOD control, recovery and clearance

Foreign object debris (FOD) is any object that does not belong in or near airplanes and as a result, can injure airport or airline personnel and damage airplanes. FOD includes a wide range of material, including loose hardware, pavement fragments, catering supplies, building materials, rocks, sand pieces of luggage, and even wildlife. Airports usually have a FOD prevention programme where control, recovery and clearance of FOD is carried out. This prevention programme, apart from training and housekeeping measures, also states the frequency for cleaning of runways, taxiways, and in general, all areas at the airfield. These recovery and clearance works are carried out by sweepers and magnets amongst other ground support equipment.

4.2.6 Water and Waste management

Airport pollution generating activities are:

- Fuelling, maintenance and washing of vehicles, equipment and aircraft
- Aircraft lavatory servicing
- Runway, buildings and grounds maintenance.
- Outdoor storage and handling of wastes generated through operations.
- Aircraft and airfield de-icing and anti-icing
- General waste and rubbish handling

The waste generated by the activities carried out at the airport follow different management paths depending on their nature. Domestic waste could be managed by the municipality. The reuse and recycling options of hazardous and non-hazardous waste will depend on the quantities generated, and market options.

Depending on local conditions, each airport adopts different options to manage sanitary waste water and rainwater. Depending on the volumes of waste water generated, the airport could consider building and operating a sewage treatment work *in-situ* or apply for a permit to discharge water into the closest municipal sewage treatment works. The largest source of sanitary waste water is from terminal operations and lavatory waste from aircraft. Aircraft lavatory waste contains chemical deodorant as well as glycol to prevent it from freezing, apart from human waste.

Depending on local conditions and precipitation rates, the airport could have detention ponds. Run-off within the airport site and to the surrounding areas must be controlled utilizing flow control and water detention technologies to prevent flooding of the airport site and surrounding land. To avoid rainwater contamination, rainwater management is completed with the implementation of oil separators down gradient from the areas where fuelling, maintenance and washing of vehicles, equipment and aircraft is taking place, bio swales and filter strips[7].

[7] Specifically designed ditch with engineered fill used to remove sediments and other suspended solids.

4.2.7 Anti-icing and de-icing operations

Aircraft ground de-/anti-icing procedures serve three purposes:

1. removal of any frozen or semi-frozen moisture from critical external surfaces of an aircraft on the ground prior to flight;
2. and/or, protection of those surfaces from the effects of such issues for the period between treatment and becoming airborne;
3. and/or removal of any frozen or semi-frozen moisture from engine intakes and fan blades and protection of external surfaces from subsequent contamination prior to take-off [5].

This service is given to the aircraft - depending on the airport, the requirements and the weather - either at a centralised pad (see section 4.1.3) or by specific trucks which are moved to the aircraft parking station.
Several of the de-icing and anti-icing products available today are non-toxic, but they may cause serious damage to the environment in and around the airport, that is why special pads are constructed and the airport is provided with a special drainage system.

The same service is also applied to runways and taxiways although more mechanical and salt-based products (e.g. glycols) are used.

4.3 Environmental impacts and management associated with current airport operations

This section focuses on the environmental problems related to airport and some aircraft operations. It identifies the major environmental issues including working conditions of airport employees and the airport's environmental conditions on site and at its surroundings. These impacts are depicted in Figure 8 below.

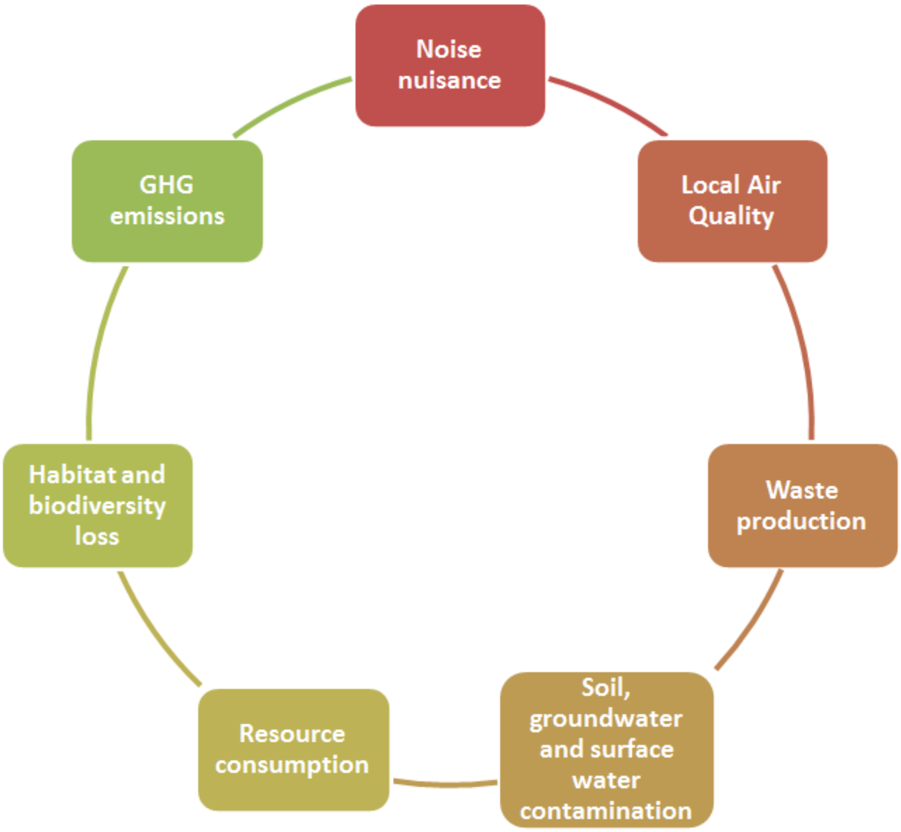


Figure 8: Airport operations environmental impacts.

For each environmental issue presented, a brief description is given including the typical compensation and mitigation measures currently taken to minimise their effects. As depicted in Figure 8, the environmental impacts arising from the operation of an airport are diverse and include:

- Noise nuisance
- Local air quality in the vicinity of the airport.
- GHG (Greenhouse Gas) emissions from energy consumption and vehicle use
- Resource use including water, energy and other consumables.
- Waste production, prevention and management of solid and liquid waste
- Soil contamination, groundwater and surface water pollution.
- Habitat and biodiversity losses.

4.3.1 Noise, nuisance and management.

Since the introduction of jet aircraft, noise has been considered to be perhaps the most important environmental and social problem associated with civil aviation [38]. Under the European Directive 2002/49/EC [20], referred to as the Environmental Noise Directive (END), major airports[8] have to produce strategic noise maps and draw up action plans designed to manage noise issues and effects, including noise reduction measures if necessary.

Noise sources from ground-based airport activities include aircraft start-up, taxiing, engine testing, auxiliary power unit use, ground service equipment, road traffic and mechanical installation such as power generation and heat/cooling station.

In general, airport operators have little control over the noise the aircraft generates. In order to decrease noise emissions from the main sources, during take-off and landing operations, European airports have gradually implemented the “balanced approach” criteria promoted by the ICAO [39]. This balanced approach gives airports a flexible way to identify specific noise problems and corresponding measures targeted and tailored to the individual airport situation.

The Balanced Approach

The balanced approach encompasses four principal elements:

- Noise reduction at the source.
- Operational procedures for noise abatement.
- Territorial management and planning.
- The introduction of operating restrictions.

The airport has very limited possibilities to reduce aircraft noise at its source; it can however implement operational procedures and operating restriction for noise abatement.

In the ICAO Balanced Approach, operational restrictions are defined as noise related actions that limit or reduce an aircraft’s access to an airport.

For example, the selection of specified approach and take-off paths and the modification of engine thrust settings for certain operational phases are commonly employed [38]. In general, operational restrictions may include the following:

- Noise quotas expressed as a limit in the number of movements during a period or as a noise limit or a combination of the two.
- Restrictions on specific types of flights during specific periods (training flights on weekends)
- Restrictions on a runway operation based on weight or time of day or single event noise levels.
- The prohibition of departures from or landings on a runway or an airport during specific night time hours.

[8] ‘major airport’ shall mean a civil airport, designated by the Member State, which has more than 50 000 movements per year (a movement being a take-off or a landing), excluding those purely for training purposes on light aircraft.

In addition to the measures that attack noise at its source through certification, operational measures and scheduling, it is possible to reduce the effects of noise by land-use planning and acoustical barriers (natural and/or artificial). For instance, engine start-up and taxiing noise can sometimes be screened by bunds, acoustic fences or screens. Such measures are beneficial if receiver locations are close to the noise source (within 50 or 100m) and have a direct line-of-sight to the noise source. According to ICAO [38] trees may be planted to screen certain areas from some airport noise.

With respect to the occupational noise levels, the measures in place are similar to the ones adopted at noise work places. Whenever possible it is advisable to separate people from the hazard by physically isolating the noise source. Otherwise, earmuffs are compulsory worn wherever noise is an issue.

Example of noise action plan

As an example of a current day Noise Action Plan, Frankfurt's pioneering active noise abatement plan [2] consists of the following measures:

1. Vertical optimisation of departure procedures
2. Dedicated runway operations (DROPS). Preferred runway operations give affected communities breaks from noise at night. This is done on odd days of the month during low-traffic hours between 23:00 and 5:00. All flights leaving towards the west (operating direction 25) take off from the parallel runway system and none of them from runway 18 West. All take-offs towards the east (operating direction 07) are form runway 18 West.
3. Segmented RNAV (Area Navigation) approach procedure: A segmented RNAV (GPS [Global Positioning System]) approach procedure bypasses densely populated areas by relocating approach paths and using Continuous Descent Approaches (CDAs).
4. Tailwind component: A tailwind component will be factored in to increase westerly traffic. In this stage, the current limit of five knots of tailwind will be used to relieve the most affected communities in the western vicinity. In the second stage, the tailwind limit will be increased to seven knots, pending approval by ICAO. The increased tailwind component may be implemented in 2012.
5. Greater utilisation of Continuous Descent Approach
6. Increased ILS Glide path angle to runway northwest: This involves increasing the ILS glide path angle for the new Runway Northwest to up to 3.2 degrees. The steeper approach will mean that aircraft are at a higher altitude of about 60 m, eight miles before reaching the touchdown zone. Currently the glide path has a slope of 3.0 degrees.
7. Modification of Lufthansa's Boeing 737 fleet: this measure will decrease noise emissions. Noise reducing panels on Boeing 737 engines reduce the noise level by 2.4 dB during landing and by between 0.5 and 1.5 dB during take-off.

4.3.2 Local air quality (LAQ) in the vicinity of the airport.

Air quality in the vicinity of airports is affected by the following:

- aircraft engine emissions,
- emissions from airport motor vehicle and access traffic, and
- emissions from other facility operations (such as terminal buildings, cargo, and maintenance facilities, heating, etc...)

Airports, either by the transposition of the EU directive 2008/50/EC [19] on ambient air quality and cleaner air for Europe or as a condition for granting environmental permission are required to assess local air quality conditions. The air quality at the airport and to a less extend in the direct vicinity of the airport is significantly affected by the Landing/Take-off (LTO) aircraft cycle, while in terms of particulate matter (PM_{10} ,Particulate Matter of 10 micrometer or less, and $PM_{2.5}$), Ground Service Equipment (GSE) and Auxiliary Power Units (APUs) also have significant impact on the local air quality (LAQ) at the airport.

The airport can improve the LAQ by the implementation of different types of measures. Table 7, below, gathers measures that can be implemented, depending on the emission source:

Table 7: List of applicable LAQ improvement measures[9].

Source	Measure type	Measure
Air Traffic	**Operational**	Scheduling improvements to reduce queuing
		Holding aircraft at terminal gates until departure slot is ready
		Single engine or reduced engine taxi
		Reduce engine idling time
		Aircraft towing to reduce taxiing with engines
	Technical	General airport layout keeping terminals central to runways to reduce taxiing times
		Taxiways improvements including high speed runway turn-offs and taxiways parallel to runways to reduce aircraft queuing
	Economic	Landing fees/charges can be scaled depending on the levels of emissions from each aircraft type based on engine certification or detailed calculations
Ground Support Equipment	**Operational**	Reduction of vehicle idling using education or anti-idling by laws.
		Efficient scheduling to reduce equipment travel and waiting times
	Technical	Efficient airport layout to minimize travel distances
		Providing 400 Hz fixed electrical ground power and pre-conditioned air at aircraft gates and stands to replace aircraft APU usage
		Providing infrastructure for alternative fuel GSE and fleet vehicle (Natural Gas, LPG (Liquefied Petroleum Gas), hydrogen, compressed air, hybrid)
		Modernizing airport owned vehicles and encouraging stakeholders to do so
	Economic	Fees charges or rebates to incentive stakeholders to modernize their equipment with more efficient models that emit less pollutants
Airport Operational Infrastructure	**Operational**	High vehicle maintenance standards
		Low emissions procedures for operational activities such as maintenance, painting and cleaning
		Driver education and training on efficient vehicle driving
		Limiting to a minimum the amount of fuel used at the fire fighting training
	Technical	Low emission power / heating plants
		Energy conservation measures in terminal and apron areas including efficient lighting and "smart" building technologies
		Purchase and use of high efficiency, low emissions and alternative fuel vehicles
	Economic	Financial penalties and fines for exceeding regulatory standards.

[9] Ineco elaboration based on ACI International, Airports Environmental Management course 2010.

Source	Measure type	Measure
Ground Access Traffic	**Operational**	Consolidation of hotel and rental car shuttle buses
		Idling restrictions
		Employee rideshare and cycling incentives
		Priority queuing for low emission taxis
		Discouraging passenger drop off including one-way taxi trips
	Technical	Road layout and design that reduces distances and congestion
		Dedicated public transit lanes
		Enhanced public transit and inter-modal connections
		Providing infrastructure for alternative fuel for vehicles
	Economic	Parking pricing and subsidies for low emissions vehicles
		Public transit subsidies and incentives for employees and public.

Air pollution originating from aircraft engine testing and maintenance facilities may be controlled through the use of test cells equipped with afterburners and catalytic converters [38].

4.3.3 GHG emissions from energy consumption and vehicle use

Airport power plant, fleet vehicles, maintenance of airport infrastructure, ground support equipment, emergency power, fire practise and waste disposal on-site are GHG emissions sources at the airport. There are other sources that, although they are not under direct control, the airport can nevertheless influence. Those emission sources are:

- Aircraft main engines
- APUs
- Landside road traffic/ground access vehicles
- Airside vehicle traffic
- Contractor owned GSEs
- Waste disposed of site.

The Airport Council International (ACI) Europe committed on 2009 to establish and operate a European wide scheme allowing airports to follow a common framework for the measurement, reporting and reduction of carbon emissions with the possibility of becoming carbon neutral.

The Airport Carbon Accreditation assesses and recognises the efforts of airports to manage and reduce their carbon emissions with four levels of certification: 'Mapping', 'Reduction', 'Optimisation' and 'Neutrality'.

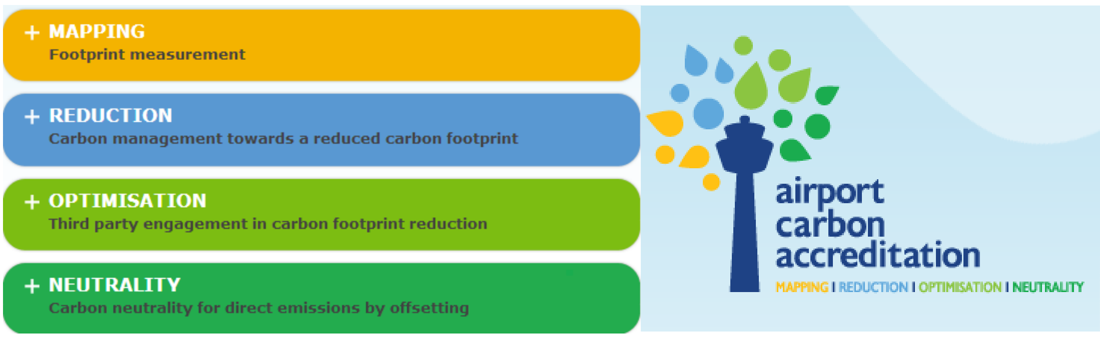


Figure 9: Airport carbon scopes and levels of accreditation, source: [61]

Up until June 2013, 74 European Airports have been Airport Carbon Accredited to at least the mapping level. These airports have calculated and mapped their emissions and have set objectives for reducing their impact on CO_2 emission levels.

Energy and power needs
Airports are currently upgrading the power, heating and cooling plants to improve efficiency. Also, they are preferably consuming energy from renewable sources such as wind, solar, hydroelectric, geothermal or biomass (e.g. Arlanda airport, Tenerife Airport).

Airport buildings are also increasingly being designed to be “smart” and energy efficient according to standards such as LEED (Leadership in Environment and Energy Design) or BREEAM (BRE Environmental Assessment Method), since the airport emissions are generally dominated by electricity, consumed to provide power and heating or cooling to buildings and to operate ground vehicles and facilities.

Other measures taken by airports to reduce the GHG emissions are gathered on Table 8:

Table 8: GHG emission management measures[10].

Source	Measures
Airport operator's emissions	Modernization of the power, heating and cooling plants to improve efficiency
	The generation, use or purchase of electricity, heating and cooling from renewable energy sources, including wind, solar, hydroelectric, geothermal and biomass.
	The design, inclusion or retrofitting of “smart” and energy efficient buildings and component technologies such as double-glazing, window tinting, variable shading, natural lighting, LED (Light Emitting Diode) lighting, absorption-cycle refrigeration, etc.
	Modernization of fleet vehicles and ground service vehicles including the use of alternative fuels such as compressed natural gas, hydrogen electric, compressed air and hybrid.
	Driver education on fuel conserving driving techniques
Non-aircraft emissions These emissions are dominated by ground transportation.	Provision of public transport
	Educational campaigns and or by laws to reduce vehicle idling, taxi dead-heading (one way trips) and individual passenger drop off
	Facilitating hotel and rental car agency shuttle bus
	Encouragement of alternative fuel or hybrid taxis, rental and other cars, using incentives such as priority queuing, parking cost reduction and priority parking areas.
	Providing infrastructure to fuel and power low emission vehicles including recharging stations
	Establishing working groups with business partners to share best practices and responsibilities.
Aircraft emissions Airport operators can contribute to decrease in emissions from taxiing and auxiliary power unit (APU) usage of the aircraft	Providing and enforcing the use of fixed electrical ground power and pre-conditioned air (PCA) supply to aircraft at terminal gates allowing APU switch off (APU ban)
	Improvements in aircraft taxiways, terminal and runway configuration that lead to reduced taxiing distance and ground and terminal congestion
	Departure management including holding aircraft at the gate (with APU turned off) until departure slot is ready.
	Arrival management that provides gates for aircraft as close as possible to the runway

10 Elaboration by Ineco, based on [ref. 3].

Source	Measures
	Coordinating with aircraft operators and ATM to improve arrival and departure procedures and flow, especially in working with stakeholders on the value of trade-offs between stakeholders' objectives.
	Engaging passengers to off-set their share of trip emissions via on-site carbon calculation and program to pay an offset fee for local GHG improvements.

4.3.4 Use of resources

Resources such as water and energy are significantly consumed at the airport. Other resources (e.g. soils) are used in a lesser extent.

Airports consume significant quantities of water providing basic services to passengers, staff and infrastructures. Water is no longer seen as an unlimited resource and the cost of water supply increases. Airports are managing their consumption of water for the direct commercial benefits of reducing costs and as part of their sustainable development.

On terms of resource management, there are two fundamental approaches to potable water management and conservation.

1. Reducing the use of potable water
2. Replacing the use of potable water with other sources of water such as the collection and reuse of rainwater, treated waste water and recycled cooling water.

The main indoor uses of potable water occur in toilets, kitchen and for general cleaning throughout airport buildings and terminals. Typical conservation measures include [1]:

- The use of low flow fixtures for wash basing taps
- Replacement of timer based urinal flushing system with detector controlled systems or the use of waterless urinals.
- Installation of low consumption dual flush toilets.
- On-going maintenance of plumbing fixtures so that they shut off properly and do not leak or drip.
- The use of recycled water for washing ground support equipment and vehicles.

Ideally, high quality potable water should not be used for irrigation. In these situations the use of non-potable water (storm water or recycled water) should be used whenever possible. If this is impractical, there are number of ways to reduce water consumption including:

- Reduce the need for watering landscaping vegetation by selecting low maintenance plants. Plants native to local region are best for outdoor areas
- Water required for road construction and dust suppression should be carefully planned to take advantage of non-potable sources of water when environmentally acceptable.
- Avoid excessive watering that causes run-off
- Reduce evaporation loss by watering early in the morning or late in the evening. Up to 50% of the water applied to lawns and gardens can be lost due to evaporation or run off due to over watering.
- The use of drip or tickle irrigation which tends to be more efficient and uses less water than spraying or sprinkling.
- The modernization of cooling towers for technological and efficiency improvements.

In terms of energy consumption and conservation, the majority of energy used at an airport is associated with the provision of ventilation, air conditioning, heating and lighting. According to ICAO 2002, the essential services such as airfield lighting and instrumentation use a relatively small amount of energy. It is estimated that energy costs account of about 5% of the operating costs of a modern airport.

Electricity is usually purchased from off-site producers so any reduction in the consumption of electricity will represent a direct cost saving for the airport operator. Some large airports have their own power stations, such as Madrid – Barajas Airport in Spain. The Cogeneration plant at this airport is more efficient than a utility operated central power plant since thermal energy that would otherwise be wasted is captured for use at the facility. The result is a much more efficient use of fuel which can generate substantial savings for the airport [49].

Apart from cost savings, electricity use reduction will also improve local air quality and reduce GHG emissions.Table 9 below summarizes a number of energy savings measures:

Table 9: Energy consumption management measures[11].

Energy Consumption Management	
Reduction	Avoiding unnecessary energy use (switching lights off in unoccupied areas an improving thermal insulation of buildings)
	Modernizing equipment
Reuse	Using warm water from power station for winter heating or driving absorption cycle refrigeration systems
	Heat pumps that draw heat from the ground in winter and provide cooling in summer
Recycling	Generating electricity from renewable source such as wind, solar and geothermal
	Using the heat from incinerated waste for heating and electricity generation

Alternative/renewable energy sources used and available to airports
Depending on the location and resources available at the airport and its surroundings, alternative energy sources to reduce the consumption of energy at the airport could be the following:

Solar photovoltaic
Solar PV (Photovoltaic) cells convert the energy from sunlight to electrical energy. PV is successfully used in airports and does not pose an obstruction risk to aircraft or radar systems. PV cells have been successfully used at Munich airport [48] and other airports.

Wind turbines
Produce energy by converting the force of the wind into electricity. They have the capacity to produce large amounts of electricity. This technology may not meet all airports zoning regulations and may pose an obstruction risk to aircrafts or radars if not located properly [29]. Wind turbines have been successfully installed at some airports.

Geothermal
Energy is derived from the earth's natural internal heat and requires specific geological conditions. There are various types of geothermal technologies designed to access this heat energy and then utilise it to generate electricity or supply hot water. At Paris-Orly, a geothermal energy plant is in operation since 2011 enabling the airport to reduce greenhouse emissions by 9,000 tonnes of CO_2 per year [45].

Energy from waste
Waste to energy generation. Waste materials can be used to generate heat and electricity.

Combined cycle: using "waste heat"
The de-icing fluid recycling process carried out at Munich Airport generates heat as a by-product. This "waste heat" is used to keep Munich Airport warm [27].

[11] Elaborated by Ineco, based on ACI International. Airport Environmental Management course 2010 [ref. 1].

To a lesser extent, airport development activities can affect soil resources. The effects are mainly due to the removal of the substrate and the physical occupation of land by the new paved surfaces with consequent permanent loss of land. Also, pollution and degradation of soils can occur as a consequence of certain airport operations which involve waste management and fuelling of vehicles and aircrafts.

In any case, the adoption of appropriate corrective and protective measures (i.e. preservation of soil resources by removing top soil during construction to avoid compaction and sound waste management and oil separators installation) will attenuate negative effects on the ground.

4.3.5 Waste prevention and management including the management of solid and liquid waste

Effective waste prevention and management at airports is crucial to maintain compliance with environmental laws and regulations. One of the drivers of sustainable practices is that they are not only good environmentally but also typically save money for the airport operator.

The categories and types of waste generated from airport operators, concessions and passengers are similar from airport to airport. The different approaches to waste management are determined by the specific regulations, and environmental awareness of the airport's operators. Typical wastes generated at airports are:

- Hazardous waste from airport maintenance facilities (such as paint, aerosol cans, used oil, antifreeze, abandoned materials, mercury switches and light bulbs containing mercury)
- Municipal waste from concessions and passengers (used cooking oil, food, plastic, paper and aluminium).
- Confiscated items from security checkpoints and checked luggage.
- Waste from airfield operations including derelict equipment, pallets and rubbish removed from the plane.
- Construction and demolition debris including asbestos, lead paint, mercury containing services, wood, scrap metal, etc.
- Waste from derelict electronic equipment.
- Waste water and contaminated storm water containing soaps, petroleum, glycol and other de-icing and anti-icing chemicals.
- Contaminated soils from spills or other historical releases and materials such as runway rubble and paint chips and storm water collection system sludge

The EU's approach to waste management is based on the following waste hierarchy:

Figure 10: European Union Waste Hierarchy, source: [21].

Driving waste management up the waste hierarchy is central to the development of sustainable waste management.

Waste prevention is the first goal of the waste management strategy, which avoids the production of waste. The second best management option is waste re-use. This is a valuable option with some types of waste water. Recycling is the third step down the hierarchy. Most urban regions provide recycling services for consumer materials such as plastic bottles, mixed paper, card board, aluminium cans, glass bottles, scrap metals, concrete, used oil, antifreeze, batteries and asphalt. Waste-to-energy incineration is under "other recovery" management options. It is the 4th aspect to solid waste management, after Reduce-Reuse-recycle. It is the controlled burning of solid waste at extremely high temperatures. Waste-to-energy incineration is widely used in Japan and in Europe (Germany, Switzerland, and the Netherlands amongst other countries), as is evidenced by e.g. the existence of organizations such as the confederation of Europe Waste-to-Energy Plants, see Figure 11.

Waste disposal is the last available option for waste.

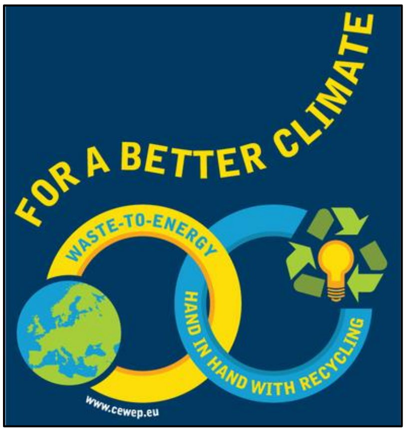


Figure 11: Confederation of Europe Waste-to-Energy Plants, source: [51].

With this waste management approach, the waste hierarchy is changing the mentality and the conception of waste. Currently, waste is seen as a resource itself. This change of mentality can be seen in programmes such as the UK (United Kingdom) National Industrial Symbiosis Programme [21]. This programme has created a market which puts together those producing waste with those that can use it, and are willing to pay for it. A similar strategy has been adopted by Zurich airport, which sells the recovered de-icing glycol to a company that uses it as a resource.

In regards to liquid waste, as stated at section 4.2, depending on local conditions, each airport adopts different options to manage sanitary waste water and rainwater.

De-icer recycling example

At Munich Airport, most aircraft de-icing is carried out by mobile de-icing units at specially designated areas close to the runway heads. These areas are equipped with a system to trap wastewater from de-icing operations and channel it into underground storage tanks. There the water is cleaned mechanically and chemically, then distilled and turned back into de-icing fluid by means of additives. This process of recycling enabled Munich airport to treat and reuse 65 % of the de-icing fluid used during the 2010–2011 winter [60].

At Zurich airport 50% or more of the by-product glycol is recovered and sold. At Amsterdam Airport Schiphol, a test has been conducted and successfully completed to store and decompose the glycol waste water using algae; afterwards, the algae can be harvested and sold for use in a variety of applications.

4.3.6 Soil contamination, groundwater and surface water pollution

Water pollution can result from a direct or indirect discharge of substances into water courses or water bodies, leading to alterations in the properties of the natural ecosystems and water chemistry. Surface water is most often affected, as pollutants may run off the airport pavements and enter into the streams, rivers, etc. However, groundwater may also become contaminated when leaks or spills of fluids seep through the soil into the ground [38].

Fuel is the most common airport contaminant. Jet fuel, aviation gas, gasoline, diesel and heating oil are the different types of fuel that can contaminate soils and groundwater at the airport. The areas subject to having soil and groundwater contamination from operational use, spillage and leaks are locations where fuel is stored, transported and handled.

Glycol releases are typically associated with storage, transport and application operations. Solvent, lubricants and heavy metals can be released to soil / groundwater creating contaminated sites at aircraft hangars, maintenance facilities, paint shops and GSE facilities.

Soil, groundwater and surface water pollution is prevented at modern airports by good housekeeping, solid and liquid waste management and de-icing pads management.
Most airports in Europe have elaborated environmental emergency plans to provide a complete and immediate response to an environmental incident.

4.3.7 Habitat and biodiversity losses

Airport development frequently entails clearing and cutting back of trees and other vegetation. The location of some airports may interfere with the shoreline of rivers, lakes and the sea.

Biodiversity and habitat losses refer to impacts on wildlife and the area where they live. Impacts on biodiversity and habitats include the reduction of number of species and number of individuals, reduction in type of habitats and their extent, bird strike and road kill, as well as disturbance from light pollution and noise.

According to ICAO [38], an important consideration related to airport operational safety is the prevalence and habits of birds in the area and the associated risk of aircraft bird strikes. Bird hazards at new airports can be minimized by careful selection of the site to avoid established bird migration routes and areas naturally attractive to birds and by using the land surrounding the airport for purposes which will not attract birds to the area. Bird problems at existing airports are controlled by scaring techniques and other means to make the airport unattractive to birds.

However, new airports or the expansion of existing ones may be located at environmentally sensible areas due to restricted space and insufficient land use planning. According to ACRP (Airport Cooperative Research Program) 2010 Airport Sustainability Practices Report [4], two key issues related to wildlife have an impact on airports: the conflict between wildlife preservation and aircraft safety, and the effects of noise on migration and nesting patterns.

To avoid bird strikes during the operation of the airport, the following measures apply:

- Management of grassed areas inside the airport. The existence of high grass increases the probability of wildlife species sheltering. Lawns are routinely mown allowing the grass not to exceed a certain height.
- Avoid the presence of elements attractive to birds inside the airport. In this sense water bodies and accumulations of trash or debris act as focal point because they provide food or suitable habitat.

4.4 Summary of the reference airport context and key challenges

This chapter aimed to offer a concise view on presently practised procedures, services and infrastructure design at the airport of today. The purpose of this chapter is also to describe current environmental effects and their management options to set a reference for comparison to the Ultra-Green Airport of 2050+ and to highlight possible areas of improvement.

The key challenge for airport environmental performance is to achieve zero environmental effects. Noise, GHG emissions and extreme weather adaptation are the principal environmental issues, although habitat and biodiversity loss, waste and water management are also of great importance. Legislation will become tougher on environmental responsibilities and waste and water management are key to preventing soil and water contamination. Although most airports have similar environmental effects, the degree of the impact and the importance of each environmental issue depend on the particular characteristics of their specific locations. The challenge is to design concept ideas that can target different particular characteristics and that can be used in isolation or in combination to achieve airport sustainability and neutrality by means of zero environmental effects.

The following table summarises environmental aspects, existing objectives and current practice.

Table 10: Summary of environmental aspects, existing objectives and current practices.

Environmental aspect	Existing objectives	Sustainability principles	Current practice
Noise	Avoid and reduce damage to human health and the environment due to noise pollution.	Achieve reductions in noise emissions. Reduce the size of the population affected by inadequate noise levels.	Information gathered in section 4.3.1 Noise, nuisance and management.
Local Atmospheric Pollution	Not to exceed air quality limits established in atmospheric pollution legislation (Directive 2008/50/EC of the European Parliament and of the council, of 21 May 2008 on ambient air quality and cleaner air for Europe)	Endeavour to reduce emission of pollutants. Avoid air quality limit values are exceeded in populated areas.	Information gathered in section 4.3.2. Local air quality (LAQ) in the vicinity of the airport.
Glocal Atmospheric Pollution (GHG Emissions)	Limit growth in emissions of greenhouse gases.	Reduce GHG emissions (total, per operation, per passenger). Reduce emissions of acidifying and eutrophying pollutants and tropospheric ozone precursors.	Information gathered in section 4.3.3 GHG emissions from energy consumption and vehicle use
Energy	Increase energy saving and efficiency.	Reduce energy consumption Increase energy efficiency Increase the use of green energy from renewable sources.	Information gathered in section 4.3.4 Use of resources
Water	Avoid water pollution. Increase the re-use of water	Reduce water consumption. Reduce water pollution risks. Increase the amount of water reuse / recycling	Information gathered in section 4.3.4 Use of resources

Environmental aspect	Existing objectives	Sustainability principles	Current practice
Soil	Preserve soil resources. Avoid the pollution and degradation of soils and groundwater.	Give priority to environmental integration, rehabilitation and improvement of existing infrastructure, rather than new construction. Reduce the risks of pollution and degradation of soils and groundwater.	Information gathered in sections 4.3.4 Use of resources and section 4.3.6 Soil contamination, groundwater and surface water pollution
Waste	Reduce the generation of residues. Increase the level of recycling.	Reduce the generation of waste in the design, construction and operation phases of the airport infrastructure. Manage according to type (Domestic, hazardous or non-hazardous waste) and in line with the hierarchy principle: Prevention, Reuse, Recycling, Energy recovery and Disposal.	Information gathered in section 4.3.5 Waste prevention and management including the management of solid and liquid waste
Fauna and Flora, Biodiversity	Minimise the impact on natural areas and protected species. Protect and improve biodiversity.	Avoid (temporary or permanent) interventions on protected or valuable natural heritage elements. Guarantee, where possible, the connectivity of natural areas and territorial permeability.	Information gathered in section 4.3.7 Habitat and biodiversity losses

5 The advanced Ultra-Green airport concept

5.1 Overview of the concept

The advanced UG airport for 2050 and beyond will meet the expected increase in demand and fulfil its role in the Transport Network within Europe. It will be servicing a broad range of destinations, by being the European wide binding factor for other modes of transport such as the rail and high speed rail network, as well as for road transport. The large hub airports in Europe have the lead in this development. To improve the effectiveness of such an intermodal hub a central terminal concept can be used. This intermodal hub can also be situated remote within a metropolitan city with a high speed connection to the actual airport.

Looking at operations around the airport and at the airport, the more challenging improvements aiming at greening the airport are those improvements that reduce aircraft emissions. Leaving aside the improvements that fall prominently in the ATM (Air Traffic Management) domain, all operations based on aircraft or combustion engines on the ground will be reduced or transferred to electrified movement in order to reduce or even eliminate emissions. An extension beyond the take-off roll is added through electric engine accelerators. The usage of split runways will further reduce taxi distances. The ideas of electric engine accelerators, split runways and other concept ideas are elaborated further on in this chapter.

Stemming mainly from enhanced logistics, turnaround flight support services, passenger and baggage transfer services and processes will be automated with robots. This in turn, will deliver time savings, seamless processing, increases in efficiency and thus an overall reduction in needed resources.

Regarding the infrastructure, the challenge is to make efficient use of resources, minimize waste production, improve waste management and decrease emissions, whilst being energy efficient and sustainable in constructions. In the future strict construction standards aimed at sustainability will be applied to airport infrastructures in general. The sustainability is further enhanced through innovative airport constructions like weather protected apron operations.

Smart information technologies on personal devices will further improve up to 2050 and beyond providing passengers with an individualized experience at the airport resulting in a significant reduction in equipment and resources for general information services.

Possibly more radical solutions were subjectively rejected given the scope of interest of this project. It was assumed that aircraft frames would not be radically different from today, given the lead times needed for the design and building of radical new constructions in a large, established transport system due to long amortization times, legacy and transition problems, in addition to the requirement to fulfil cost, efficiency and environmental constraints. New developments that are aimed at pilotless aircraft are not foreseen for passenger transport within the mentioned timeframe. Also resource intensive concepts, like having the pier underground or having a circular banked runway, are kept outside the scope of the project.

5.2 State-of-the-art airport operations in 2050

The airport of the future will be working in a different operational environment than todays. Many differences from todays are the result of improvements developed, implemented and operated already before 2050. The following improvements are already on major development and implementation agenda's for beyond 2020, or are evolutionary steps from today's state-of-the-art airport operational developments:

- SESAR implementations in operation in 2050
- Energy efficiency and greenhouse gas emission management
- Resource/waste management
- Intermodal transport
- Individualized airport information

- Intelligent airport

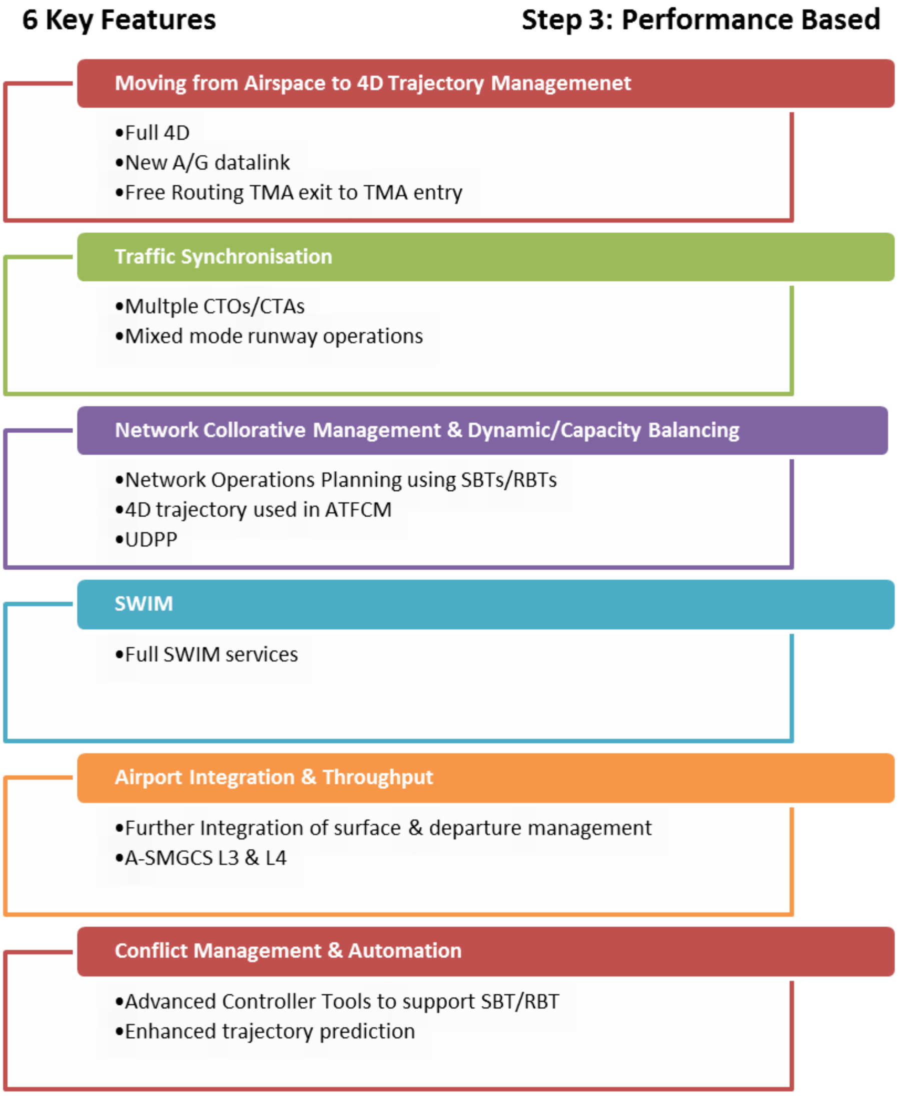


Figure 12: SESAR Key Features at Step 3 - ATM Masterplan, source: [55][12].

SESAR implementations in operation in 2050:
The SESAR ATM [53] program currently running will have by 2050 surpassed and implemented performance based operations (Figure 12). Next steps will show further performance improvements that go beyond those stated already for 2025. The major change coming from SESAR is that the aircraft and airport become part of a large and fully connected air traffic system. Other important changes regarding the airport are that operations become weather resilient, the runway throughput is enhanced, and that surface management will be integrated.

- ***Weather resilience:*** Runway operations during low visibility conditions up to Cat III visibility conditions based on satellite navigation with ground based augmentation. Compared to conventional ILS-systems such a system is easier to install and certify, and allows for reduced low visibility separations and smaller protected areas.
- ***Enhanced runway throughput:*** By implementing time based separations on final, measures to reduce the runway occupation times, and methods to reduce separations by dynamically avoiding wake vortices.

[12] Note: The large number of abbreviations can be found in the acronyms section on page 108.

- ***Integrated Surface Management:*** Arrival, departure, and surface operations will be synchronized to allow optimal usage of the available runway and taxiway infrastructure.
- ***Integrated and Collaborative Network Management:*** Through collaborative decision making the available resources at the airport are used optimal and faire during conditions where the airport demand exceeds the available capacity.

Energy efficiency and greenhouse gas emission management:

- ***Energy efficiency***: Concepts like switchable and efficient airport wide illumination ("lighting on demand") will help to reduce emissions by using wisely available low-energy technologies. Airport's power, heating and cooling plants will have been upgraded to improve efficiency. Passenger and staff support buildings (i.e. terminal building) will have been modified or built to be "smart" and energy efficient according to the latest sustainable building standards (e.g. LEED – Leadership in Environment and Energy Design, etc..). This includes passive climate control techniques.
  The baggage handling system will have lowered energy consumption by reducing the empty running times of the many electric engines.
- ***Greenhouse gas emission management:*** Nowadays, there are 75 European Airports Airport Carbon Accredited [6]. These airports have mapped their emissions and have set objectives for reducing their CO_2 emission levels. It is foreseen that for 2050 all European airports will be pursuing the neutralization of their GHG emissions.
  One of the results of airports' GHG management by is the replacement of fossil fuels based apron equipment and vehicles for electric variants.

Resource / Waste management:

- ***Resource management***: The utilization of organizational resources (energy, fuel, potable water, land use, wildlife, etc.) will be controlled and managed to minimize the impact that it causes on the environment. Simultaneously it will result in cost reductions to the airport.
- ***Waste management***: Waste management is carried out following the European Waste Management Directive [21]. Waste is conceived as a resource and management options have shifted away from landfill. Waste management options are according to EU's approach: Being wise with waste. It will offer also opportunities for on-site energy production (waste to energy). The waste cycle is also closed by introducing for instance biodegradable de-icing fluids based on natural and local resources.

Intermodal transport:

Autonomous vehicles being available on demand may become an important competitor. The autonomous vehicle could provide important services to travellers including (1) door-to-door travel at the travellers own time of choice, (2) being able to do activities (e.g. preparing a meeting, entertainment, etc.) during the full commute, (3) being not separated from the personal luggage, (4) not needing to go through security checks, and (5) having personal space. Also an autonomous vehicle might be considerably more Cost-Effective per unit of distance than the current day alternative: the taxi with driver.

For commutes up to 500 km travel by autonomous vehicles could become the preferred way of travel as air travel cannot provide the same level of service to the traveller. Only beyond door-to-door distances of 500 km air travel is starting to provide a considerably reduced trip time compared to road travel.

The autonomous vehicle will provide just-in-time travel to and from the airport. This will improve the time efficiency of door-to-door travel for the passenger. This new service to the traveller will not improve the competitiveness of air travel compared to other modes of transport, as these other modes of transport can likewise make use of the advantages of autonomous transport.

For the airport the integration of autonomous vehicles for intermodal transport have two advantages: (1) the need for large parking spaces and road infrastructure will be considerably reduced, and (2) for smaller types of airports the autonomous transport is a viable alternative to other intermodal transport systems likes busses and trains. The autonomous transport does not need the large infrastructural investments like with trains.

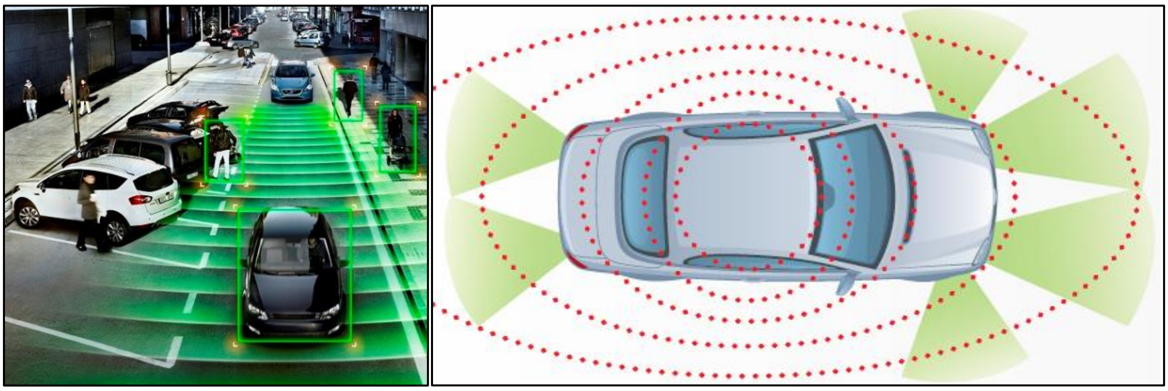


Figure 13: The autonomous vehicle driving from door-to-airport and vice versa, source: [44].

Individualized airport information

Replacing airport information systems by individualized information on personal devices is aimed to reduce the dedicated information infrastructure at the airport.

Airports have large infrastructures for informing and guiding passengers about where they are, where they have to be and when they have to be there. Still passengers get lost, and arrive unnecessarily late at their check-in desk, security check or gate. Late or no show passengers result in delays to the flight and other passengers.

By providing passengers with individualized information on their personal devices it becomes easy to inform passengers about the status of their flight, and to guide them efficiently and in-time through the airport along the different processes of check-in, security and boarding.

The airport gets also information on the status and location of the passengers. The airport will be informed about the expected arrival times at check-in, security, and gate. The aggregated information from the passenger information allows the processes at the airport to be optimized. For instance, additional security gates can be opened just-in-time for a new passenger peak, or a passenger can be offered a “fast-lane” through security as an in-app purchase when the passenger is likely to arrive (too) late to the gate.

The physical airport information system can be replaced by a virtual airport information system that is individualized to each passenger. This reduces the energy consumption and the need for hardware for maintaining this physical airport information system. The system can also be improved in an evolutionary fashion over time without a need for replacing airport hardware infrastructure. Delays to flights and passengers are reduced.

Intelligent Airport

Flow control of passengers and goods inside the airport may be a difficult task at times, when communication is not good or unforeseen things happen (strike, adverse weather, prolonged delays, etc....). Growing already is the initiative and idea of assuring that all the stakeholders of the airport are made aware of the information needed in a coordinated way (A-CDM [Airport Collaborative Decision Making], SWIM, TAM [Total Airport Management], etc...). However, these management systems need information to be received in real time. Current sensor networks, although progressing, are not designed for this yet.

The airport is built with sensors which detect the flow of passenger and goods, the needs of every stakeholder and provides resource management to tackle the necessities instantly. The development of this currently not existing infrastructure is a challenge since it needs to be sufficiently precise (position and numbers) and finely-meshed.. How would it work? Imagine a strike which has not been communicated. Since airports are built mostly for supporting a flow of passengers, only allowing for a very small amount to be static (staying long periods inside) a problem as the one mentioned above may lead to the collapse of the whole system. The capability of the intelligent airport system in this case is decisive as it knows how many passengers are already inside the airport, and also knows the flight of each individual passenger. which passengers take which flights.. This opens the possibility of prioritising the passengers and flights not affected while blocking upstream the entrance of those which will be delayed (in the future there will be no limits to the word upstream –see intermodality).

Other uses: tell those passengers inside the airport (through smart devices) where to go; keep the passengers updated with the last news; know how many passengers have turned up for the flight (different from checked-in numbers). Inform those who are not in the airport at the moment of the delay.

Benefits are wide ranging from ability to control the flows of passengers and goods entering and exiting the airport system, making sure the services provided respond to the flow instead of reacting when it is too late. Provide tailored information. Other benefits are reduction in energy consumption for environmental control, lighting, security, waste and water management, and A reduction in the amount of traffic coming and going to the airport in case of a disruption in the service.

5.3 Airport concept development following the invariant processes

The invariant processes (Figure 5) are the minimum processes that are needed to achieve the loading and unloading of passengers and their luggage into and off the aircraft. This diagram shows the areas that can be improved in order to create an UG airport concept.

The solutions selected by the UG-airport concept are chosen for their foreseen benefits to the environment (Figure 8). The solutions are assessed regarding the requirements on time-efficiency and Cost-Effectiveness. Safety is considered to be out of scope for the assessment. Each identified concept solution is assessed towards its influence/impact on one or more of the so-called Invariant Processes (e.g. processes that were identified to be still part of an airport in 2050). The processes are decomposed according to the transport flows through the airport.

Given the objectives and value attributes for the UG airport concept, several areas of improvements can be identified. The greening of airport operations aims to improve the five main KPI's (Key Performance Indicator) which are also found below in Figure 14. By analysing the Invariant Processes and their flows, the best opportunities for Ultra-Green improvements were selected and their related solution areas can be found listed below and in depth in the next sub-section.

Solutions were created based on the following principles to create maximum benefits regarding the environmental performances:

- *Aircraft engine emissions on the airport are within the circle of influence of the airport.* Once an aircraft is on the airport surface it is possible for the airport to provide alternative means of movement to minimize aircraft engine usage, and also minimize taxi distances.
- *Airport resources must be used effectively.* The airport must provide optimal services by maximal usage of a minimal set of resources (equipment, infrastructure and personnel).
- *Waste production must be minimized.* Alternatives must be created to process steps on the airport where waste is produced.
- *The airport is part of a larger system.* The environment has only maximum benefit of the Ultra-Green airport concept when it is considered that the airport is part of a larger system. That means that not only the airport must become greener, but also other elements within the context of the airport can become greener by choices made for the airport.
- *The UG airport complies to the expected standards of efficiency and safety.* Also the UG airport is an airport that must be able to function effectively in a competitive world, and must be able to allow aircraft to operate safely on the airport.

Performance improvement objective	Operations/Invariant processes	Proposed solutions
Reduced noise production	ATM, landing, take-off, taxi-in/out	Electrified aircraft movement (Rwy/Twy/Climb phase)
Reduced emissions	Turnaround, unloading/loading, (de)boarding	Turnaround automation
Reduced use of energy	Passenger feeds, passenger transfers	Bax transport robots
Optimized use of resources	Check-in, security and passport control	Pax automated transport
Reduced residual waste	Baggage processing, baggage feeds, baggage transfers	Individualized information
	Intermodal (arrivals & departures)	Weather protected turnaround
	Commercial services	Dual threshold/Split runway
	Infrastructure and landscape	Single/City terminal
		Vegetation with added value

Figure 14: Development of the UG airport concept of 2050+

Concept solutions and expected benefits
In summary, the UG concept follows a known structure of processes along lines (called the invariant processes), and which takes into account the flow of passengers and luggage through the airport from arriving by any means of transport to departure by any means of transport. In order to achieve the operations as described, innovative concept solutions need to be implemented. Solutions are described for four areas: (1) airside airport services, (2) landside airport services, (3) intermodal transport services, and (4) infrastructure. Each solution is elaborated and the expected contribution to the UG airport concept's objectives is given. Table 12 shows the solutions of the UG airport concept, which will be discussed in Sections 5.4-5.7. The solutions are presented in the following order: airside airport services, landside airport services, intermodal transport services, and infrastructure.

In order to give the reader a better insight in the expected[13] benefits that the proposed solutions have for the UG airport concept, the solution descriptions are followed by an estimation of their impact on the low-level objectives of sustainability. Five low-level objectives were established for sustainability in Table 6. The expected impact are visualised in a spider graph, indicating the effect of the solution on each low-level objective.

The expected impact per objective is given for each solution. This score is given on a linear scale, ranging from -2 to 2. Negative scores indicate a negative contribution to the given objective, while positive scores indicate a positive contribution to the objective. In summary, score -2 is the worst-case scenario, while score +2 represents the best contribution to the objective. Score 0 indicates no variation. A justification of the chosen scores can be found under the solution description. An example of the radar plot given per solution is shown in Figure 15, in which a positive score (0, +1, or +2) is

[13] The benefits presented in Chapter 5 are first estimations made by the consortium. Chapter 6 (validation of the ideas) will give the expected impact by different stakeholders from outside the project.

shown in green, while a negative score (-1 or -2) is shown in red. The same format will be used in Chapter 6 to display the results of the expert's value assessment.

Table 11: Overview of solutions in the UG airport concept presented in this chapter.

Identifier	Area	Description
UG1	Airside	Electric engine accelerators for take-off
UG2	Airside	Electric ground movement
UG3	Airside	Cleaning & de-icing robot
UG4	Airside	Parafoil landing
UG5	Landside	City & single central terminal
UG6	Intermodal	Automated Seats
UG7	Infrastructure	Dual threshold runway
UG8	Infrastructure	Magnetic levitation (MAGLEV) for take-off and landing (M-TOL).
UG9	Infrastructure	Automated apron services
UG10	Infrastructure	Weather protected turnaround
UG11	Infrastructure	Shielding landing and take-off operation by landscape design

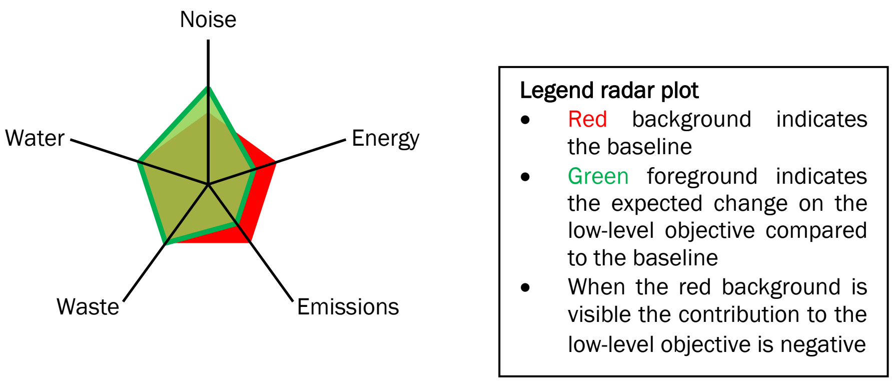


Figure 15: Example radar plot indicating how solutions contribute to the objectives.

5.4 Airside services

5.4.1 Electric engine accelerators for take-off

Purpose: The size, weight and power of aircraft main engines are mainly determined by the take-off and climb-out requirements. During en-route and landing operations a smaller engine would be sufficient. Coupling additional electric engines to the aircraft for assistance during the take-off phase, would help to reduce the size of the main engines.

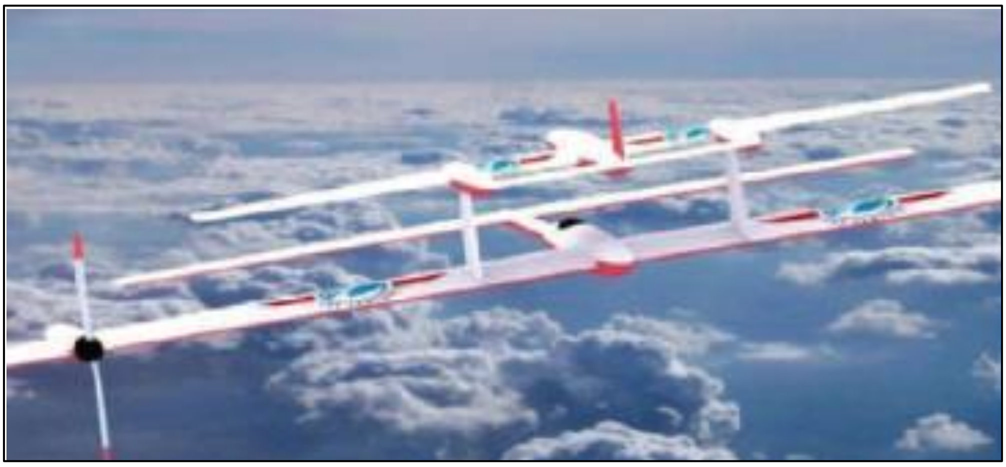


Figure 16: Example of an aircraft with take-off assistance by a drone, source: [17].

Detailed Description: The power needed for a take-off is determined by the take-off weight of the aircraft and the required acceleration, which depends on the aircraft take-off (TO) speed and the length of the runway.

The high demand for power during take-off results in the need for high performance engines that burn a lot of fuel during this phase of flight, resulting in high local emissions and high amounts of noise. Furthermore, the weight of these big engines has to be carried during the whole flight even though during the cruise and approach phases the thrust requirements are considerably lower. Therefore, additional benefit can be gained by reducing the size and weight of the main engines. Although the efficiency of aircraft main engines has been improved during the last decades, a more significant weight reduction during cruise can be achieved by attaching temporary engines to the aircraft that support the aircraft with additional thrust during take-off. After reaching a minimum altitude the extra engines would be removed automatically and turn back to the airport as autonomous unmanned aerial systems (UAS[14]). To maximize the benefit of this technology in an airport context, electrical powered UASs would be used. At the airport the UASs are recharged or energy cells are replaced for the next assisted take-off. That said, the airport has to provide and maintain all facilities required for the use and charging of those vehicles/engines.

Foreseen benefits: The greening effects of this technology are threefold:

- By using electrical powered engines local noise and local air quality related emissions can be reduced significantly.
- Due to the weight reduction during cruise flight the fuel burn and hence the overall greenhouse gas emissions are lowered.
- Part of the aircraft energy consumption can be replaced by an alternative energy source resulting in more sustainable aircraft operations (bearing in mind that this energy needs to be produced sustainably).

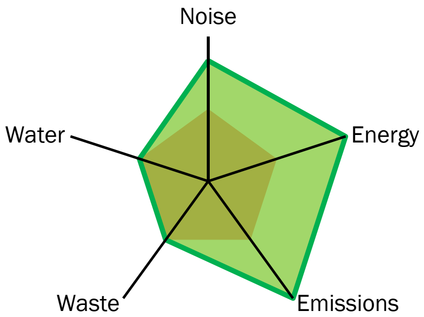


Figure 17: Expected impact of electric engine accelerators on the UG KPIs.

5.4.2 Electric ground movement

Purpose: Aircraft ground movements currently consume considerable amounts of fuel by performing these operations using the main engines of the aircraft. This is highly inefficient. Fuel consumption, emissions and ground taxiing noise can be reduced by altering the ground movement operations. Conventional pushbacks, apron movements and taxiing can be replaced by towing and/or the application of electric gear engines. This will reduce fuel consumption significantly as well as pollution by emissions and possibly decrease local noise.

[14] UAS will be included under the new definition of Remotely Piloted Aircraft System or RPAS

Detailed description: Although using the thrust of the main engines for ground movement instead of installing a dedicated drive system seems to enable a double use, there are a couple of problems associated with this procedure. Most obviously the operating point of the engines in idle thrust setting is highly inefficient, which leads to relatively high fuel consumption and emissions. The permanent thrust requires the pilot to regularly slow down the aircraft which results in brake wear. Moreover, due to the pull of engine suction there is the risk of FOD as long as the engines are running. All of these aspects consequently cause additional maintenance cost.

Taking into account the problems which are associated with all- or single-engine taxi, the most consequent idea is to introduce a method which allows aircraft to get to the runway without using thrust of their engines and thus eliminating the aforementioned disadvantages including relatively high fuel consumption and emissions. Therefore, the following four measures can significantly improve the situation either separately or as a combination:

- Operational towing
- Electric engines
- Stationary recessed towing system

Operational towing

Advanced taxi operations can either be realised by “operational towing” or by the use of electric engines, which are installed on the aircrafts nose or main gear. Operational towing is to use a towing vehicle which takes the aircraft from the gate to the runway on departure and vice versa on arrival. By this, the engines can remain switched-off during most time of the taxi except for the warm-up and cool-down phases (depending on the manufacturer’s instructions approximately 4 minutes on departure and 3 minutes on arrival). Depending on the size of the airport and the number of movements, more towing vehicles than today would be required and additional service roads would have to be built to assure their provision. Ground control operations have to accommodate the additional ground movement operations of the tows.

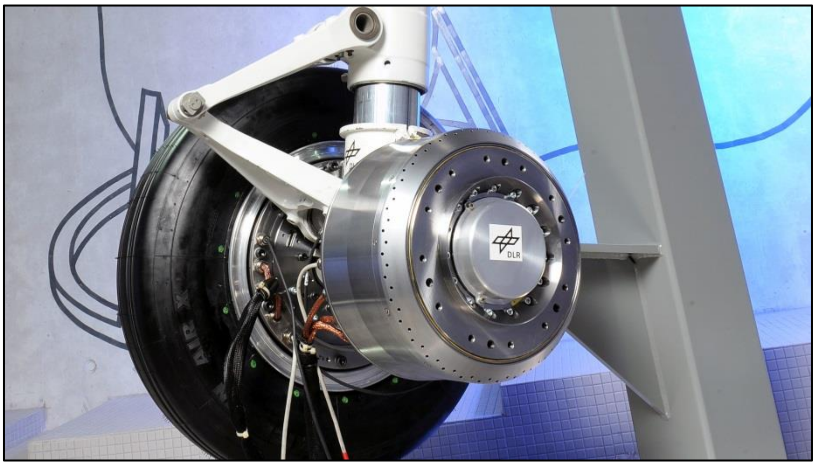


Figure 18: Nose gear with electrical engine, source: [62], © DLR.

Electric engines

Another approach comprises the integration of electric motors into the landing gear of the aircraft. This concept, called “electric taxi”, is likely to be limited to narrow body aircraft since wide body aircraft would need a large number of actuators, which would add too much weight to the aircraft to be carried during flight. The motors can either be powered by the APU or a fuel cell. A regenerative braking system can be added as well. The acceptance of the electric taxi system by the airlines depends very much on its added weight. Therefore, only if the fuel savings during taxi exceeds the increased fuel consumption during flight, the airlines will accept the costs for acquisition. Besides the potential fuel savings and related reduction of emissions, the electric taxi also makes the pushback by a tug obsolete. As the electric motors are also capable of driving in reverse, the aircraft can back out of the parking stand autonomously. This implies cost savings to the airline, further reduction of emissions due to the non-use of a tug, time savings as the towing vehicle does not have to be detached and driven away, and a simplification of ground operations as towing operations do not need to be coordinated between multiple departing flights.

Stationary recessed towing system
In the future, other technologies for replacing the conventional taxi might become available, e.g. a stationary towing system which is integrated into the taxiway and the aprons (similar to the cable cars in San Francisco an aircraft could hook on a cable of the integrated towing system of the taxiways). Although the expenses for installation would be very high, the reduction of emissions from towing vehicles and aircraft engines could justify the investment.

The system has similar benefits as the operational towing concept without needing to coordinate the tows on the manoeuvring area. This concept will only work in combination with towing operations as otherwise the main engines of the aircraft have to remain running to allow the aircraft to move towards and from the stationary towing system.

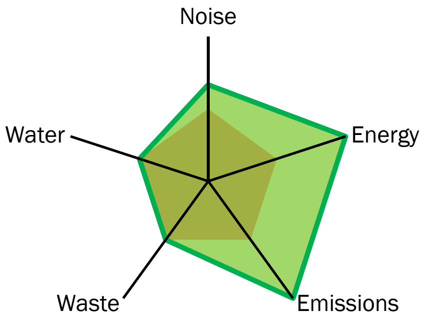


Figure 19: Expected impact of electric ground movement on the UG KPIs.

Foreseen benefits: Facilitating ground operations with aircraft's engines shut down, save energy, save fuel, and reduce noise nuisance. Also, local emissions at the airport can be strongly reduced, improving local air quality.

Future benefits: The electric ground movement concept can also be integrated with advanced ground movement guidance and control systems that allow for efficient ground movement operations that can more easily be controlled by air traffic control.

5.4.3 Cleaning & De-Icing robot

Purpose: The purpose of this technology is twofold:

- Keeping the aircraft frame clean, means to have an aircraft with a smoother skin. The reducing in aircraft frame drag leads to fuel savings to the airline.
- Using robots for the de-icing process allows for a more closed loop regarding the de-icing fluids. This process has less impact on the environment.

Detailed Description: An aircraft that has been cleaned at the outside has shown to have lower fuel consumption than a soiled aircraft. This is due to a reduced drag, and a reduction in weight of the dirt. By having a cleaning robot the exterior of aircraft can be cleaned during the regular turnaround process. A cleaning robot can focus on the most critical areas for cleaning to limit the time needed, and coordinate areas to be cleaned between subsequent turnarounds.

Robots can also be used for de-icing the aircraft. Aside from the benefit to improve the turnaround process, this would also help to make the process more environmental friendly. The cleaning or de-icing robot can be designed such that the apron stays dry and the dirt, oil residues, and de-icing liquid can be collected by the de-icing robot for recycling purposes. Furthermore, the robot will work independent from ground staff. So when an aircraft arrives the robot starts automatically with the cleaning and/or de-icing process, and when the aircraft is about to leave the cleaning and/or de-icing process is ended. Then the robot will provide the collected dirt, oil residues, and de-icing liquid to a collection point, and from there it goes to the next arriving aircraft.

Figure 20: A cleaning robot, source: [50]

Foreseen benefits: The air flows over the aircraft's skin in a more smooth way, and will result in fuel savings to the airline and emission reduction in general and locally at the airport. Furthermore, pollution of ground water by de-icing liquids will be reduced due to a closed recycling loop provided by the de-icing robot.

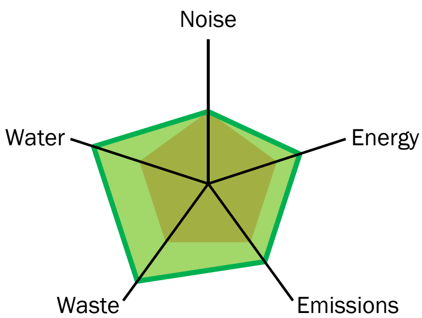


Figure 21: Expected impact of cleaning / de-icing robots on the UG KPIs.

5.4.4 Parafoil landing

Purpose: Parafoils (steerable parachutes) are mainly used in military applications for delivering supplies and Unmanned Aircraft Systems and in recreational applications. This technology can also be applied to allowing aircraft to perform parafoil-assisted landings at low speeds and low engine thrust settings resulting in a substantial shortened landing distance.

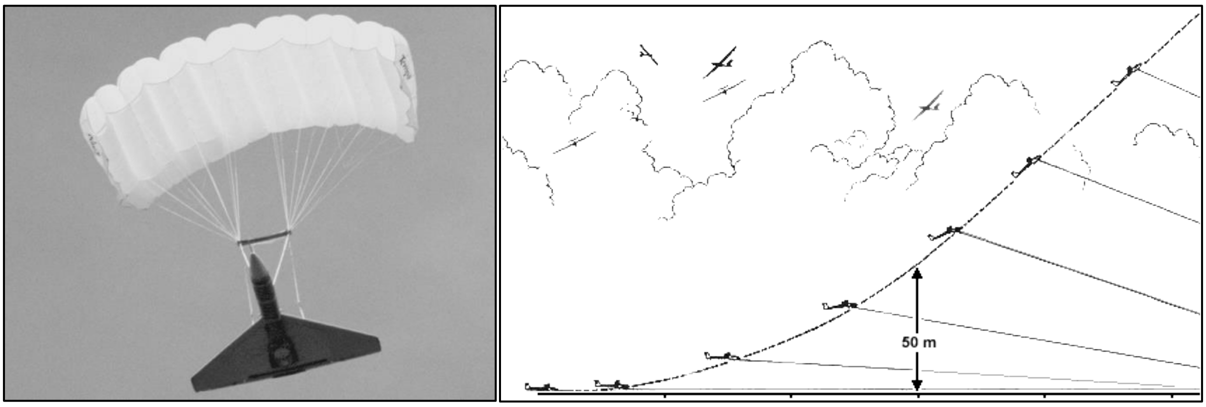


Figure 22: a. Banshee air vehicle under parafoil canopy. b. Winching technology being applied to (gliders and) parafoils for assisted (take-off and) climb. Source: [66].

Detailed description: In this concept an aircraft can deploy a parafoil to allow it to increase its lifting surface area during approach and landing. This allows an aircraft to fly at a reduced landing speed resulting in a shorter landing distance and runway length. With a short runway an airport can be constructed that has a reduced land usage compared to conventional airports.

The descent angle of a parafoil approach path is larger than that of a fixed wing aircraft approach. The larger glide angle results in a later top-of-descent and therefore an increased fuel consumption and additional emissions. Also the lower speed allows parafoils to make shorter turns and performing these turns closer to the runway. These three elements combined allow the low altitude phase of the approach to be located closer to the airport.

Overall the fuel consumption of the aircraft operations with parafoils will increase. By having to take along the parafoil for the approach phase the aircraft weight is increased. Furthermore, the relatively large parafoil glide angle requires aircraft having to fly closer to the airport before they are at their top-of-descent and start gliding into the airport.

The effect on passengers of the deceleration during parafoil deployment needs further research. Methods to extend the deployment period can be considered.

Foreseen benefits: The reduced landing speed allows parafoil operations to be operated on shorter runways. This will reduce infrastructure and land use costs to the airport.

The lower landing speeds, the steeper glide angles and the shorter turns closer to the runway lead to reduced noise levels during approach and a smaller populated area affected by aircraft noise.
The reduced noise during landing together with the reduced land use makes it easier to locate an airport closer to populated areas.

Future benefits: Parafoil systems are sometimes applied in recreational applications in combination with a winch. Applying a winch to a parafoil-assisted aircraft will allow a power-assisted take-off and initial climb. This is an alternative to the electric accelerator for take-off or the Maglev concept as discussed in sub-sections 5.4.1 and 5.7.2, respectively. It has already been applied for decades with gliders, but scaling the concept to usage with large aircraft needs further research. Questions remain regarding how this winch concept would be implemented, the safety during the winching, the effective operations, and the business case.

The winched take-off has a number of benefits. It allows an aircraft (1) to use less fuel during take-off and initial climb, and (2) to use less engine thrust resulting in less aircraft noise and emissions during departure.

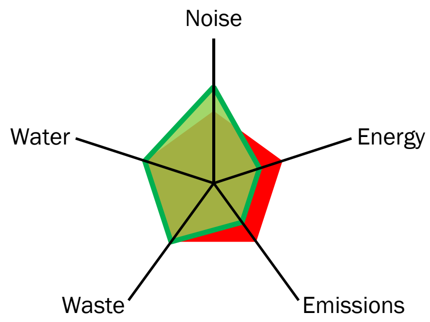


Figure 23: Expected impact of parafoil operations on the UG KPIs.

5.5 Landside services

5.5.1 City & Single Central Terminal

Purpose: The city & single central terminal supports the development of remote airports that results in the limitation of noise levels and local air quality within the city. The single central terminal at the airport is connected to the city through an environmental-friendly and efficient transport system. Within the city a remote terminal is available where passengers can check-in and drop-off their baggage. This city terminal is part of a metropolitan intermodal hub connecting public, individual and air transport at a single location.

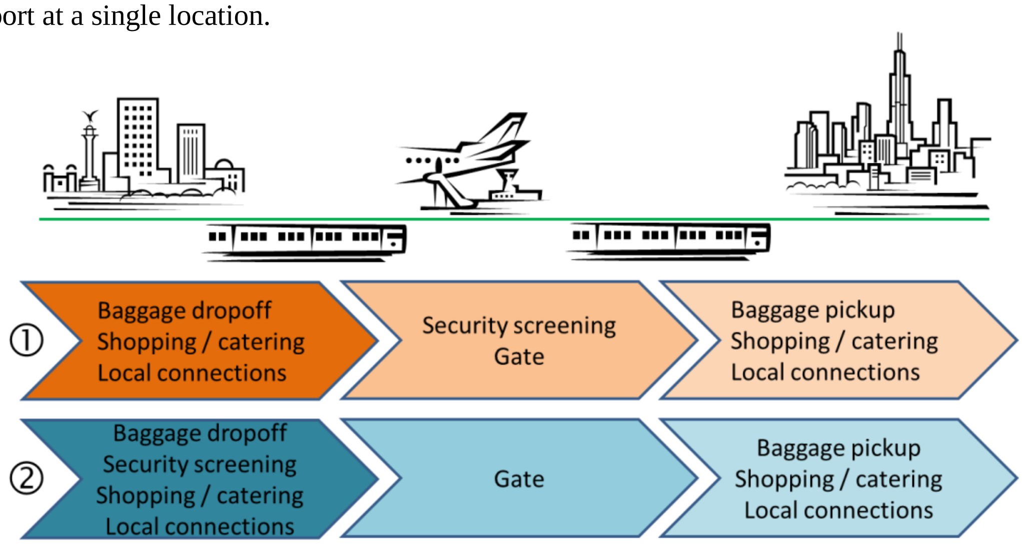


Figure 24: City terminal connected through high speed rail to a single lean airport terminal with security in the city (2) or at the airport (1).

Detailed description: This concept can be split into two versions. One with the security remaining at the airport (1), and one with the security also being implemented at the city terminal (2).

Security at the airport (1)

The city & single central terminal concept is based on two ideas. First of all, the introduction of a city terminal allows the creation of a true intermodal hub within the centre of a major metropolitan city. Secondly, the single airport terminal connected to the city terminal allows for having the airport remotely from densely populated areas.

With the city terminal as part of a metropolitan intermodal hub it becomes possible to combine all major modes of transport: public, personal and air transport at a single location. It becomes easy to transfer between modes of transport and get a seamless connection to the densely populated metropolitan centre. At the intermodal hub additional services like shopping and catering are available to all commuters without restrictions. Economics of scale makes this an efficient commercial location.

At the city terminal air passengers can drop-off their baggage. This baggage is transported by high speed link to the central airport terminal for security screening and loading onto the aircraft.

The traveller can also use the high speed link to the central airport terminal. At the airport terminal the passenger only needs to go through security and to the gate to board the aircraft. At the airport only a minimum set of additional services to passengers are available to keep the airport lean.

Due to the use of the high speed link the airport can be at considerable distance from the metropolitan city centre. This allows for the airport to be located within low populated areas minimizing noise nuisance and emission effects on the local community.

Security at the city terminal (2)

This version of the concept is a combination of two ideas. Firstly, by providing passenger-friendly check-in and security procedures in the city and efficient, green transport (i.e. fast train) between city and airport, the use of (remote) terminals is promoted. Secondly, by performing check-in and security checks in the city, the city terminal itself can blend in with other modes of transport within the city resulting in a true multimodal hub within the city centre.

The passengers and baggage are checked in and screened in the city terminal. Thereafter, a secure, i.e. not accessible from the outside, transfer will take place to an airport terminal or runway system using high speed public transport. A high speed link with separate trains, coaches or cabins for each flight shall deliver the passengers close to their departure gate. Also possible is a single central terminal, which is connected with several city terminals from different cities. In that case the coaches or cabins, which go to the same flight, have to be coordinated.

The floor plan of current terminal buildings is determined by the current functionalities that they should offer. Among those the most important are the check-in, passport control, security check and hosting of passengers in case of prolonged waiting time. Because the check-in and security check will be done in the city for most passengers, only limited facilities are needed at the airport for providing check-in and security checks for those who are arriving to the airport individually (taxi or car). The use of transport robots (section 5.7.3) and/or seats (section **Error! Reference source not found.**) optimises passenger and baggage flows. Because the waiting times at the airport are reduced due to the application of ICT (Information Computing Technology) alerting services and enhanced airport logistics (section 5.2) the need for shopping and eating facilities may well decrease as compared to the current situation. The combined reduced need for check-in, security, shopping and eating facilities make a smaller, single central terminal possible at the airport.

Foreseen benefits: The city & single central terminal concept provides potentially efficient, fast, environmental and passenger friendly access to a remote airport, while at the same time decreasing the environmental impact of the airport on the local community. By clustering all passengers in a mass transport system from the city to the airport/runway system, less individual traffic is generated. Several cities can make use of the same airport within the centre of the city cluster. The land use is restricted to locations that are not near large cities, and therefore less costly in exploitation.

Future benefits: Baggage that is dropped off at the city terminal can also be transported by other means of transport (rail/road) to the final location when time permits. The alternative route for the baggage has two advantages: (1) no need for security screening of the baggage, and (2) saving fuel during flight and replacing it with a sustainable alternative transport.

In terms of environmental KPIs the following benefits are foreseen:

- **Noise:** An airport/runway system, which is not located in the direct vicinity of a city, can be used. By doing this, the number of people affected by the noise of aircraft movements can be reduced. This might not be possible or beneficial in very densely populated areas but in some other areas this might be an option.

- **Emissions:** Due to the smaller size of the airport less energy is used for heating and transport, resulting in less local airport emissions. However, the city terminal and the bulk transport between city and airport also require energy which may lead to emissions. Since this bulk transport replaces many individual transports it is expected that total emissions are reduced.
- **Energy:** The smaller size of the airport leads to less need for heating and smaller transport distances on the airport. Also the total energy use of the bulk transport is envisaged to be less than that of the total energy consumed by the individual transports to and from the city. So the total energy used by this concept is expected to be less than for current airports.
- **Waste:** Since waiting times for passengers at the airport are less it is assumed that waste will decrease.
- **Water:** As for waste, it is assumed that shorter waiting times will lead to less water usage.

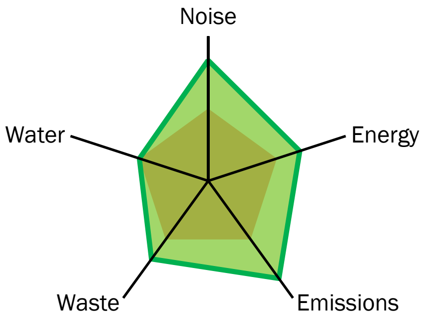


Figure 25: Expected impact of the city and single central terminal on the UG KPIs.

5.6 Intermodal transport services

5.6.1 Automated Seats

Purpose: The purpose of using Automated Seats is to minimise time spent between security and waiting at the gate and to decrease the surface needed for the passenger process.

The idea is based on two main premises: security is before the gate and transport in the airport to and from the aircraft is only via an automated seat. Infrastructure wise this would mean a simplification of the system in terms of environmental control (air-conditioning, fresh air, humidity, heat, etc...).

Detailed description: In Figure 26 the passenger process is shown for Automated Seats. Automated Seats reduces the time involved in the processes depicted by the boxes with a brown cross. Most actions in the passenger process would be done by the single moving seat, responsible for transporting timely and efficiently the passenger to his flight and making the necessary security checks autonomously. Security would be integrated (biometrics, passport control, security, etc.) into the seat as well as baggage handling, leaving cargo only to the airport handling system. The flow of seats would be controlled centrally, efficiently and adaptively.

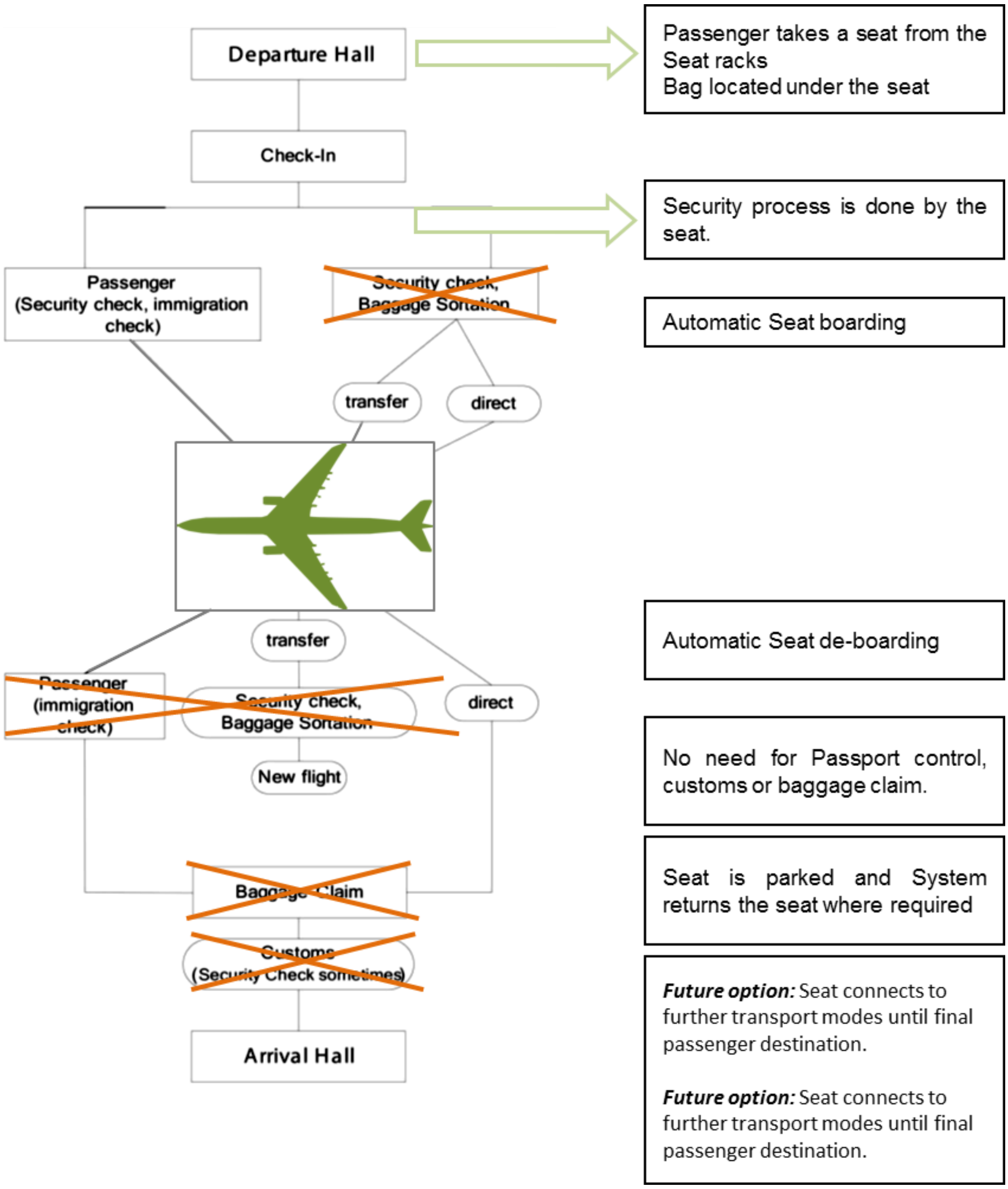


Figure 26: Automated moving seat system - changes in future processing of passenger flows.

Another result of the above scheme is that there is no need for lounges inside the airport, since the only thing needed would be corridors to take the people in the required time [8] to their flight. The idea is to have a service as swift as taking the metro with the rest of the time being spent outside the airport.

Automated Seats would open up a whole range of improvements and tailoring including entertainment, temperature control, monitoring and information awareness. Standardised baggage compartments will be necessary.

The airport would have to change drastically with respect to how it is arranged today to accommodate the Automated Seats concept. Due to the radical change in the way passengers move through the airport this concept will probably be only suited for greenfield airports, not for existing airports. The Automated Seats airport would only provide for the connection between the curb side and the gate. Terminal corridors would benefit from less expensive infrastructure and an efficient automated flow management. Security would have to be tailored to the new service and technology. When an airport implements this concept, the commercial area will be located outside the controlled/operational area, since the time spent by the passenger beyond the check-in would be only required for security and boarding.

Aircraft and seat manufacturers would need to change the passenger deck. Overhead bins would not be required, boarding would be swift and cargo space would be better organised as well as the aircraft's weight distribution.

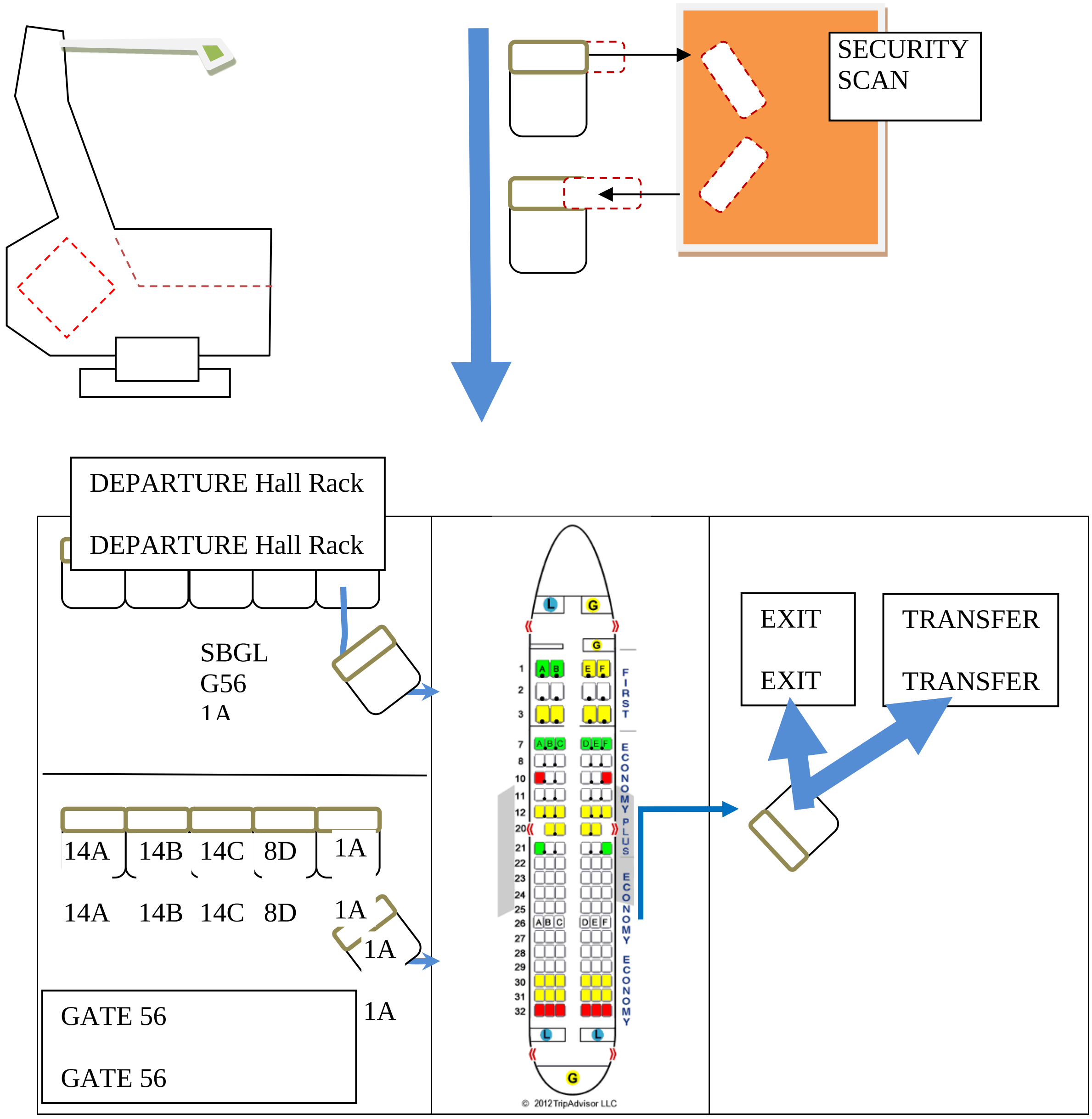


Figure 27: Scheme of passenger flows by moving seats

Foreseen benefits: The following benefits are reflected by the KPIs:

- **Noise:** noise produced by aircraft dependant on the weight of the a/c may well diminish due to the fact that the weight is better distributed while there would be no more need to take empty seats (if any) on the aircraft.
- **Emissions:** As for noise the emissions may well diminish on the aircraft side due to better weight distribution and improved calculation of the fuel needed by the aircraft (no empty seats, pre-knowledge of passenger and luggage weight through seat communication, etc...). At

an airport level the need for environmental control may well become considerably smaller since there is no more need for big infrastructures to be controlled (this is true if carbon based fuels are used as sources for heat production) or the seat already integrates that.

- **Energy:** Energy directly required by the airport may well maintain a balance between the high requirements of the new electric energy based infrastructure and its gains in efficiency and ability to be compact. The greatest improvement will be the possibility of centrally managing all the energy requirements of the system, which will be able to adapt promptly to the passenger flowing in/out of the airport.
- **Waste:** the system may be able to reduce the amount of waste coming from the passenger part due to the reduction in the services offered inside the security/controlled area (by then it is understood that information will all be digital no need for luggage labels, etc...). However servicing of the seats and commercial services as food stores, etc....may well contribute to other forms of waste even though they are located outside the security/operational area.
- **Water:** The need for water by the infrastructure may well be reduced by shifting or locating the passenger commercial services outside the airport. However seat servicing, toilets, etc... will still be required.

These benefits can be depicted in a radar graph illustrating the positive impact of this concept idea on 5 relevant UG KPIs:

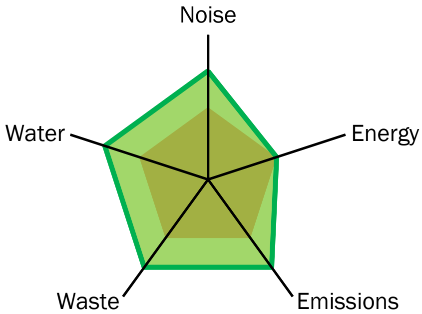


Figure 28: Expected impact of Automated Seats on the UG KPIs.

Besides the KPI reflected benefits, the following benefits are also foreseen:

- Less need for big spaces or gigantic living quarters, no need for check-in desks, no need for boarding cards (e.g. less paper - already implemented in bar or bidi code on current smart phones and near future Bluetooth/WIFI (Wireless Local Area Network) security coding).
- Less time is spent inside the airport: the airport is just a gateway as a metro station platform. Reduction in the time the passenger spends in the airport actually decreasing the need for energy consumption and the environmental footprint.
- Indirectly the autonomous seats would also make boarding swifter and crosscheck of baggage much easier, releasing the burden of delays from the ATM system which has an impact on energy and the environment.
- Aircraft would not be carrying empty seats since no seat would be present if the passenger did not come. Empty spots could possibly be filled up with small cargo/express containers.
- Luggage been located under the passenger would make traceability and the need for further logistics structures more simple (luggage pick-up conveyors and collection would be needed no more).

Future benefits: The expansion of this idea to a wider scope or longer range would mean bringing this to other modes of transport. The idea envisages the direct transport door to door of the passenger with its seat. This opens new horizons to modular multimodal transport, where the passenger never changes its own seat from one type of transport to another: it is the seat that changes transport mode.

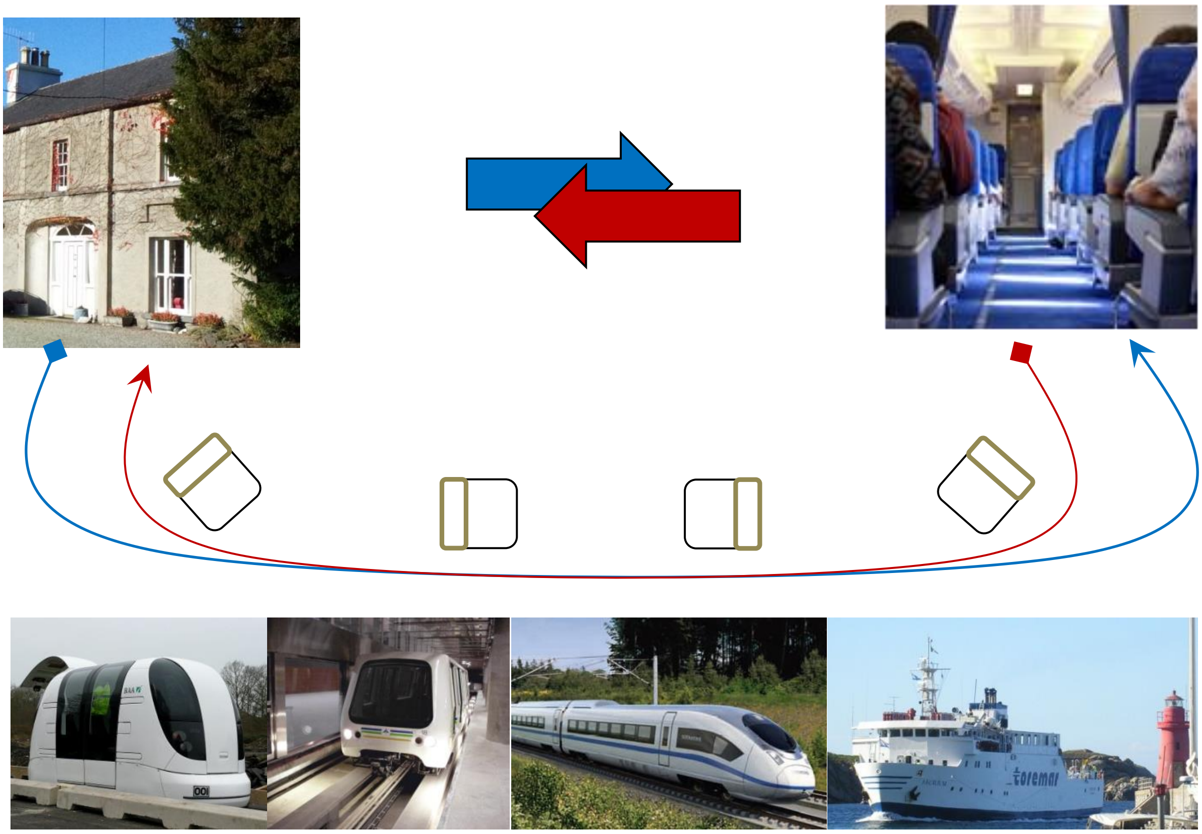


Figure 29: Example of Door-to-door use of the Automated Seat Concept.

This requires further research and development into a future standard platform for intermodal distribution (docking/undocking, propulsion, communication, etc....) of passenger seats.

5.7 Infrastructure

5.7.1 Dual Threshold Runway

Purpose: The dual threshold runway (also called split runway) consists of a long runway that can be used as a single runway for heavy type aircraft or as two separate smaller runways for medium type aircraft. The purpose of this split runway concept is to increase the runway capacity.

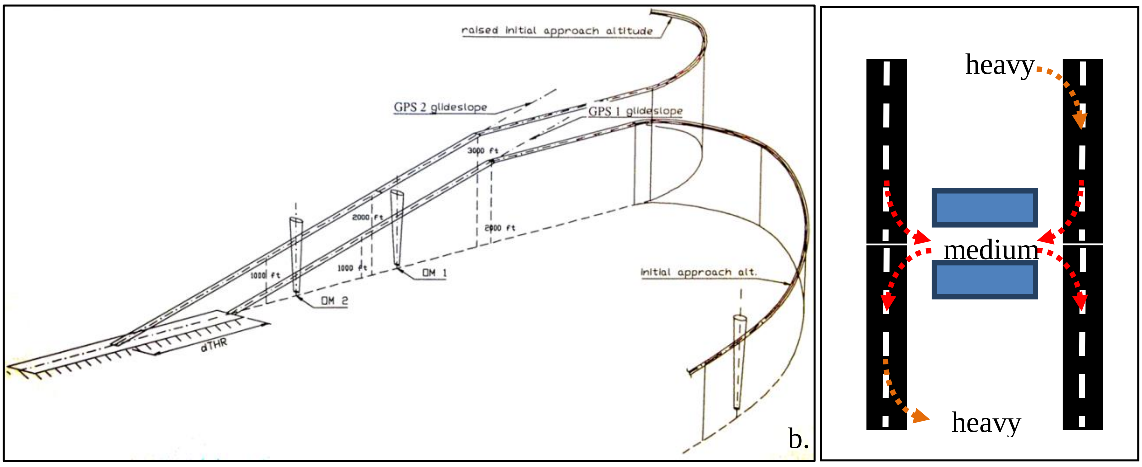
a.


Figure 30: a. Displaced threshold landing with raised initial approach altitude, source: [59]. b. Reduced taxi distances for medium type aircraft.

Detailed description: The dual threshold [59] or split runway [30] allows for simultaneous runway operations with two medium type aircraft on a single large runway separated into two sections. The complete runway can also be used by a single heavy type aircraft.

Operations on this runway can be split into four modes:

- In the conventional mode heavy type aircraft land at the first threshold, or take-off starting at the beginning of the full runway. Heavy type aircraft are able to use the complete runway length for their landing or take-off roll.
- During mixed mode operations with medium type aircraft the first runway section is used for landings, and the second runway section is used for departures. The two runway sections are separated such that they can be used quite independently. Care must be taken for missed approaches and overruns on the first runway section.
- During simultaneous landing operations medium aircraft follow vertically separated glide paths to both runway sections. A vertical separation allows aircraft on the first runway section to be not hindered by wake vortices from aircraft landing on the second runway section. This vertical separation is not enough without radar separation which therefore still needs to be applied between both flights.
- During simultaneous departure operations medium aircraft follow vertically separated departure paths that are laterally separated by applying a 15 degree difference in heading. By applying the vertical separated departure paths aircraft on the first runway section are free of vortex interference from aircraft departing from the second runway section.

A variation to the concept was implemented in Frankfurt having two closely spaced parallel runways [33]. The idea was to reduce the dependency between the two parallel runways, but currently the procedure is not used anymore.

Foreseen benefits: The application of dual threshold or split runway operations has a number of benefits during simultaneous operations with medium type aircraft:

1. During mixed mode and simultaneous departure operations the runway capacity is expected to increase. Verbeek showed in [59] that during simultaneous landing operations there is no net increase in runway capacity.
2. During mixed mode operations the taxi distance applied for landing and departing aircraft is minimized as the location where aircraft turn off the runway or line-up onto the runway is in the middle of the large runway. The terminal can be located near this location independently of the runway direction. This reduces time, fuel and emissions needed for taxiing operations compared to a conventional set of parallel runways. The shortened taxi time can also improve anti-icing operations during winter.

3. By using separate runway sections the long runway has the potential to reduce runway incursions as aircraft are physically separated.
4. Due to the fact that aircraft using the dual threshold runway or split runway follow the same ground track allows flights to be concentrated over the same area. This keeps aircraft noise exposure in other areas low.

Future benefits: A runway configuration with two sets of split runways does not need to accommodate aircraft runway crossings because all four runways have an exit directly to the side of the terminal. This contrasts with a conventional runway configuration with more than two parallel runways where runway crossings have to be accommodated, aircraft have to taxi around the end of the runway, or the runway system uses considerable land by applying a cascading runway system.

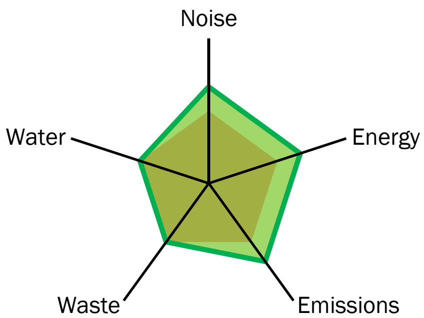


Figure 31: Expected impact of dual threshold runway on the UG KPIs.

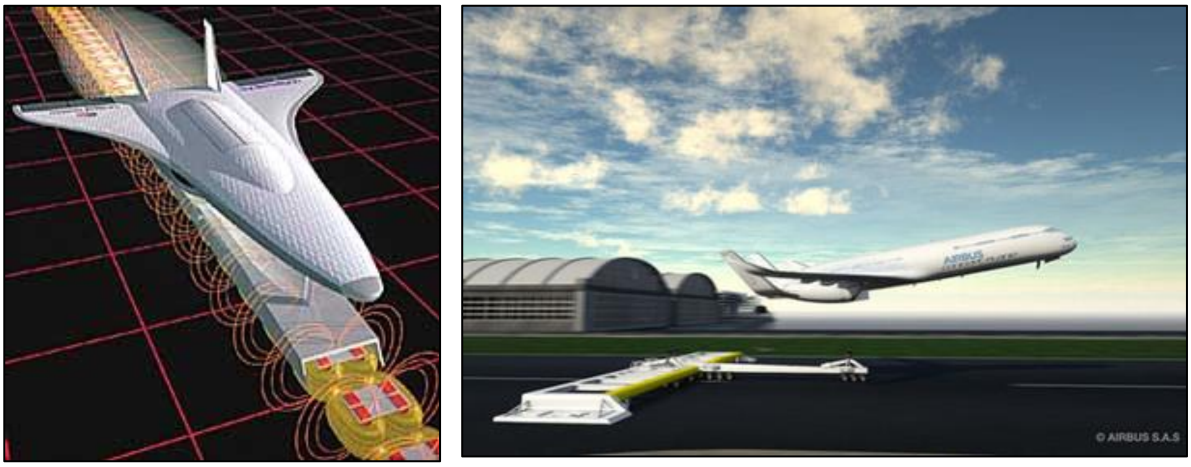
5.7.2 Magnetic Levitation (MAGLEV) for Take-off and Landing (M-TOL)

Purpose: The idea is to assist the aircraft on take-off by accelerating it through the use of ground power and to retain it again on touchdown. It is a challenging concept, requiring significant changes in fleet and infrastructure. Implementation may therefore take place significantly beyond 2050. The undercarriage design is the link to the integrated design and will dictate the steps towards implementation.

Detailed description: Currently aircraft use only own power for take-off. Depending on the type of aircraft, the atmospheric conditions and the length of the runway this translates to 150kg to 500kg of fuel consumption during the take-off roll. Considerable emissions are produced during the take-off and initial climb phase, which affect the local air quality at the airport. Also considerable noise is created, which affects surrounding neighbourhoods. This requires departure profiles to be designed and tailored for low noise impact and mitigating solutions have to be implemented on the surface.

Much can be done to mitigate these problems through aiding the take-off with magnetic levitation (see [57]) or catapult technology (this solution is already widely used by aircraft carriers) in which the aircraft, locked onto a ground module by for instance a hook to the nose wheel, would be launched forward until meeting its take-off speed. Among other benefits delivered directly by the efficiency of this flight stage it would reduce the runway length (30% less has been estimated within the “smarter skies” project of Airbus [28]) and a reduction in engine maintenance checks.

Depending on the technological solution available, the undercarriage may need to be totally or partly redesigned. The nose wheel is during conventional runway operations important for control during take-off, while the rest of the main gear is important for distributing the landing load. The main gear (as shown in Figure 32a below) is not deployed making the aerodynamic profile of the airplane smoother and thus reducing aerodynamic noise and needed thrust.



a b

Figure 32: Maglev concept for TOL: a) NASA, source [63]; b) AIRBUS, source [64].

After touch-down the aircraft needs to lose its speed, to be able to leave the runway via the runway exit. To do this the aircraft uses aerodynamic brakes, landing gear brakes and reverse engine thrust. These components need frequent maintenance due to the heavy loading and its critical application. Furthermore, the turbulence related noise produced from the high-drag aerodynamics and engine reversing is considerable as a lot of kinetic energy needs to be lost. The capturing of this energy for other purposes is among the objectives of an aided touchdown retainer system which will:

- diminish the use of on-board braking systems;
- reduce the need for long runways and multiple runway exits;
- allow the partial recovery of the kinetic energy, and
- allow landings at high cross wind limits without needing to turn towards the runway direction just before touchdown.

These ideas exploiting different technologies are currently on the scope of aircraft manufacturers [28] and are subject of interest to future airports [52]. Currently ideas for aided take-off are more mature than for aided landing. If both technologies mature then the enhancements in precision navigation and aircraft control together with magnetic levitation or other retention technologies, could deliver this conceptual system and possibly lead to smaller or even no undercarriage.

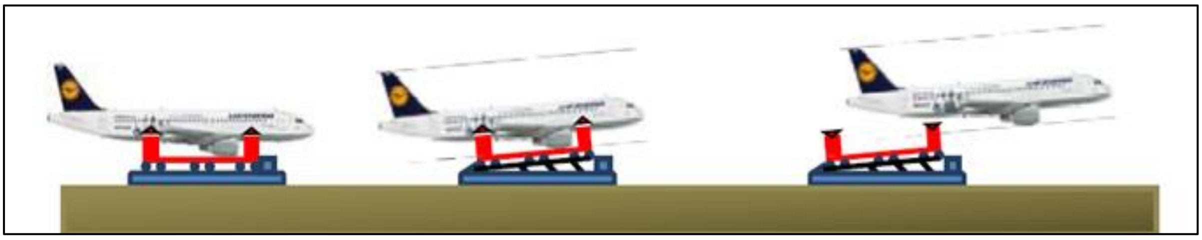


Figure 33: Aided Take-off and Touch-down retention systems conceptual design, source: [52]

Foreseen benefits: Environmental area benefits for both systems are wide ranging, beginning with a reduction in runway length and tarmac and related land use, maintenance and the possible local encroachment problems. Other benefits include a decrease in noise and emissions due to the aircraft engine operations; a decrease in fuel consumption; the reuse of captured landing energy; a reduction in lighting due to the automated landing system, and an increase in storm water retention in the ground due to increased ground absorption in the absence of an actual tarmac.

Also other KPAs such as predictability will benefit from controlled launching and braking, but are not part of this preliminary analysis.

- **Noise:** noise on take-off is reduced by cleaner a/c (aircraft) profile, lower engine thrust settings and mitigated through reduced RWY (Runway) requirement.
- **Emissions:** The quantity of fuel needed for take-off is not used anymore; Engines are smaller; drag is reduced through cleaner a/c profile; no need for thrust reverse.
- **Energy:** Energy for take-off and reverse is substituted by maglev energy (which can be tapped by many alternative sources – its mix may increase or decrease the value presented); energy on landing can be recovered by the maglev system through breaking the aircraft.

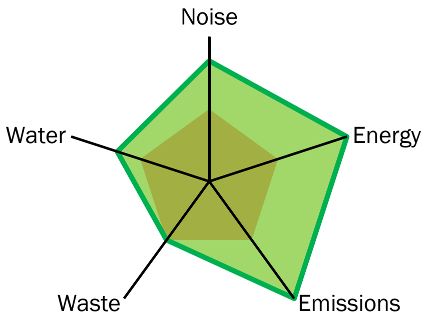


Figure 34: Expected impact of Maglev runway operations on the UG KPIs.

5.7.3 Automated Apron Services

Purpose: the purpose of the Automated Apron Services (AAS) is to make sure the service is fully automated. Automation of the turnaround processes increases predictability, control, and efficiency, and most of all leads to an uncluttered apron.

Detailed description*:* The idea is to have one system automatically offering all the services normally given on the apron.

ICAO's Annex 14 [36] defines the apron as an area intended to accommodate aircraft for purposes of loading and unloading passengers, mail or cargo, fuelling, parking and maintenance. These activities are known as turnaround (see section 4.2).

The following summations taken from section 4.2 details the services which would be included:

Service set 1:
- Fuelling operations and storage.
- Minor maintenance activities.
- Engine start.
- Provision and operation of systems for electricity, engine start assistance, and cooling and heating of the cabin.
- External and internal cleaning of the aircraft.

Service set 2:
- Load control.
- Transport of passengers between the aircraft and the terminal building and vice versa.
- Baggage handling including loading and unloading, and transporting baggage between the aircraft and the baggage handling system.
- Freight handling including loading and unloading, and transporting freight between the aircraft and the freight handling system/area.
- Consumables/waste handling including loading and unloading, and transporting between the aircraft and the appropriate handling area.

Service set 3:
- Marshalling the aircraft on the apron during arrival and departure (not required unless manoeuvre made by aircraft).
- Aircraft parking assistance (same as above).
- The movement of aircraft in between arrival and departure at the gate or parking (supported by automatic tug and further detailed in Section 5.4.2 by the Electric Ground Movement concept).
- De-icing of the aircraft at the gate or parking spot (also detailed in Section 5.4.3 by the Cleaning and De-icing Robot concept).

Additional services:
- Fire services could be included as part of the service, but covering a wider area with the same concept of been automatic and available all over the airport.
- Engine cleaning could also be added to this service, to be performed on demand.

Automated apron services should be understood as a way of controlling the different services and processes undergone by the aircraft on the apron (including other solutions related to these services detailed in other sections) in the most efficient way for its environmental sustainability, bringing also benefits to important areas such as Safety (which is not analysed here).

Centralised, decentralised or hybrid services
Depending on the needs of the airport, including platform layout flexibility, apron services can be performed in three different ways:

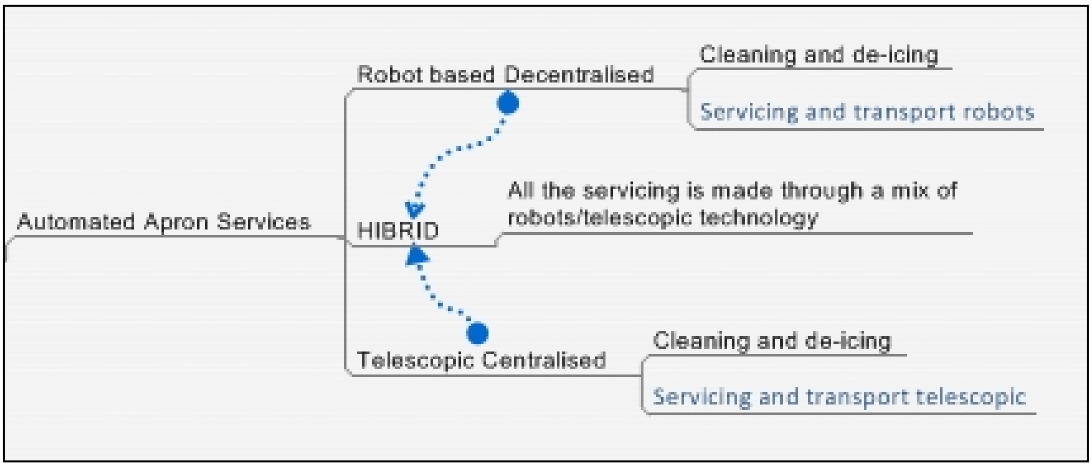


Figure 35: Automated Apron Services split into decentralised robot based, telescopic centralized and a hybrid of the two.

- **Centralised**
  Centralised provides all the services through underground-parked telescopic arms or apparatus which would offer the services automatically during the turnaround at the gate or platform.
- **Decentralised**
  Decentralised provides all the services through the use of decentralized robots which service the aircraft on demand at the preferred location on the airport. The robots will park themselves at an unobstructive location when not needed.
- **Hybrid**
  Hybrid services have a mix of decentralised and centralised services.

The premise of this system is that the apron is always left clear of any servicing moving part or vehicle. Below, a number of different centralised, decentralised and hybrid apron automation options are discussed and evaluated in terms of their foreseen benefits and KPA impact.

5.7.3.1 Service set 1 + Fire Support

Purpose: These services are fully or semi-automated, and provided by dedicated equipment at or near the aircraft. This can benefit the level of service provision, introduce a clean apron and the reduction in emissions and noise from current petrol driven ground fleets giving these services (See Figure 36 below).

Detailed description: An area of interest for future operations is to have the servicing system as an autonomous service which automatically connects to the aircraft at the gates:

Centralised (see Figure 36):

- Servicing arms are installed under the tarmac to provide services only when needed (this idea follows the global idea of having the apron working as an automated shop floor, clear and clean)

Or, decentralised (see example for transport robots):

- Refuelling through automated bots which would provide services on the platform. The refuelling bots will plug into the fuel system of the airport and the aircraft and feed the aircraft parked autonomously.
- Automated fire extinguishing system will be active during the refuelling process such that refuelling can be done without obstructing other turnaround processes (i.e. boarding) too much.

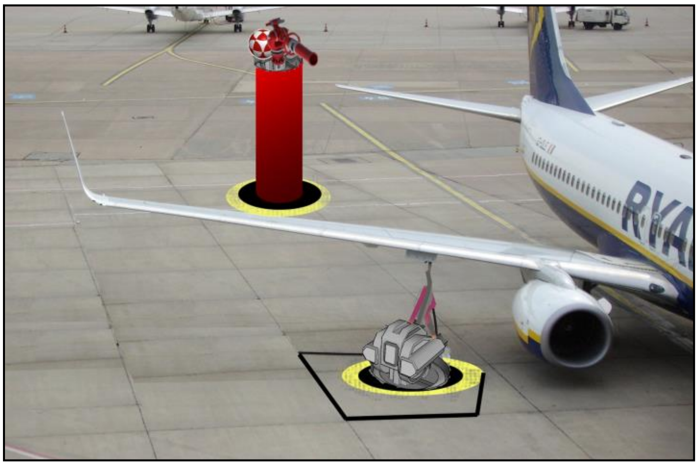


Figure 36: Re-fuelling and fire system tower.

5.7.3.2 Telescopic concealed servicing towers/arms

Purpose: To offer the dedicated required service to any type of aircraft on the apron. In Figure 36 above we see fire support and refuelling.

Detailed description*:* the telescopic towers will adapt to the aircraft and deliver the required turnaround or other apron services. Through either static or dynamic platforms all the towers will be linked to various supply networks underground (i.e. luggage, cargo, water, fuel, waste, compressed air, electricity, etc.). Once the servicing is finished the towers will disappear underground leaving the apron clear of obstacles.

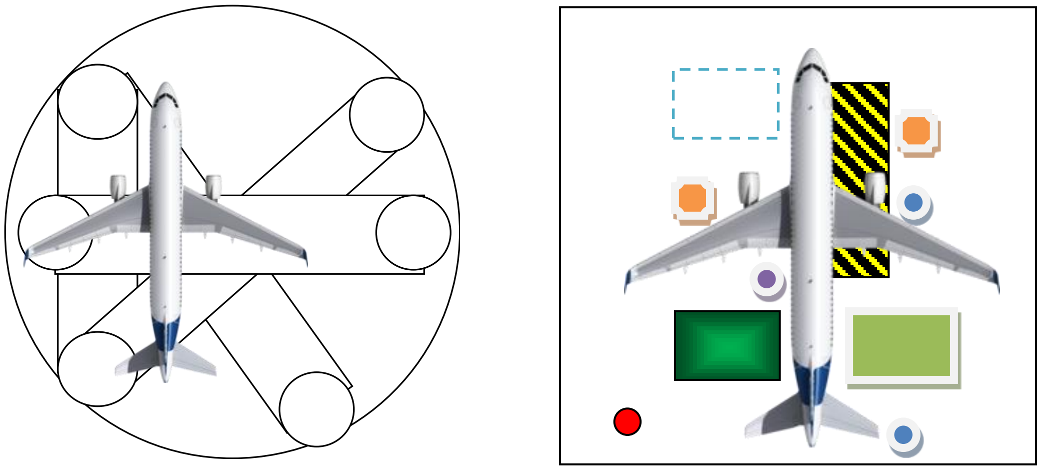


Figure 37: Moving towers (dynamic apron) and Fixed towers (static apron), A320 image: © Airbus

Foreseen benefits: More seamless and readily available service provision with no need for equipment with combustion engines or necessity of manned fire escorts. All the servicing will be done based on electric engines and centrally controlled in order to adapt to the aircraft's necessities.

5.7.3.3 Transport robots to transfer baggage, consumables & equipment

Purpose: The flexibility of robot transporters is used to increase the effectiveness of transport operations. This will support a less complex baggage transport system allowing point-to-point transport of each individual item including tail-to-tail.

Detailed description: The introduction of small robots allowing transportation of equipment, consumables, and baggage can fundamentally change the turnaround process. This concept is based on a revolutionary idea that is currently being introduced in stock picking warehouses [42] and already used on commercial work floors.

Figure 38: Warehouse robots, source: [42], © Kiva Systems.

The warehouse robots transport the stock from the storage to the stock picker. The stock picker will take the stock from the robot and puts it in the right box for the customer. The robots provide in this way the stock picker with a continuous flow of stock [42].

The concept of the transportation robot can also be introduced on the airport to transport: (1) baggage, (2) consumables and waste, and (3) equipment. The transport of individual passengers is also an option, but this is already addressed in section **Error! Reference source not found.** regarding Automated Seats (4).

Baggage:
With remote identification technology each individual piece of luggage can be identified. In this way it is known for each piece of luggage what the next destination is. This can be the security check (see Figure 41), the (transfer) flight, an intermediate storage, or the luggage pickup location. A centralized computer system can plan the next destinations of the transporters to bring or pick up luggage. Furthermore the system can optimize the sequence of handled luggage. The optimization would allow (1) prioritized handling of late luggage in the security check, (2) the sequencing of luggage when taken on-board such that expected short transfers are entered last-in-first-out resulting in no time lost during the connection, (3) the sequencing of luggage such that the aircraft has an improved centre of gravity for optimal flight performance, and (4) fast and dedicated tail-to-tail transport of transfer baggage.

Consumables:
Consumables and waste can be handled by the same transporter as the luggage. Only the destinations are different. Furthermore it is possible to pass the consumables through the same security check as the luggage before it is allowed into the aircraft. The quantity of consumables can be adjusted just-in-time to the number of passengers on-board or even to the passengers wishes indicated just before the flight through the passengers personal information device. This reduces the amount/quantity of consumables needed for each flight, and consequently reduces the weight of consumables transported by air.

Waste:
Waste that has been separated on-board can be transported by the transport robots to the appropriate waste recycling locations depending on the waste material types. By incorporating weight measurement capabilities in the transport robots it becomes possible to let the airline pay for the waste depending on the weight and type of waste. This will promote waste reduction and waste separation.

Equipment:
Equipment that is needed for the turnaround process can also be transported to the right locations by using multiple transport robots in a collaborative fashion. Due to the centralized planning it is possible to have equipment positioned at or taken away from the aircraft just-in-time. In this way the quantity of equipment on the total airport can be minimized.

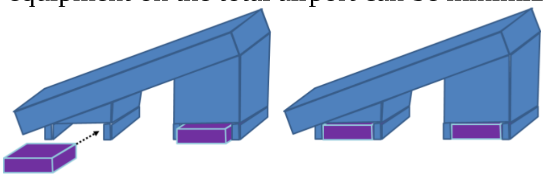


Figure 39: Equipment (blue) is moved by multiple transport robots (purple)

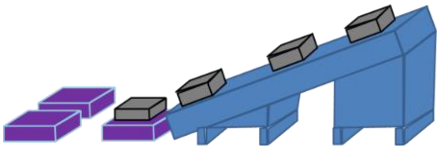


Figure 40: Luggage (grey) is handled individually by transport robots (purple).

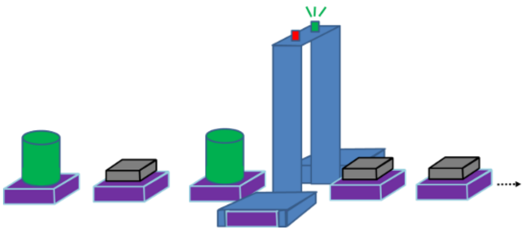


Figure 41: Security equipment can be transported to the needed location for screening.

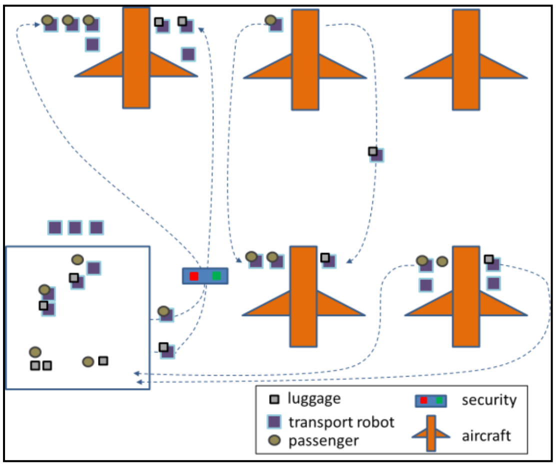


Figure 42: Transport of luggage between a central terminal and aircraft using transporters.

The transporters being electric would not produce emissions locally. The batteries for the robots can be charged at charging stations, or replaced at battery switching stations. Individual robots can easily be taken out of rotation for maintenance without disturbing the overall airport process. The number of robots can easily be adjusted to accommodate the current needs. Robots can be moved eventually between airports to adjust to changes in the seasonal capacity needs.

Foreseen benefits: The concept of transports aims to make individual transport of baggage and other items within the airport possible. This replaces the complex and energy consuming baggage handling systems and apron vehicles currently used at airports. This saves energy and, moreover, it supports flexible and efficient turnaround operations. Further research is required however to investigate the feasibility of the concept at large, busy airports, involving a large number of individual movements.

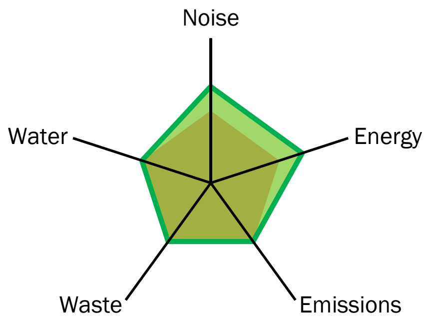


Figure 43: Expected impact of transport robots on the UG KPIs.

5.7.3.4 Optimised load control

Purpose: The loading of aircraft can be optimised when cargo and passengers are weighted systematically, and when this information is used to optimize the weight distribution whilst loading the aircraft.

Detailed description: For load control the transport robots can be equipped with weight measurement equipment. In this way the transport robots can determine for each piece of luggage, the consumables, and even the passengers what their weight is. This data can be used for a smart loading of the aircraft for an optimal placement of the aircraft centre of gravity. This in itself will improve the aircraft efficiency and performance. An improvement of the weight estimate for the fuel calculations will give an additional improvement of the aircraft efficiency as on average less reserve fuel needs to be carried. The optimized load control can instruct the centralized computer system for the transport robots about the loading sequence for the luggage, and boarding sequence for the passengers.

Foreseen benefits: When aircraft are loaded carefully to maintain a balanced distribution of weight, this may help to save fuel during the flight.

5.7.3.5 Anti-icing and De-icing services and Pads

Purpose: Improving anti-icing and de-icing services with the objective to reduce waste, energy and water pollution (See Figure 44).

Detailed description: Possibly new technologies and fluids or aircraft materials will be available to make this service, more efficient, effective and environmentally more friendly. The real change here described is actually on the way the anti-icing and de-icing service are applied: through automated underground towers and/or bots (i.e. linked to robot cleaners See section 5.4.3) available throughout the apron.

Currently organic volatile fluids are applied to remove and to prevent icing. Modern, more advanced techniques may apply physical rather than chemical techniques and as another example, advanced materials, deploying super-lubricious thin layers may contribute to reduce the use of organic fluid liquids with damaging properties. Overall the service would be given in place when required or on specific self-contained pads (as shown in Figure 44 below).

Figure 44: Automated de-icing bots, when finished the bots return underground.

Foreseen benefits: Automation means control can be optimised and improved digitally; the need for anti/de-icing trucks movement on the apron is null (good for fuel consumption and safety related to too much traffic on the apron); queuing for the service is reduced thanks to decentralised towers; use of light wave technology (whichever is available for de-icing, as infrared lamps or lasers) can be applied surgically.

Overall Foreseen benefits of the Automated Apron Services system: Although each of the solutions pertaining to the AAS may tackle or benefit one of the indicators more, what needs to be underscored is that each service will be provided automatically, efficiently and as quickly as possible by a centralised or decentralised system which will always disappear once its work is finished. The result of this is better control over the services and a radical reduction in fuel consumption (partially obtainable nowadays by changes in the handling vehicles' fleet).

In summary, the following main benefits are foreseen:

- **Noise:** Environmental noise around the aircraft servicing will be reduced due to the use of electric engines. Aircraft will be supported with load control, substantially improving their performance on take-off and the need for extra fuel. The apron services supported by the APU will not be required, thus decreasing the noise produced by it.
- **Emissions:** the reduction in emissions is the result of not requiring services provided with the support of combustion engines, the drastic reduction of apron traffic and the exclusion of the APU from the services provided by the airport via the AAS.
- **Energy:** The use of energy will increase, but will be a shift to electric power as opposed to fossil fuel power, compensating. Electric power will be used in the most efficient and predictable way, through direct energy management.
- **Waste:** in general terms the type of waste may change (tyres vs valves), but the idea of this system is actually to contain the waste which occurs during the supply of the services.
- **Water:** this idea does not affect the water consumption (KPI) directly, although it opens the possibility of controlling its supply and recycling.

These benefits can be depicted in a radar graph illustrating the impact of this concept idea on 5 relevant UG KPIs:

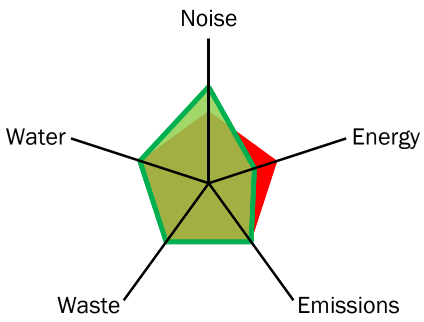


Figure 45: Expected impact of Anti-icing and De-icing services and Pads on the UG KPIs.

Note: also other KPAs (Key Performance Area) will benefit, such as Safety, from having the apron clear of traffic or parked vehicles, which currently clutter the apron.

5.7.4 High pier turnaround

Purpose: The purpose of the High Pier concept is to reduce the turnaround time and make the airport more compact, while centralising and allowing more control over the turnaround services.

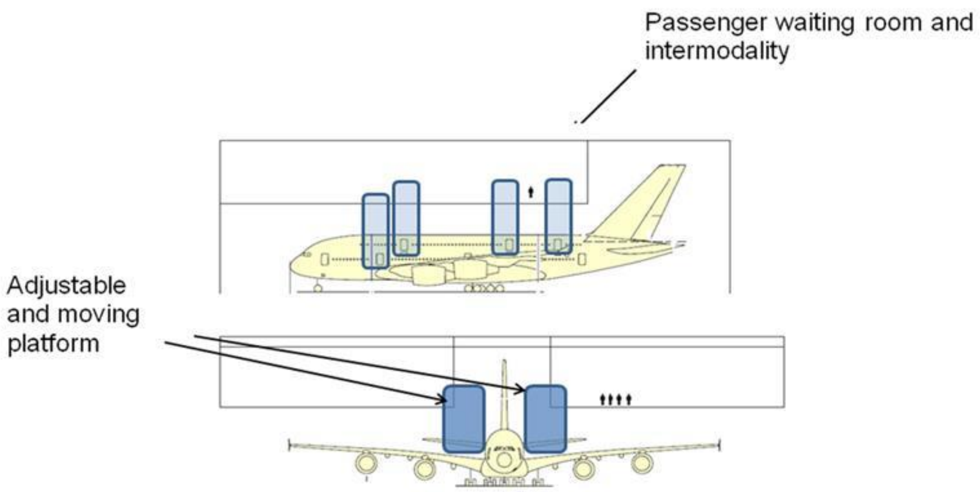
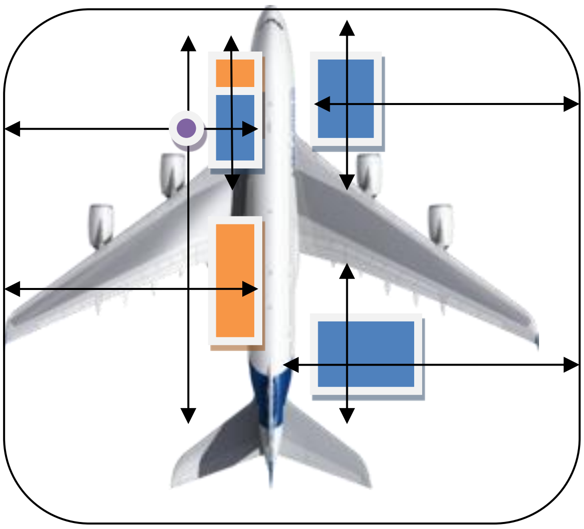


Figure 46: The High Pier disposition.

Detailed description: The High pier concept layout is similar to that of a hangar and has a building placed above the stand position of the aircraft. This terminal building is oriented perpendicular to the aircraft taxiways, allowing the aircraft to be placed below the building. The passenger boarding will be made from platforms hanging above the aircraft stand position. Furthermore, it allows separation of boarding and servicing so that the boarding is made from a higher level and does not interfere with other turnaround processes.



The boarding/de-boarding towers will extend and adapt to the aircraft that needs to be serviced.

The aircraft will be pulled into the high pier and serviced as necessary in a contained environment. The tugging will be executed on time and through automated or centrally controlled bots.

The whole turnaround will be centrally controlled offering also additional and simultaneous services like fire control and anti/de-icing.

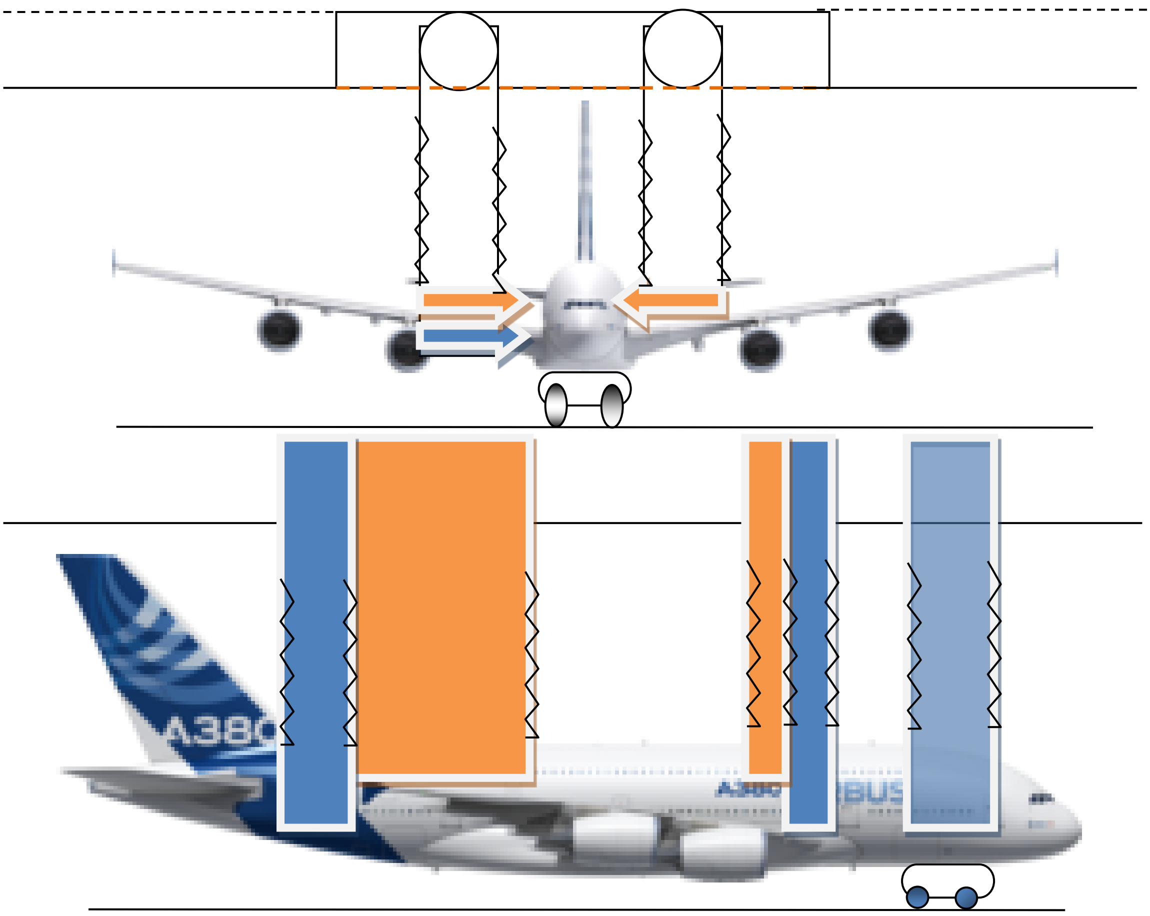


Figure 47: Deployment of elevators/towers for the boarding/de-boarding of passengers, A380 image: © Airbus

.

Foreseen benefits: Although this concept is also used within the Time Efficient airport, it has also been accepted to be an acceptable concept idea for the UG airport for the following reasons:

- The high pier airport eliminates the need for vehicles (handling, servicing, fuel, passenger buses, etc..) by offering one location where all the servicing and turnaround are made automatically;
- There is no need for pushback since all the movements are done through electric tugs;

- Since servicing and turnaround are made in the same place, fire services and de/anti-icing can be applied in a controlled environment reducing the possibility for spilling.

In summary, with regard to the KPIs the following main benefits are foreseen:

- **Noise:** Environmental noise due to servicing will be reduced since the operations are made in a closed or partially enclosed infrastructure (does not affect noise produced during the LTO cycle).
- **Emissions:** Emissions from servicing vehicles is eliminated and replaced by electric systems. Electric tugs are used for moving the aircraft in and out of the pier and for taxing;
- **Energy:** Energy use will increase. The control of the system will improve since it can adapt to the necessities and can be centrally controlled regarding all services. Moreover, compacting the infrastructure of the airport will result in reduced heating energy requirements.
- **Waste:** Waste control may possibly benefit by having all the services centralised and monitored directly.
- **Water:** The high pier does not have a direct effect on water use.

These benefits can be depicted in a radar graph illustrating the impact of this concept idea on 5 relevant UG KPIs:

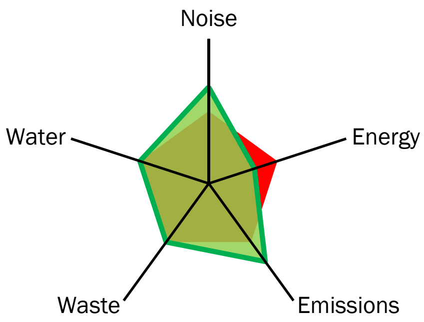


Figure 48: Expected impact of high pier turnaround on the UG KPIs.

***Future Benefits**:* The boarding/de-boarding of passengers from above the aircraft makes it a good platform for the location of an intermodal hub (see Figure 49). Trains will leave the passengers inside the high pier directly above the serviced aircraft. Environmentally speaking, this deployment would make the airport potentially more compact in design and more controllable.

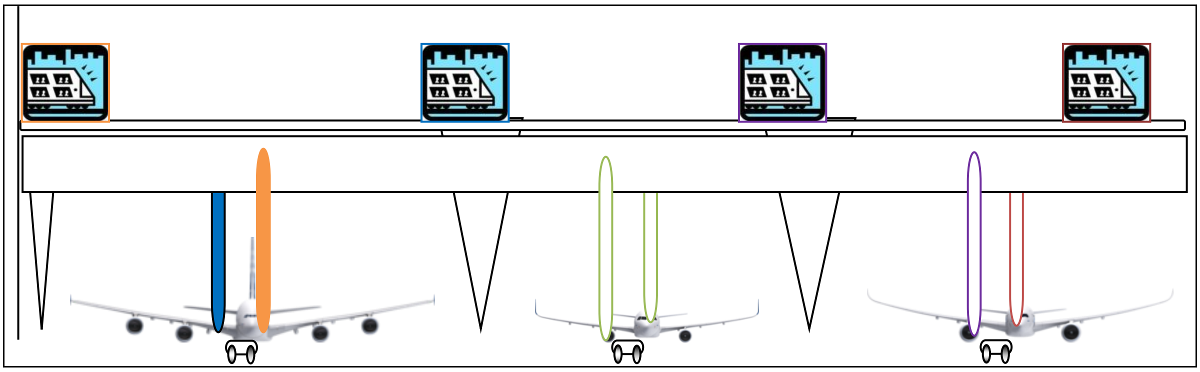


Figure 49: Integration of train to the high pier (intermodality), A320, A350, A380 images: © Airbus

5.7.5 Weather protected turnaround

Purpose: A semi-permeable roof weather protects activities in support of turnaround operations. From an environmental point of view this is done to avoid fuel and oil residues, and de-icing chemicals getting mixed with precipitation on the tarmac (see also sub-section 4.1.3). Furthermore, the roof will protect ground personal and passengers and the aircraft against the impact of weather.

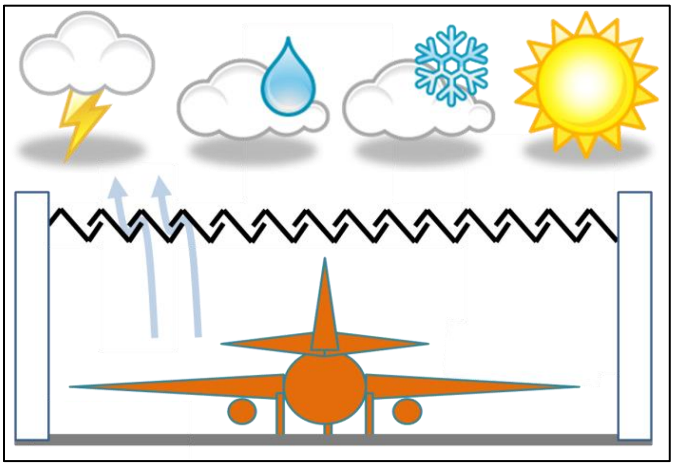


Figure 50: A semi-permeable roof allows heat and gases to pass, but no precipitation.

Detailed description: The turnaround process is performed outside. The main reasons for this is that (1) refuelling operations may not be performed inside enclosed spaces, and that aircraft must be parked at some distance from buildings due to jet blast considerations.

By introducing a roof that is permeable for gaseous substances and hot air, but not for precipitation it is in theory possible to allow aircraft refuelling under a weather protected roof. The permeable roof will also allow air pressure from jet blast to be relieved. These roofs can be placed at the gates, as extensions of the terminal building, or covering remote stands.

A permeable roof can be created by using N-shaped roof elements that are placed next to each other with a large air gap (see Figure 50). The air gap allows gasses and hot air to pass unhindered through the roof. Any precipitation falling onto the roof does not pass through it and can be transported along the gutters to the sides and does not reach the aircraft situated underneath.

The design of a semi-permeable roof has to take into account that supporting structures do not hinder aircraft movements and get into contact with the aircraft, and that snow and ice do not block the air gaps of the roof. Also the roof should allow enough daylight to pass through such that during the daytime no additional lighting is necessary.

Foreseen benefits: With the roof over the aircraft during the turnaround a number of benefits are introduced.

First of all, personnel and ground equipment can be protected from rain, snow, hail and excessive sun. This maintains productivity of personnel and reduces wear and tear of the equipment. Secondly, passengers and baggage are also protected from weather influences increasing the wellbeing of passengers, and reduces liabilities due to weather damaged baggage. Thirdly, the aircraft is protected from snow and hail. This reduces the need for aircraft de-icing minimizing departure delays in winter. Fourthly, the aircraft is protected from excessive sun, reducing the need for air conditioning during the turnaround. And fifthly, the precipitation can be collected before it has the chance of mixing with aircraft related chemicals and fuels on the tarmac. This reduces the need to separate the chemicals and fuels from the precipitation afterwards. The collected precipitation can be used unfiltered for watering vegetation around and in the airport, and for grey water toilets. Cold precipitation can be used in thermal storage and re-used in hot periods reducing the need for air conditioning.

Future benefits: This semi-permeable roof concept can be an enabler for terminal concepts that try to optimize/automate the turnaround operations like the drive-through-airport [www.drivethroughairport.com], the high turnaround concept, and the automated apron concept. Also it is conceivable that some types of equipment, like lighting, are hung from the ceiling instead of placing them on the apron making room on the apron for other operations.

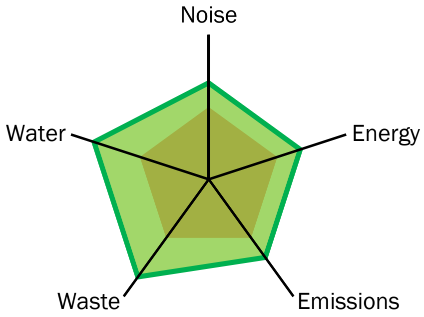


Figure 51: Expected impact of weather protected turnaround on the UG KPIs.

5.7.6 Shielding landing and take-off operation by landscape design

Purpose: By adapting the landscape design next to the runway beneficial effects can be created on noise exposure, cross-wind conditions and bird collision probabilities during runway operations. There are no major technical problems, but rather logistic, institutional and infrastructural problems to overcome.

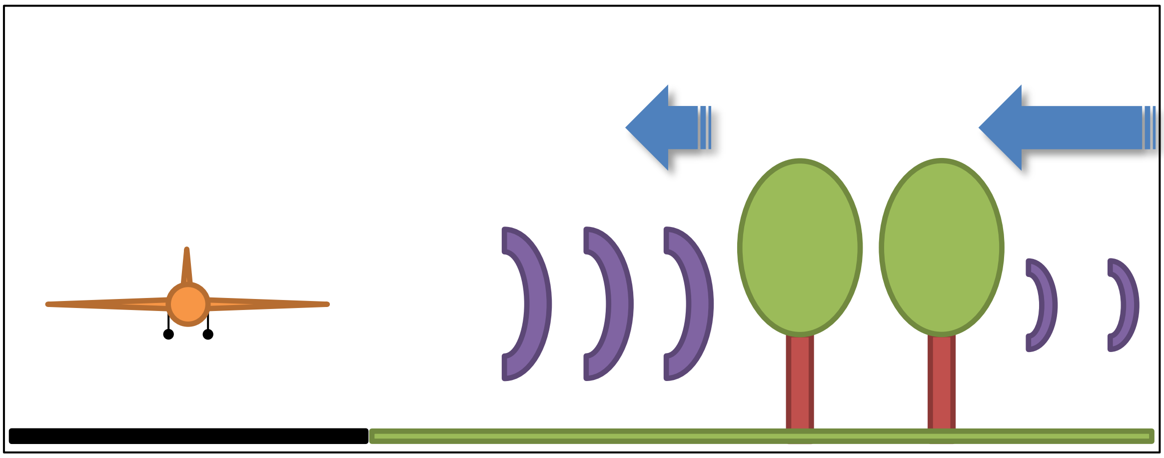


Figure 52: Shielding of runway operations through landscape design.

Detailed description: Take-off and landing operations are critical. Crosswind can especially deteriorate the landing conditions. Also noise from low flying aircraft can disturb local communities.

Shielding of the flight path is a concept that aims to reduce the effect of crosswind (depicted by blue arrows in Figure 48) on aircraft near the runway, and noise (depicted by purple wavelike shapes) on the surroundings. Several types of shielding can be considered. These include (1) shielding walls containing holes to reduce swirling effects, (2) landscape designs with pyramids and ridges to reduce ground noise effects, (3) dynamic walls that can be raised and lowered depending on the type of runway operation, and (4) placing high vegetation between the runway and urban areas.

The shielding is placed next to the runway and next to the last section of the flight path. The shielding is placed such that it is effectively reducing crosswind where it is most critical. This includes taking into account effects on how the boundary layer develops beyond the shield. The shielding is also placed such that it is clear of the obstacle free zone according to ICAO regulations. To be effective in respect to noise attenuation during thrust reversing and take-off runs on the runway the shielding should be as close as possible to the runway. Beyond the runway the shielding has no effect on aircraft noise.

The airport must provide the grounds for the forest, and must invest time and energy in realizing the forest.

Foreseen benefits: When the shielding is effective the crosswind conditions during the flair, touchdown and landing roll are alleviated. Trees tend to diminish wind forces without creating large vortices like is the case with sharp landscape structures. As a result of the lower wind forces the runway can be used during a wider range of wind conditions. This will allow runway control to keep using capacity or noise preferred runways for longer periods of time. Furthermore airlines can use the runway that is in the preferred direction more often resulting in fewer detours and therefore reduced fuel consumption and emissions

With noise shielding the effects of aircraft noise on local communities are reduced. This is not only the result of the reduction in noise levels, but also due to the fact that for some communities the aircraft are partly out of sight by the trees. As a result of this the awareness of the presence of these aircraft is reduced lowering nuisance further.

Flocks of large birds have a preference for flat areas with low vegetation (e.g. grassland areas). Both the size and the numbers of these birds make them dangerous to have around airports. High vegetation like forests and bushes will less likely attract these types of birds. Although also some forest loving birds can be still a problem. Therefore a smart landscape design can improve safety at the airport [46].

A forest can create also an additional value to local communities as a recreational area. This can also improve the relationship of the airport with the local community.

Depending on the local flora species and the types of trees that are used a forest has the disadvantage that it mostly only effective in summer, and not during the winter period when leafs have fallen of the trees. However, summer is the season that people tend to stay more hours outside and airlines have mostly their seasonal peaks. So, though the shielding by a forest is sometimes less, it provides the most shielding at the time it is most needed.

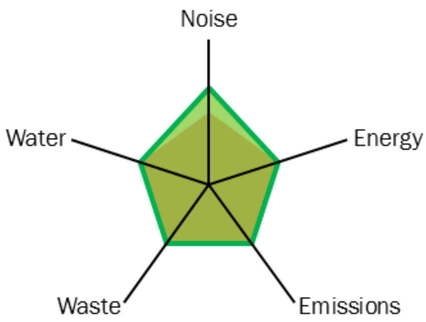


Figure 53: Expected impact of the shielding of runway operations on the UG KPIs.

5.8 Summary of the advanced Ultra-Green concept

Operations connecting the airport and aircraft movements at the airport are the most challenging aspects for airport greening. Integrating these operations can reduce aircraft emissions and result in overall environmental improvement. Leaving aside those improvements which fall prominently in the ATM domain, all operations based on aircraft or ground combustion engines will be reduced or replaced by electric movement in order to reduce or even eliminate emissions. An extension of electric movement beyond the take-off roll can be added through electric engine accelerators.

The advanced UG airport for 2050 and beyond is part of the Transport Network within Europe. It will take part in servicing a broad range of destinations. The longer distances are connected through the air, but with future intermodal hubs most commutes are with other modes of transport such as rail and road transport. To improve the effectiveness of such an intermodal hub, so-called city terminals connecting to a remote central airport terminal will be used. These city terminals will be situated within a few metropolitan cities with high speed connections to the single, central airport.

The airport can also be reached by autonomous electric vehicles which are available to the traveller. These autonomous vehicles are part of the normal day-to-day transport. People use them on demand to reach their destination within a two hour driving radius. This includes the airport for making longer distance hops. At the airport these autonomous vehicles drop off and pick up passengers and their baggage. As these autonomous vehicles are continuously active there is limited need for parking space at or near the airport.

The traveller makes a well-considered choice regarding the modes of transport to his destination. With the help of a personal information device that is familiar with personal (environmental) preferences, the desired time schedule and budgetary constraints, the best combination of transports is identified. This can be just an autonomous vehicle for distances up to 400km, or an additional high speed train for distances up to a 1000km, up to an aircraft for even longer distances. The personal information device is used for checking in for the complete commute from door-to-door and is ensuring that the passenger starts his travel just-in-time to have a semi-continuous trip with limited transfer times. Independent of the mode of transport (road/rail/air) the passenger can be active regarding work, communication, multimedia, or just reading. This allows the travelling to be minimally intrusive.

When the air traveller reaches the airport terminal the baggage is dropped off as soon as possible. The passenger walks through the security or is transported by an automatic seat system via security to the gate, and the baggage is in the meantime handled through the transport robot system. The transporter takes baggage individually through the security screening, and then to the aircraft or the meet-up location. If there is still time left the baggage is stored to free up the transporter for other tasks. The transporters allow baggage to be handled one-by-one and therefore to be entered into the aircraft or the Unit Load Devices in such a way that the aircraft has a good weight distribution. Time critical baggage is loaded last-in-first-out to make tail-to-tail connections at the destination as quick as possible. The transporters are also used for providing aircraft with consumables, and the transport of waste materials from the aircraft.

The aircraft can be standing at the terminal connected through a pier, but also on the platform. This allows making optimal use of the limited space available at the airport. The aircraft stands are weather protected through semi-permeable roofs. The weather protection is not only for the aircraft, but also for the personal, ground equipment, baggage and cargo, and passengers. Personal are protected from precipitation and excessive exposure to the sun, ground equipment is protected from excessive wear through weather influences, baggage and cargo is protected from water damage, and passengers on the platform stay dry when entering the aircraft. The most important advantage for the aircraft is the protection from cold precipitation like snow, hail and freezing dew and the heating up of the aircraft in the blazing sun. With the weather protection there is less need for de-icing operations during turnaround, and lower energy needs for the air conditioning.
Despite the use of semi-permeable roofs for turnaround, anti-icing and possibly de-icing may still be necessary. To this end, a de/anti-icing robot can be used at the gate that clamps to aircraft and moves along the surface of the aircraft to remove snow and ice and spread anti-ice products. As the de/anti-icing robot is close to the aircraft the de-icing fluids used by the de/anti-icing robot can be easily captured by the robot for recycling afterwards.

Similar to the de/anti-icing robot a cleaning robot can be used that moves along the surface of the aircraft to remove dirt and oil residues. This will allow the aircraft to have less drag, and a lower take-off weight. As the cleaning may take more time then is available during the turnaround the cleaning can be distributed over several turnarounds cleaning each time a different part of the aircraft.

During turnaround, the aircraft is provided with electric grid energy and climatized air. Therefore the aircraft does not produce emissions through the APU usage. The climatized air is produced through the usage of an underground cold/heat storage that collects heat in the summer and cold in the winter.

Once the aircraft is ready for departure the aircraft will do a pushback through electric engines fitted within the landing gear powered by the APU, or through assistance of an automated electric pushback tug. The aircraft can taxi on its own to the runway using the electric engines on the gear, or assisted through an electric tug or using a recessed towing mechanism. In this way the aircraft does not need to use main engine power until a few minutes before the actual take-off.

The actual lift-off of the aircraft will be assisted through the use of a Magnetic Levitation system accelerating the aircraft beyond lift-off speed. This will reduce the take-off power needed by the aircraft resulting in a direct reduction in fuel consumption and emissions. The overspeed can also result in a reduced power setting during the initial climb phase to reduce noise exposure to the local community.

The aircraft can also land on the Magnetic Levitation system. The advantage here is that this can be done at high cross wind levels as the MagLev platform can be turned into the wind and the aircraft does not need to decrab upon landing. Without the cross wind limit the airport can be quite compact with only a set of parallel runways and no intersecting runways allowing specific wind conditions.

An alternative to the assisted take-off is through the use of electric engine accelerators, provided with batteries/accumulators/energy cells, that are attached to the aircraft for use during the take-off and initial climb phase. These electric engine accelerators are dropped off the aircraft just after the initial climb, and can be flown back to the airport as RPAS for reuse. The take-off assistance through electric engine accelerators (and MAGLEV) allows the aircraft to save considerably on fuel consumption during the take-off and initial climb, and can also allow the assisted aircraft to have reduced size engines as the take-off and initial climb are determining factors for the engine size and weight. This reduction in engine size and weight will further save on fuel consumption during the cruise phase of the flight.

The landing path at the airport will be protected through the use of trees. This vegetation will reduce the cross wind experienced by aircraft on the runway increasing acceptable cross wind limits. Furthermore, aircraft noise is reduced next to the airport.

The airport layout can possibly be further improved through the use of a dual split runway configuration. This will improve the airport capacity, and reduce the taxiing distances from the runway entrance/exit to the terminal and vice versa. This split runway configuration allows medium type aircraft to use simultaneously two halves of the runway, whilst heavy aircraft use the complete runway.

6 Value assessment of the Ultra-green airport concept

This chapter discusses the validation of the Ultra-Green concept, which is based on the outcomes of the second validation cycle in WP3. The results are obtained from the second validation workshop held on June 19 2013 at the Polytechnic University in Madrid [65]. Goal of the workshop has been to determine together with a large audience of external stakeholders the most appropriate concept ideas supporting the Ultra-Green, Cost-Effective and Time-Efficient airport of 2050+. To accomplish this, the workshop was split up in five parts:

1. A brainstorm to select concept ideas from the initial list of ideas, and create new ones, assuming five different roles (i.e., airport, airline, passenger, ANSP, industry)
2. An expert judgment exercise (value definition) to prioritize the relevant attributes/KPIs per concept (example attributes: emissions, average taxi time, aeronautical costs)
3. A strategy game to rank the ideas per role selected in 1), from 5 (best) to 1 (worst), and identify the priorities of each stakeholder
4. An expert judgment exercise (value assessment) to assess the impact of each concept idea on each concept attribute/KPI, from ++ (very positive impact) to -- (very negative)
5. A concluding exercise to link the three best ideas ranked in 3) together to consolidate each concept

This chapter presents a post-analysis of the workshop results and draws conclusions on the expected benefits of the UG airport concept's ideas. The focus here is on the workshop conclusions relevant for the UG airport concept, whilst the workshop report [65] focuses on general conclusions and their impact on methodology and concept validity. This chapter furthermore investigates which concept ideas from the Time-Efficient and Cost-Effective airport concepts could be beneficial for the UG airport concept.

The chapter is structured as follows;

- Section 6.1 summarises UG's operational changes to the airport's invariant processes as proposed in the previous chapter.
- Section 6.2 presents the value function which has been established by expert judgement to assess the relevant attributes per concept.
- Sections 6.3 and 6.4 discuss the validation results of the experts gaming and judgement sessions respectively.
- The chapter is concluded in Section 6.5 with the best ideas and perspective of the UG airport concept and presents recommendations for further development.

6.1 Identification of operational changes in the Ultra-Green concept

The UG concept solutions presented in the previous chapter imply several operational changes to the airport's invariant processes (see Figure 5 above). Although the processes in terms of functional description are not changed, their location and the way they are performed may be modified by the implementation of the concept ideas proposed in the previous chapter. These modifications can be summarised as follows for each invariant process:

- **Landing and take-off process:** The UG airport concept proposes a number of ideas to reduce the environmental impact of landing and take-off. First, magnetic levitation is proposed to allow aircraft by means of a rail-gun or catapult to take-off with limited aircraft engine power. Combined with a touch-down retention system important benefits may be achieved by saving fuel for take-off, reducing overall aircraft weight, and retaining energy at touch-down. Second, electric engine accelerators, carried by autonomous drones returning to the airport, may importantly reduce emissions and energy use during take-off and initial climb. Third, the use of parafoils (steerable parachutes) may allow for low-noise landings on shorter landing runways, reducing the airport's land use and noise footprint. Fourth, shielding take-off and landing operations with vegetation will capture carbon and absorb noise produced during take-off and landing, thus improving living conditions in the vicinity of the airport. Finally, a dual/split threshold runway allows for simultaneous landings on the same runway, reducing taxi-distance (and thus fuel), land-use and the noise footprint at the airport.

- **Taxi process**: For the taxi process, the use of electric ground movement is proposed to reduce noise, emissions and energy use during taxiing. The main purpose of electric ground movement is to prevent the aircraft from using its main engines for taxiing. Electric ground movement can be implemented either by an electrical engine in the nose wheel or main gear or a stationary recessed towing system integrated in the taxiways and aprons.
- **Turnaround process**: Several ideas are proposed to 'green' the turnaround process. First, a cleaning and de-icing robot may clean aircraft more efficiently, saving fuel in-flight, and doing the de-ice at the gate, and reducing water pollution by recycling de-icing fluids. Second, a weather protected turnaround by means of a semi-permeable roof may significantly reduce the need for de-icing. This yields, together with the possibility to collect precipitation and block sunlight, important environmental benefits. Third, automated apron services lead, via a system automating and integrating all services performed during turnaround, to a reduction of fuel use. For instance, the use of electric telescopic towers for refuelling or baggage (un)loading renders the use of fuelling trucks or baggage carts superfluous. Fourth, the high pier concept, allowing aircraft to park below the passenger terminals/concourses, eliminates the need for passenger buses and for push-back, thus saving fuel.
- **Passenger and baggage transport**: For door-to-airport transport electric cars are proposed to substitute current-day car transport. This leads to reduced local emissions. In addition, a city & single central terminal may be used to allow passengers to board at a city terminal and use electric mass transport to cluster city-to-airport traffic. This eliminates the need for individual, less energy-efficient transportation and may allow airports to be located further away from the city – preventing noise pollution in high-populated areas. Within the airport, an automated moving seat system is proposed to take passengers on their seat from the departure hall to the aircraft, and from the aircraft to the arrival hall. By rendering a number of current-day processes obsolete, this automated seat system may lead to reduced land-use of the airport; in addition, a lower weight (no empty seats) and better balance of weight on-board the aircraft may yield reduced emissions and noise. Alternatively, electric transport robots may be used to transfer baggage to and from the aircraft. The use of transport robots for baggage may save energy over the use of continuously running conveyor belts, and by sequencing baggage the weight distribution on-board the aircraft is improved leading to reduced fuel usage in-flight.
- **Infrastructure**: Many of the concept ideas presented above have a large impact on the infrastructure of the airport. This particularly holds true for the following concept ideas: magnetic levitation for take-off, dual/split threshold runway, parafoil landing, high-pier for turnaround, automated apron services, city and single central terminal, weather protected turnaround, and recessed towing systems.

During the validation workshop the concept ideas were presented in a simple, short format and participants were encouraged to think of the changes these ideas imply for the airport's operation. From this an expert judgment of the expected impact on the five Ultra-Green attributes noise, energy, waste, emissions and water use was made for each idea.

6.2 Composing a value function to evaluate the concept

6.2.1 Determination of the value function

The value function was established at a high-level in WP2, as is described in the Concept Development Methodology in D2.1.2 [10]. Based on the high-level objectives for each concept, a set of low-level attributes were then iteratively established throughout the project to further define the value function. Recall the value function from D2.1.2:

$$\Delta V(AP_{2011}^{2050}) = \lambda_E \left(\frac{E_{2050}}{E_{2011}} \right) + \lambda_M \left(\frac{M_{2050}}{M_{2011}} \right) + \lambda_S \left(\frac{S_{2050}}{S_{2011}} \right) \quad (1)$$

Where ΔV represents the change in value, λ_i represents the weight of the different objective areas, and *E*, *M*, and *S* refer to sustainability (UG), economics (CE), and mobility (TE) respectively. Taking ω_i as the weight of the low-level attributes *noise*, *energy*, *waster*, *emissions*, and *water*, the Ultra-Green element *S* in the contribution per area in equation (1) can be described further by its low-level attributes in the form:

$$\left(\frac{S_{2050}}{S_{2011}}\right) = \omega_1\left(\frac{noise_{2050}}{noise_{2011}}\right) + \omega_2\left(\frac{energy_{2050}}{energy_{2011}}\right) + \omega_3\left(\frac{waste_{2050}}{waste_{2011}}\right) + \omega_4\left(\frac{emissions_{2050}}{emissions_{2011}}\right) + \omega_5\left(\frac{water_{2050}}{water_{2011}}\right) \quad (2)$$

Similarly, the low-level attributes of economics and time-efficiency can be included. The (final) value function that has been used during the validation workshop included 16 low-level attributes. Workshop participants had the opportunity to propose new attributes to be included, but these were not taken into account during the final, quantitative analysis of the workshop results.

6.2.2 Determination of the weight factors

The weight factors were determined per concept from expert judgement during the validation workshop. All stakeholders (airport, airline, passenger, ANSP, and industry) were asked to – *from a time-efficiency point of view* – give

1. a distribution of weights for the three key performance areas (KPAs) λ_i , and
2. a distribution of weights for the low-level attributes (KPIs) per KPA ω_i .

The weight factors given by the experts were averaged from the different stakeholder roles during the workshop. The final weight distribution for the KPAs is given in Figure 54 below.

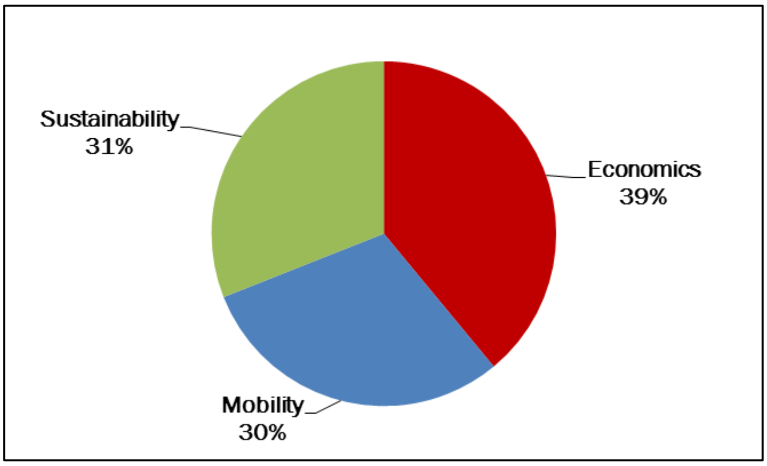


Figure 54: Weight distribution of the three KPAs for the UG airport concept.

The weight distribution for all low-level attributes, i.e. including those related to Cost-Effective and Time-Efficient, is given in Table 12 below. Note that this table expresses the relative importance of each low-level attribute for Ultra-Green, with weights adding up to 1 for each concept.

Table 12: Weight distribution of all low-level attributes for the UG airport concept

Low-level attribute	Importance for the Ultra-Green (i.e. weight factor)
Ultra-green	
Keep noise within or below legal limit	0,28
Reduce energy use	0,24
Reduce emissions	0,22
Optimal use of resources (recycling)	0,15
Optimal use of water	0,11
total	*1,00*
Time-efficient	
Minimise taxi times	0,10
Minimise turnaround time	0,18
Minimise delays	0,15
Minimise travel time through airport	0,07
Minimise waiting time between processes	0,13
Minimise processing time	0,12
Minimise connecting times between modes	0,27
total	*1,00*
Cost-effective	
Reduce Aeronautical Cost	0,23
Reduce Non-aeronautical cost	0,18
Increase Aeronautical income	0,27
Increase Non-aeronautical income	0,32
total	*1,00*

A few notes are in place here. First of all, in the UG airport concept time efficiency and economics still play an important role in the determination of the added value. In addition, economics (Cost-Effectiveness) is the most important KPA with a weight of 39%; sustainability (Ultra-Green) has a 31% share of total weight. Regarding the low-level attributes of sustainability, it can be concluded that first of all noise reduction, and second energy consumption and emissions reduction are evaluated to be the main drivers for a green airport. Waste reduction and reduced water consumption are valued to be of relatively less importance.

It is striking that noise is a larger concern to the experts than any of the other green KPA's. This could show that currently noise is more than any of the other green KPA's hindering the growth of airports. This could mean that for airports to really go green they must have a direct incentive, like being hindered in growth when not complying with local environmental standards on noise, emissions, energy use, waste and water.

Besides the determination of the weight factors, experts were also asked to assess the completeness of the value structure. During the Time-Efficient gaming session, an interesting new attribute was introduced for Ultra-Green: social working conditions could be taken into account as a measure for sustainability, as sustainability may imply more than being environmentally friendly.

6.3 Expert judgment of the Ultra-Green concept solutions

6.3.1 Set-up of the validation workshop

Validation of the concept ideas was performed in two ways: (1) an expert judgment gaming session and (2) a value assessment of the chosen ideas[15]. The gaming session included all ideas developed in

[15] For a complete description of the validation workshop, the reader is referred to the WP3 Validation Plan [ref. 13] and Workshop Report [ref. 65].

WP4, including the TE and CE concept ideas. Experts were asked to assume one of five roles: the airport, the airline, the ANSP, the passenger, or the industry. Subsequently, experts were asked to choose those ideas best suited to support the Ultra-Green airport taking their specific role into account. Next, the selected 25 best ideas were ranked and evaluated by the experts using the value structure. The ideas were then placed on the invariant processes map (see Figure 55) to clarify their position and relation to the specific airport processes. See the validation workshop report [65] for further detail. This section discusses these results.

6.3.2 Results of expert brainstorm session

In a brainstorm session, experts were asked to select the 25 best Ultra-Green ideas and rank them by assigning scores to them. Table 13 below lists the selected ideas in the order of the score given by the experts. These results reflect which concept ideas are favourable according to the different stakeholders. The best UG idea is the electric ground movement. This solution was judged to be both feasible and beneficial to the overall sustainability of the airport. Other UG ideas that were judged beneficial are the cleaning and de-icing robot, the electric engine accelerators for take-off and the automated apron services.

Some ideas of the two other concepts were also considered beneficial in terms of sustainability. The automation of turnaround processes, the use of electric taxis for door-to- airport transport and the use of Automatic People Movers (APMs) at the airport were assessed to have a positive impact on the Ultra-Green airport. Conversely, several UG ideas were not chosen by the experts during the gaming session and are thus found less beneficial for sustainability. Consequently, no value assessment for these solutions was made in the next step of the gaming exercise. The following UG solutions were not selected:

- Parafoil landing
- High-pier and weather protected turnaround
- Shielding take-off and landing operations with vegetation
- Transport robots to transfer baggage
- Automated moving seats (idea 24) or displaceable seat loading (idea 25)

Table 13: Ranking of ideas from expert's gaming session.

Idea	Concept	Points
Idea 23: Automation of the turnaround processes	TE	30
Idea 7: Electric Ground Movement	UG	27
Idea 10: Electric taxi for door-to-door airport transport	TE	23
Idea 36: Door-to-door integrated transport chain	All	23
Idea 20: Automatic People Movers	TE	21
Idea 11: High speed a/c taxi system	TE	18
Idea 33: Active Building Technology	CE	16
Idea 29: Walk through check corridor	TE	15
Idea 12: Electric Guided Taxi System	TE	14
Idea 15: Cleaning and de-icing robot	UG	14
Idea 6: Remote Tower	CE	14
Idea 30: Self-cleaning materials (terminal, aircraft)	CE	14
Idea 3: Electric Engine accelerators for take-off	UG	12
Idea 13: Automated Apron services	UG	12
Idea 38: Intermodal SWIM	CE	12
Idea 5: 3D Holographic HMI TWR-Apron controller position	CE	8
Idea 32: City and single central terminal	UG	8

Idea 8: Synthetic vision for cockpit	CE	7
Idea 2: Magnetic levitation for take-off/landing	UG	4
Idea 34: Circular terminal concept	TE	4
Idea 26: Door-to-door transportation of baggage	CE	4
Idea 16: On-Board self-boarding gate	CE	4
Idea 24: Automated moving seat system	UG	3
Idea 1: Dual split threshold runway	UG	2
Idea 37: Intelligent ICT supported airport	All	1

The 25 best ideas depicted in Table 13 were placed on the invariant processes chart to clarify their position and relation to the specific airport processes. Figure 55 below shows the invariant processes chart with the amount of chosen ideas per process in the expert's gaming session. Most ideas chosen are related to the take-off, passenger transfer, taxi in/out and intermodal transfer processes. Two ideas, city & single central terminal and active building technology, have been placed a bit outside the map (upper left corner) since these relate more to infrastructure than to specific airport processes. Six ideas related to the take-off process were chosen, e.g. magnetic levitation and a dual threshold runway. As such, experts concluded that these areas have opportunities for improvement and that promising solutions may exist for this and related areas.

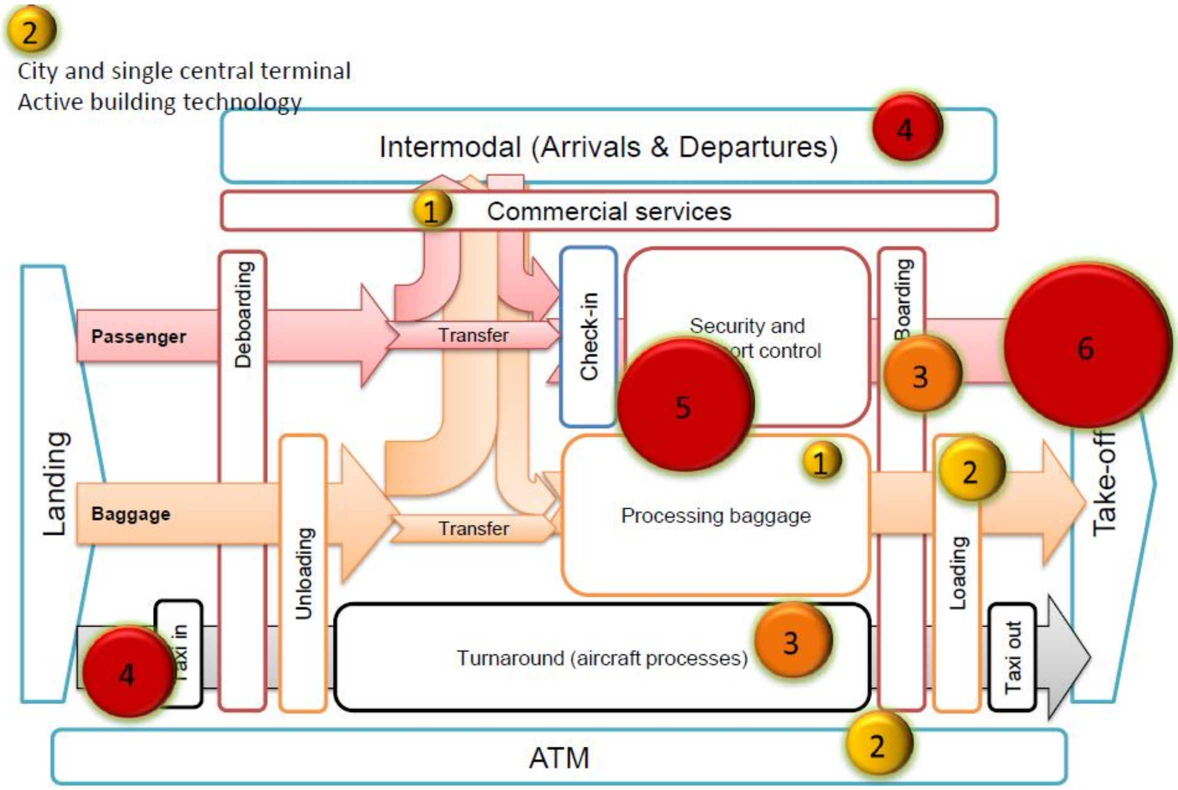


Figure 55: Ideas chosen by experts and placed on the invariant processes chart.

A review of the invariant process chart as final part of the workshop showed that experts were not sure about the location of some of the processes. Especially some of the intermodal processes could equally well have been placed elsewhere, according to the experts. In addition, the experts could also not agree on the location of commercial services. Some experts expect no commercial services at all at airport in by 2050, while others do. Many of the take-off related ideas have a strong relation to infrastructure and could equally well have been placed outside the process map – similar to City and single central terminal, and active building technology.

6.3.3 Improvements to the Ultra-Green concept solutions

For some ideas improvements were suggested during the gaming session, which are summarised in Table 14 and which could improve the sustainability of the ideas considered.

Table 14: Suggested improvements to some of the ideas.

Ideas	Proposed improvement
Idea 7: Electric ground movement	Optimise operations and adapt them for low visibility conditions
Idea 33: Active building technology	Use energy from people walking through the airport
Idea 3: Electric engine accelerators for take-off	Use the same engine for taxi; use steeper take-off in electric mode for longer range
Idea 8: Synthetic vision for cockpit	Expand for all operating phases, not only flight
Idea 15: cleaning and de-icing robot	Add recycling robot
Idea 30: Self-cleaning materials	Sustainable and reusable as well
Idea 16: on-board self-boarding gate	Integrate it with idea 24: automated moving seat system

6.4 Value analysis of the Ultra-Green concept solutions

In a subsequent expert judgment exercise (the ΔV assessment), the experts were asked to assess the impact of each of the selected concept ideas on all value attributes. This assessment was done using a simple scale ranging from ++ (very positive impact) to -- (very negative). Using this assessment together with the value function established in Section 6.2 the added value for the idea can be calculated. The results of this calculation are given in Table 15 below.

6.4.1 Most value-adding ideas

By calculating the added value, another ranking of ideas could be made. Note that this ranking, based on the added value calculated from expert assessment by scale (from ++ to --) is different from the ranking obtained in the strategy game (see section 6.3.2). The UG concept ideas electric ground movement, the dual/split threshold runway, and the cleaning and de-icing robot are expected to provide the most value to the UG airport concept. Interestingly, the top two ideas, automation of the turnaround processes and a high speed aircraft taxi system, are not concept ideas invented as part of UG, but instead, as part of TE. Both ideas are expected to lead to important Ultra-Green benefits via the fuel consumption saved by implementing more Time-Efficient operations.

Table 15: Expert's value assessment of ideas for the UG airport concept.

Ideas	Concept	ΔV
Idea 23: Automation of the turnaround processes	TE	48.7
Idea 11: High speed aircraft taxi system	TE	42.1
Idea 7: Electric ground movement	UG	33.4
Idea 38: Intermodal SWIM	CE	33.2
Idea 33: Active building technology	CE	32.1
Idea 12: Electric guided taxi system	TE	31.7
Idea 26: Door-to- door transportation of baggage	CE	30.1
Idea 1: Dual/split threshold runway	UG	29.1
Idea 30: Self-cleaning materials (terminal, aircraft)	CE	27.8
Idea 15: Cleaning and de-icing robot	UG	27.3
Idea 32: City and single central terminal	UG	26.1
Idea 24: Automated moving seat system	TE	25.2

Idea 20: Automated people movers (APMs)	TE	22.6
Idea 29: Walk through security check corridor	TE	21.9
Idea 10: Electric taxi for door-to-door airport transport	TE	20.6
Idea 3: Electric engine accelerators for take-off	UG	18.4
Idea 36: Door-to-door integrated transportation chain	All	17.5
Idea 8: Synthetic vision in cockpit	CE	16.3
Idea 5: 3D holographic HMI tower/apron controller position	CE	16.3
Idea 2: Magnetic levitation for take-off & landing	UG	14.7
Idea 6: Remote tower	CE	12.7
Idea 34: Circular terminal concept	TE	3.9
Idea 13: Automated apron services	UG	-0.3
Idea 27: Microwave and terahertz metrology for homeland security	CE	-2.6
Idea 16: On-board self-boarding gate	CE	-3.7

6.4.2 Validation of the Ultra-Green specific ideas

In order to analyse the impact of the UG concept ideas in more detail, the following sections show two radar plots. The left plot is indicating the impact of the idea on the five value attributes related to Ultra-Green. The right plot is showing the value contribution to the three airport focusses (Key Performance Areas [KPAs]), which is calculated using the composed value function. The latter plot is thereby also indicating from a high-level how the chosen ideas are affecting time-efficiency and Cost-Effectiveness.

Electric ground movement

Concept idea 'electric ground movement' is assessed to have a very positive effect (++) on three of the five Ultra-Green attributes/KPIs: noise, energy and emissions. Reducing/eliminating the use of the aircraft's main engines for ground movement, e.g. by using electric engines in the nose gear or a stationary underground towing system, is therefore assumed to have a positive impact not only on emissions and noise, but also on energy use. In contrast, no positive effect is expected on water use and waste reduction. In addition, this concept idea is not expected to bring any positive impact on the two other KPAs: mobility (time-efficiency) and economics (Cost-Effectiveness).

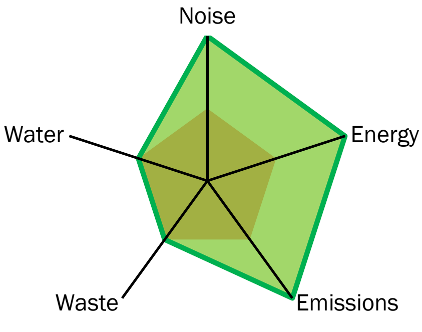


Figure 56: Impact of electric ground movement on UG attributes.

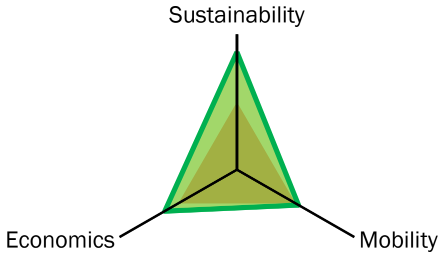


Figure 57: Impact of electric ground movement on KPAs.

Dual/split threshold runway

A dual/split threshold runway is expected to have a positive (+) effect on noise only. The impact on the other four Ultra-Green attributes/KPIs is assessed to be zero. For mobility, however, a positive impact on taxi times and overall delay is expected since the taxi distance is minimized when medium-sized aircraft depart from or vacate the runway in the middle. Interestingly, however, most benefits are foreseen for economics since constructing one large runway instead of two may lead to important cost and revenue advantages.

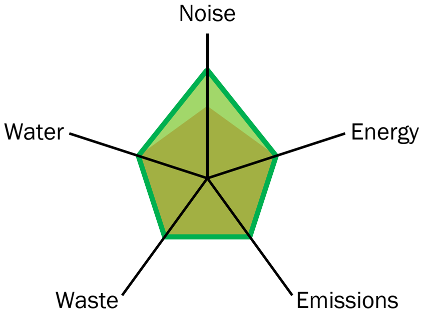


Figure 58: Impact of dual/split runway on UG attributes.

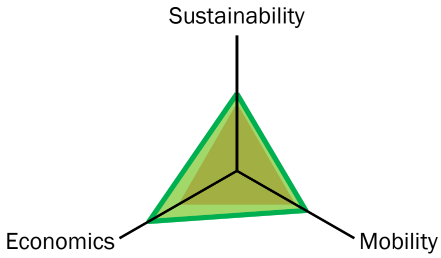


Figure 59: Impact of dual/split runway on KPAs.

Cleaning and de-icing robot

The use of a cleaning and de-icing robot is assumed to have a very positive effect on energy use, emissions and waste reduction. The impact on noise, but also water use, is expected to be zero (not affected). Cleaning aircraft is assumed to lead to less drag and thus lower in-flight fuel consumption, yielding lower energy consumption and reduced emissions. The use of automated de-icing services is assumed to reduce the use of fluid liquids, leading to lower emissions as well including a reduction of waste compared to current-day de-icing operations.

In terms of mobility, the cleaning and de-icing robot may eliminate the need to taxi to remote de-icing stations, leading to a shorter turnaround time, less delay and therefore increased time-efficiency. With respect to economics, the use of robots may lead to a reduction of staff and de-icing robots may decrease operational cost in the long run.

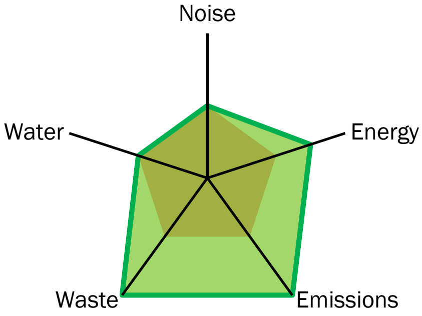


Figure 60: Impact of cleaning and de-icing robot on UG attributes.

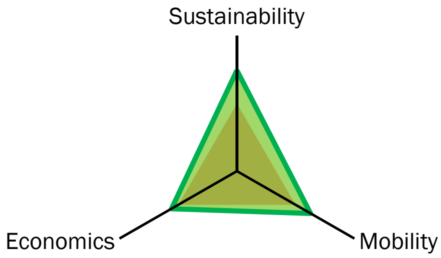


Figure 61: Impact of cleaning and de-icing robot on KPAs.

City and single central terminal

The city and single central terminal is expected to have a positive (+) on both noise, water use, waste production and emissions. These benefits are achieved by offering green transport between city and terminal, thus eliminating the use of private cars of passengers traveling to and from the airport. In addition, since baggage drop-off and optionally security services are performed in the city the airport can become very concise, consisting of a single central terminal; this leads to decreased waste production and emissions. Regarding mobility, very positive effects are expected on waiting, processing and connecting times of passengers due to the early city baggage drop-off and optional security checks and the implementation of efficient city-to-airport transport.

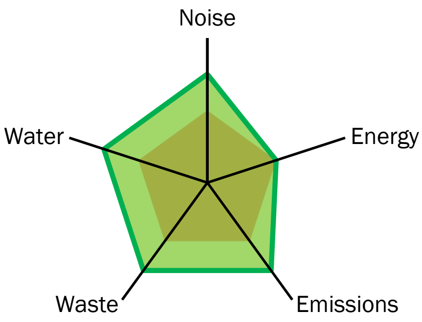


Figure 62: Impact of city & single central terminal on UG attributes.

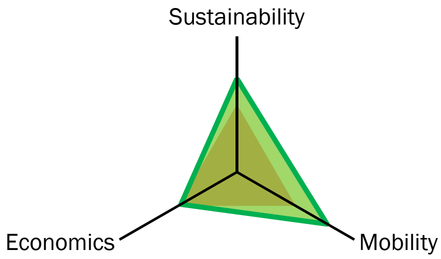


Figure 63: Impact of city & single central terminal on KPAs.

Electric engine accelerators for take-off

The use of electric engine accelerators for take-off is expected to have a very positive (++) effect on noise, energy consumption and emissions. This effect is attributed to the use of electric engines, returning to the airport as autonomous drones after take-off and initial climb. Electric engines both reduce noise and emissions during take-off as well as allow aircraft to use smaller aircraft engines for the less power-demanding en-route and landing stages of flight. No effects on mobility are expected to occur however, and the impact on economics might be negative due to the use of electric engine accelerator combined with autonomous drones increasing aeronautical costs.

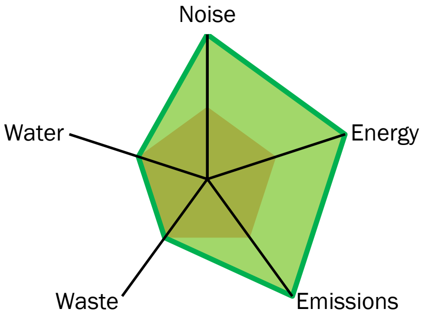


Figure 64: Impact of electric engine accelerators for take-off on UG attributes.

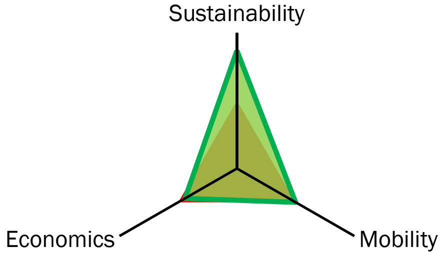


Figure 65: Impact of electric engine accelerators for take-off on KPAs.

Magnetic levitation for take-off & landing

Using magnetic levitation for take-off and landing is expected to yield very positive (++) effects on noise, energy consumption and emissions. This may be due to the fact that using MAGLEV importantly decreases noise and emissions during take-off; in addition, when combined with a landing carriage less in-flight weight (no undercarriage) and the regaining of kinetic energy may lead to less overall energy consumption. On the downside, no positive effects on mobility are expected and aeronautical costs are expected to increase due to high construction costs.

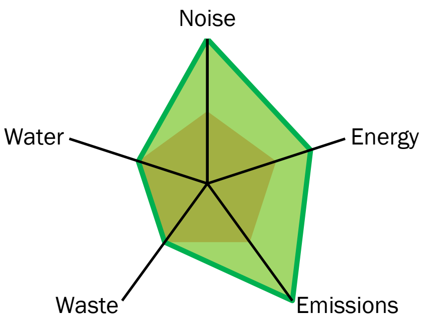


Figure 66: Impact of magnetic levitation for take-off and landing on UG attributes.

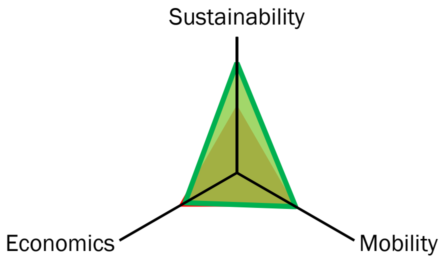


Figure 67: Impact of magnetic levitation for take-off and landing on KPAs.

Automated apron services

The use of automated apron services is, contrary to expectation, assessed to have no positive impact at all on any of the 5 Ultra-Green attributes/KPIs. Positive impact is only anticipated in the area of mobility, where the use of one system of integrated apron services is assumed to lead to a decrease of waiting, processing and connection times for passengers through a more efficient service provision. The effects on economics are assumed to be negative due to the need to invest in e.g. automated telescopic towers for refuelling or baggage loading, increasing non-aeronautical costs.

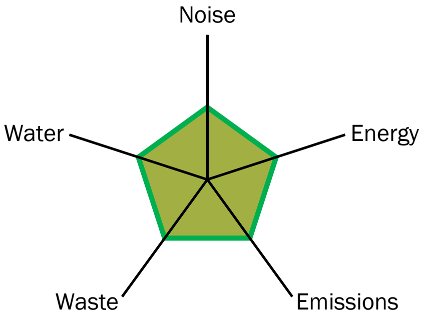


Figure 68: Impact of automated apron services on UG attributes.

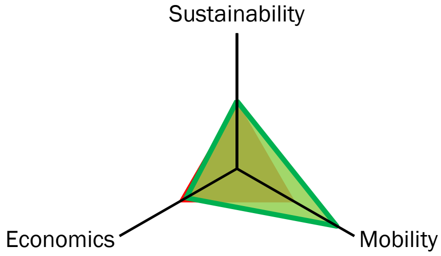


Figure 69: Impact of automated apron services on KPAs.

6.4.3 Limitations to the analysis

The preceding sections demonstrated the estimated impact of the selected UG concept ideas on their KPIs/attributes, as judged by aviation experts. It should be noted that this analysis is based on the opinion of one or more experts. As such, the results are just a first estimation of external experts (i.e. external to the project) of the impact that solutions have.

6.5 Summary, perspective, and potential of the Ultra-Green concept

The previous sections detailed the results of the UG concept idea validation as part of the AP2050+'s second validation workshop. Results were based on the outcomes of the brainstorm exercise to select concept ideas, the strategy game to rank the concept ideas, and the expert's change-impact analysis to assess the impact of each concept idea on relevant KPIs/attributes. From these exercises and analyses, a list of 'best' ideas could be deduced in two ways (see section 6.5.1 below).

First, ideas can be ranked based on expert judgement. This relates to the 1st and 3rd part of the validation workshop: the brainstorm exercise to select existing or identify new concept ideas, and the strategy game to rank the selected concept ideas for each role. This resulted in another ranking of concept ideas based on expert judgement: see Table 13 above.

Second, ideas can be ranked based on the value function. This relates to the 4th part of the validation workshop: the change-impact analysis (ΔV assessment) conducted by the experts. During the analysis, experts assessed the impact (from ++ to --) of each concept idea on each concept attribute/KPI. This resulted in a ranking of concept ideas based on their assessed value impact: see Table 15 above.

6.5.1 Best ideas for the Ultra-Green concept

Selecting the 10 best ideas for each method, expert judgement and value assessment, leads to the following table of best ideas for the Ultra-Green concept:

Table 16: 10 best ideas for UG based on expert judgment and value assessment.

Expert Judgement [Table 13]	**Value assessment** [Table 15]
Idea 23: Automation of the turnaround processes	Idea 23: Automation of the turnaround processes
Idea 7: Electric ground movement	Idea 11: High speed aircraft taxi system
Idea 10: Electric taxi for door-to-door airport transport	Idea 7: Electric ground movement
Idea 36: Door-to-door integrated transportation chain	Idea 38: Intermodal swim
Idea 20: Automated people movers (APMs)	Idea 33: Active building technology
Idea 11: High speed aircraft taxi system	Idea 12: Electric guided taxi system
Idea 33: Active building technology	Idea 26: Door-to- door transportation of baggage
Idea 29: Walk through security check corridor	Idea 1: Dual/split threshold runway
Idea 12: Electric guided taxi system	Idea 30: Self-cleaning materials (terminal, aircraft)
Idea 15: Cleaning and de-icing robot	Idea 15: Cleaning and de-icing robot

Figure 70From this table, it becomes apparent that ideas 23, 11, 7, 33, 12 and 15 are common to both methods.

Figure 70 below depicts again the best 10 ideas coming out of the value assessment (left side) and expert judgement (right side), now visualizing as well the ideas both methods have in common (centre). Electric ground movement and the cleaning and de-icing robot can therefore be considered the most beneficial ideas of the UG airport concept. Furthermore, automation of the turnaround processes, the high-speed aircraft taxi system and the electric guided taxi system – ideas originating from the TE and CE airport concepts – are also considered to be highly beneficial for the UG airport concept.

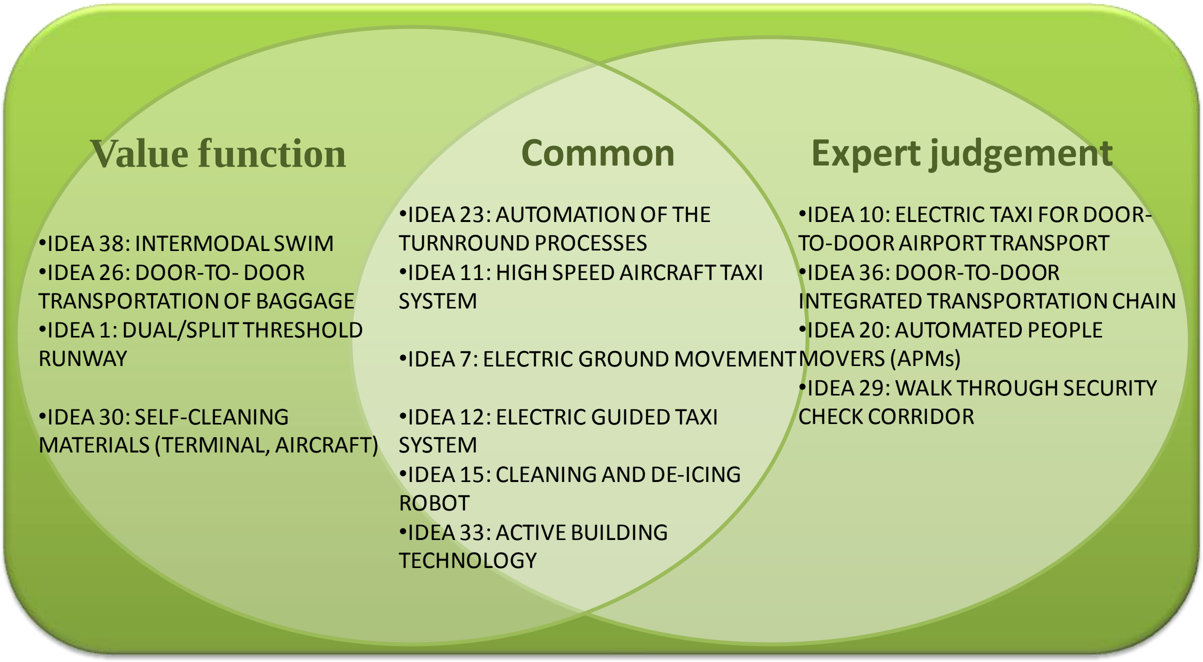


Figure 70: Best ideas for UG according to value assessment and expert judgment, and combined.

6.5.2 Expert's most promising combinations of ideas

As last part of the validation workshop, after the experts had become familiar with the ideas of Airport 2050+, they were asked to write down a combination of three ideas that could work together to improve the overall efficiency of the UG airport concept. This lead to the following results, with three idea-combinations for each of the five experts involved the UG session:

Table 17: Expert's judgement on the best three idea combinations for the UG airport concept.

	1	2	3	4	5
Idea 1	Idea 29: Walk Through Security Check Corridor	Idea 11: High Speed Aircraft Taxi System	Idea 7: Electric Ground Movement	Idea 33: Active Building Technology	Idea 38: Intermodal SWIM
Idea 2	Idea 36: Door-to-door Integrated Transportation Chain	Idea 13: Automated Apron Service	Idea 10: Electric Taxi for Door-to-door Airport Transport	Idea 15: Cleaning and De-icing Robot	Idea 36: Door-to-door Integrated Transportation Chain
Idea 3	Idea 3: Electric Engine Accelerators for Take-off	Idea 36: Door-to-door Integrated Transportation Chain	Idea 3: Electric Engine Accelerators for Take-off	Idea 3: Electric Engine Accelerators for Take-off	Idea 13: Automated Apron Service

For further detail on the workshop results the reader is referred to the workshop report [65].

7 Conclusions and recommendations

Within the 2050+ Airport project three airport concepts have been developed for the year 2050 and beyond: the Ultra-Green (UG), Time-Efficient (TE) and Cost-Effective (CE) airport concept. This document reported on the Ultra-Green airport, the airport designed, operated and managed in such a way that environmental impacts are minimized and made sustainable. Starting point has been the extensive WP2 “2050 Vision” document [8], providing an overall vision on 2050+ and supporting the formulation of bottlenecks to the accomplishment of the Ultra-Green airport. This report outlines the reasons for developing the UG concept, the requirements, the goals to be achieved and the means to adapt the bottlenecks discerned in current airport operations and infrastructure to achieve the Ultra-Green (UG) airport of 2050+. In addition, the individual UG concept solutions have all been validated (see chapter 6) to assess – by means of expert judgement – their impact on relevant KPIs: emissions, noise, water use, waste, and energy consumption. Together with the Cost-Effective and Time-Efficient concept documents, this document may be of interest to all airport managers and related stakeholders focusing on the competitive, sustainable and Time-Efficient airport of the far future.

After explaining the purpose and background of the 2050+ Airport project (chapter 1), a summary is given of the Concept Development Methodology and the most important global trends in demography, society, politics, economics, environment, mobility and technology as identified in the “Vision 2050” document (chapter 2). Next, the trends related to sustainability are analysed and the scope, bottlenecks and objectives of the Ultra-Green airport concept is formulated (chapter 3). In the following, a reference airport of today is described to investigate current-day environmental challenges and adopt mitigating measures (chapter 4). Subsequently, the Ultra-Green concept is elaborated, distinguishing between solutions assumed to be in place by 2050 (state of the art), and solutions proposed by the 2050+ Airport project consortium to meet the environmental challenges of 2050 and beyond (chapter 5). Finally, the results of the second validation workshop are presented as a means to validate the quality of the overall Ultra-Green concept and its constituent concept ideas (chapter 6).

When looking into the far future, the level of air transport is generally expected to increase. In contrast to Europe, the world’s population will grow significantly and the demand for air travel of growing middle classes - particularly in the BRIC[16] countries - will increase along with it. At the same time, the scarcity of resources limits growth; the price of air transport is expected to increase, favouring other modes of transportation. In addition, environmental awareness is expected to spread and increase. By 2050, a further growth of air transport, of affected populations, levels of pollution and perceivable climate changes may lead to a minimal tolerance for any form of pollution and a high pressure towards fully sustainable air transport. This necessitates the development of the Ultra-Green airport concept.

The Ultra-Green airport concept in this report is wide in scope. Parts of its solutions are beyond control of airport authorities; nevertheless, the concept may encourage these authorities and other stakeholders to recognise the importance of defending those elements applicable to their specific conditions and scope of interest. This relates in particular to solutions for intermodal transport services, aiming to increase sustainable mobility within the catchment area of the airport. The required development of infrastructure and its operational deployment are evidently beyond the direct control of the airport, but the impact on air transport flows and their door-to-door sustainability can be significant.

The Ultra-Green airport is designed and operated such that its environmental impact is limited and made sustainable. To achieve this, the airport should be self-sufficient regarding its energy needs, operated in a climate-neutral way and conscious of the need for consensus on limiting the noise exposure to surrounding municipalities. This is no easy task, but fortunately a number of green improvements have already been initiated (see section 5.2, state of the art). For instance, SESAR’s 4D-trajectory enabled Continuous Descent Operations (CDO) and Continuous Climb Departures (CCD)

[16] Brazil, Russia, India and China.

will be implemented by 2030, saving fuel and reducing noise and emissions. The CLEANSKY JTI (Joint Technology Initiative) aims to make major steps towards ACARE's (Advisory Council for Aeronautics Research in Europe) environmental goals, striving to reduce CO_2 emissions by 50%, NO_x (Nitrogen Oxides) emissions by 80% and external noise by 50% by 2020. And current Airport Environmental programs, such as the Airport Carbon Accreditation defined by ACI, should be in place. All these initiatives can be assumed to have a positive impact on reducing pollution, and noise nuisance and emissions at airports.

These developments, however, are not enough. To achieve a fully sustainable, Ultra-Green airport, a number of new solutions need to be implemented on top of those already under way. These new solutions, presented in this report as concept ideas, aim to make the landing and take-off, taxiing and turnaround, passengers and baggage transport processes and/or the entire infrastructure at airports more sustainable. For landing and take-off, magnetic levitation is proposed to allow aircraft - by means of a rail-gun/catapult and retention system - to take-off and land with reduced own engine power. Electric engine accelerators, carried by autonomous drones returning to the airport, may reduce energy and emissions during take-off. Parafoils may allow for low-noise landings on shorter landing runways, reducing airport land use and noise footprint. Shielding with vegetation will capture carbon and absorb noise during take-off and landing. And a dual/split threshold runway, finally, allows for simultaneous landings, reducing taxi-distance, land-use and noise nuisance.

For taxiing and turnaround, the use of electric ground movement – either through an electrical engine in the nose wheel, or a recessed towing system - is proposed to prevent aircraft from using its main engines taxiing. A cleaning and de-icing robot can clean and anti/de-ice aircraft more efficiently during turnaround, saving fuel in-flight, and reduce water pollution. Weather protected turnaround by means of a semi-permeable roof can eliminate the need for de-icing altogether. Automated apron services lead, by integrating automated services during turnaround, to a reduction of fuel use. And a high pier, allowing aircraft to park below the passenger terminals/concourses, eliminates the need for passenger buses and for push-back, thus saving fuel.

For passenger and baggage transport, door-to-airport transport electric cars are proposed to substitute current-day car transport. A city & single central terminal may be used to allow passengers to board at a city terminal and use electric mass transport to cluster city-to-aircraft traffic, greening transport and reducing city noise. Within the airport, an automated moving seat system can transport passengers on their seat between departure/arrival hall and aircraft, allowing for smaller airports and better weight-balanced aircraft. The use of transport robots for baggage may save energy over the use of continuously running conveyor belts and sequencing baggage may improve the weight-balance on-board the aircraft leading to reduced fuel use.

The infrastructure at airports will be affected by nearly all solutions proposed. This particularly holds true for magnetic levitation, the dual/split threshold runway, parafoil landing, high-pier for turnaround, automated apron services, city and single central terminal, and weather protected turnaround. The overall challenge is to be climate-neutral regarding air, water and waste, whilst being energy-efficient and sustainable in constructions.

Taken together, these concept ideas aim to establish an Ultra-Green airport at which:

(1) The use of fossil fuels is replaced by electric energy as far as possible for all processes at the airport

(2) The processes themselves are automated as far as possible to improve efficiency and thereby sustainability

(3) The infrastructure is made as compact as possible to reduce the environmental footprint

The individual concept ideas can be regarded as building blocks to constitute the Ultra-Green airport of 2050+. The modular approach taken implies that not all ideas should be regarded as mandatory for a sustainable airport; instead, interested airport managers and stakeholders are given the choice to combine only those ideas that fit their specific airport, business plans, target groups and local community. In addition, many of the Cost-Effective and Time-Efficient ideas (e.g., increased efficiency may lead to lower fuel-burn) may also contribute to an Ultra-Green airport and could be combined to develop an encompassing concept of a Cost-Effective, Time-Efficient and sustainable airport. With the development of these three concepts, the AP2050+ consortium hopes to make a contribution to the long-term development of European airports to meet the challenges of the far future.

Acronyms and Definitions

Acronyms

A-CDM	- Airport Collaborative Decision Making
AAS	- Automated Apron Services
4D	- 4D aircraft trajectory (route/flight level/time)
a/c	- Aircraft
ACARE	- Advisory Council for Aeronautics Research in Europe
ACI	- Airport Council International
ACRP	- Airport Cooperative Research Program
A/G	- Air/Ground
ANSP	- Aeronautical Navigation Service Provider
APM	- Automated People Mover
APU	- Auxiliary Power Unit
A-SMGCS	- Advanced Surface Management Ground Control System
ASU	- Air Start Unit
ATM	- Air Traffic Management
ATC	- Air Traffic Control
ATFCM	- Air Traffic Flow and Capacity Management
AVOL	- Aerodrome Visibility Operational Level
BREEAM	- BRE Environmental Assessment Method
BRIC	- Brazil, Russia, India and China
BWB	- Blended Wing Body
CAD	- Context and Architecture Description
Cat III	- Category III
CDA	- Continuous Descent Approach
CDM	- Concept Development Methodology
CE	- Cost-Effective
C-I	- Change-Impact
CO_2	- Carbon dioxide
CTA	- Controlled Time of Arrival
CTO	- Controller Time Over
DG	- Directorate General (of EU)
DME	- Distance Measuring Equipment
DROPS	- Dedicated Runway Operations
EC	- European Commission
END	- Environmental Noise Directive
E-OCVM	- European Operational Concept Validation Methodology
EU	- European Union
FOD	- Foreign Object Damage
FP	- Framework Program of EU
GA	- General Aviation
GBAS	- Ground Based Augmentation System
GDP	- Gross Domestic Product
GHG	- Greenhouse Gas
GPS	- Global Positioning System
GPU	- Ground Power Unit
GSE	- Ground Support Equipment
HMI	- Human Machine Interface
IATA	- International Air Transport Association
ICAO	- International civil Aviation Organization
ICT	- Information Computation Technology
IFR	- Instrument Flying Rules

ILS	- Instrument Landing System
JTI	- Joint Technology Initiative
KFA	- Key Focus Area
KPA	- Key Performance Area
KPI	- Key Performance Indicators
LAQ	- Local Air Quality
LED	- Light Emitting Diode
LEED	- Leadership in Environment and Energy Design (architectural design terminology)
LPG	- Liquefied Petroleum Gas
LTO	- Landing/Take-Off
MAGLEV	- Magnetic Levitation
M-TOL	- Magnetic levitation for Take-Off and Landing
MTOW	- Maximum Take-Off Weight
NB	- Narrow Body aircraft
NO_x	- Nitrogen Oxides
O/D	- Origin-Destination (passengers)
PCA	- Pre-Conditioned Air
PM_x	- Particulate Matter of x micrometer or less
PRM	- Passengers with Reduced Mobility
PV	- Photovoltaic
RBT	- Reference Business Trajectory
RNAV	- Area Navigation
RPAS	- Remotely Piloted Aircraft Systems
RWY	- Runway
SBT	- Shared Business Trajectory
SESAR	- Single European Sky ATM Research (EU)
SMAN	- Surface Management system
SWIM	- System Wide Information System
TAM	- Total Airport Management
TE	- Time-Efficient
TMA	- Terminal Manoeuvring Area
TO	- Take-Off
TOL	- Take-Off or Landing
TWR	- Tower
UAS	- Unmanned Aerial System
UDPP	- User Driven Prioritisation Process
UG	- Ultra-Green
UK	- United Kingdom
VHF	- Very High Frequency
VOM	- Value Operations Methodology
VOR	- VHF Omnidirectional Radio Range
WB	- Wide Body aircraft
WIFI	- Wireless Local Area Network
WP	- Work Package

Definitions

Connectivity	Connectivity is support of transport intermodality is defined as the overall performance of services in support of traveling services to passengers, in our context through Europe. It includes number of required transport connections for displacements, required waiting time, and user friendliness of applicable transport modes.
Invariant Processes	Processes, identifying invariant airport operational processes, which describe together the activities at and around the airport to accomplish transport operations in a high level and generic way.

References

1. ACI, *Airport Environmental Management Course*, 2010.
2. ACI, *Frankfurt airport special report*, 2011.
3. ACI, *Guidance Manual: Airport Greenhouse Gas Emissions Management*, 1st Edition. November 2009.
4. ACRP, *Airport Sustainability Practices*, Transportation Research Board, 2008.
5. AEA, *Recommendations for De-icing / Anti-icing Aeroplanes on the Ground*, 28th Edition, July 2013.
6. Airport Carbon Accreditation, *Annual Report 2012-2013*, June 2013.
7. AP2050, *Grant Agreement: The 2050+ Airport project, Project Work Description*, Collaborative Project, FP7-AAT-2011-RTD-1, AAT.2011.6.2-3 – Airports, Brussels, September 2011.
8. AP2050, WP2, *D2-1-1 Vision 2050*, D2-1-1, Draft V0.06, TU Delft, August 2013.
9. AP2050, WP2, *D2-1-2 Methodology framework and introduction VOM*, D2-1-2, Draft V0.07, TU Delft, August 2013.
10. AP2050, WP2, *D2-1-3 Concept context and architecture description method*, D2-1-3, Draft V0.09, TU Delft, August 2013.
11. AP2050, WP2, *D2-1-4 Change-Impact method*, D2-1-4, Draft V0.05, TU Delft, August 2013.
12. AP2050, WP2, *D2-1-5 Methodology manual*, D2-1-5, Draft V0.03, TU Delft, August 2013.
13. AP2050, WP3, *D3-1, Validation Plan*, D3-1, Version 1.0, CRIDA, Madrid, December 2012.
14. AP2050, WP4, *D4-1 The Time-Efficient Airport Concept*, D4-1, Draft V0.3, TU Delft, August 2012.
15. AP2050, WP4, *D4-3 The Cost-Effective Airport Concept*, D4-3, Draft V0.3, SLOT, Budapest, August 2012.
16. Bruntland, G., *Our common future: The world commission on environment and development*, 1987.
17. Chip Yates, *Flight-of-the-Century*.
18. EC, *A framework for the setting of ecodesign requirements for energy-using products*, Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005.
19. EC, *Ambient air quality and cleaner air for Europe*, Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008.
20. EC, *Assessment and management of environmental noise*, Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002.
21. EC, *Being wise with waste. The EU's approach to waste management*, 2010.
22. EC, *Ecodesign requirements for fluorescent lamps*, Commission Regulation (EC) No 245/2009 of 18 March 2009.
23. EC, *Regards the fixing of maximum levels for pesticide residues*, Commission Directive 2002/42/EC of 17 May 2002.
24. EUROCONTROL, *Challenge to Growth 2008*, Summary Report, Brussels, November 2008.
25. EUROCONTROL, *E-OCVM European Operational Concept Validation Methodology*, Vol. I and II, version 3.0, EUROCONTROL, Brussels, February 2010.
26. European Commission – High Level Group on Aviation Research, *Flightpath 2050, Europe's Vision for Aviation*, Publication Office of the European Union, ISBN 978-92-79-19724-6, Luxembourg, 2011.
27. FAA, *History, Processing, and Usage of Recycled Glycol for Aircraft Deicing and Anti-Icing*. DOT/FAA/AR-00/55, 2001.
28. Gardner, R., *2050 Vision*, Aerospace Engineering, February 2013.
29. Geest, P. J. van der, Wind Turbines near Airports, NLR.
30. Gellert, D., *Aircraft Vertically Separated Approaches,("VSA") Takeoffs,("VST") and Split Runway ("SR") Operations*, AIAA 2008-182, January 2008.
31. Grundy, P., *Shell energy scenarios to 2050*, Shell International BV, 2008.

32. Gugliermetti, F., F. Bisegna, A. Carmela Violante, and C. Aureli, *Noise exposure of the ramp's operators in airport apron*, Proceedings 20th ICA 2010, Sydney, Australia, August 2010.
33. Helmke, Hartmut, et al., *Time-based arrival management for dual threshold operation and continous descent approaches.*, 8th USA/Europe ATM Seminar, Napa, CA, USA. 2009.
34. Honeywell, *Performance-based Navigation*, Honeywell SmartPathTM Ground Based Augmentation System (GBAS), Hughes/Honeywell, Pacific Aviation Directors Workshop, March 15, USA, 2012.
35. IATA, *Airport Handling Manual (AHM)*, 32nd Edition, 2012.
36. ICAO, *Aerodromes – Aerodrome Design and Operations*, Annex 14, Volume I, 5th edition, July 2009.
37. ICAO, *Airport Planning Manual. Part 1. Master Planning*, Doc 9184, Second edition, 1987.
38. ICAO, *Airport Planning Manual. Part 2. Land use and environmental control,* Doc 9184, Third edition, 2002.
39. ICAO, *Guidance on the Balanced Approach to Aircraft Noise Management*, Doc 9829, 2nd edition, 2008.
40. ICAO, *ICAO Environmental Report 2010 – Aviation Outlook*, 2010.
41. ICAO, *Manual of aircraft ground de-icing / anti-icing operations*. Doc 9640-AN/940, Second edition, 2000.
42. Kiva Systems, *Creating a distribution powerhouse: Why rapid deployment matters*, White paper, 2011.
43. Kolukisa, A., *Evaluating aircraft turnaround process in the framework of airport design and airline behaviour*, University of Porto, 2011.
44. KPMG, *Self-driving cars: The next revolution*, 2012.
45. La Journal de la Geothermie – *Paris-Orly passé a la geothermie*, 2010.
46. Massachusetts Aeronautics Commission, *Vegetation management at airports*, 2004
47. Meier, C., P. Erikson, *TOTAL AIRPORT MANAGEMENT (Operational Concept & Logical Architecture)*, Version 1.0, Eurocontrol, Brussels, October 2006
48. Munich Airport, *Perspectives – Environmental Statement 2008*.
49. Oak Ridge National Laboratory, *Combined Heat and Power – Effective Energy Solutions for a Sustainable Future*, December 2008.
50. Press release: Serbot AG, *Serbot presents new cleaning solution for solar power plants*, 2012.
51. Profu, *Evaluating waste incineration as treatment and energy recovery method from an environmental point of view*, Final version, May 2004.
52. Rohacs, J., D. Rohacs, P. Schmollgruber and M. Voskuijl, *GABRIEL Operational Concept*, D2.9, Project GABRIEL, August 2012.
53. SESAR, *SESAR Concept of Operations*, version 01-00, DLT-0612-222-01-00, Brussels, 2007.
54. SESAR, *SESAR D3: The ATM Target Concept*, version 02-00, DLM-0612-001-02-00, Brussels, Sept 2007.
55. SESAR, *SESAR D5: SESAR-Masterplan*, version 02-00, DLT-0710-001-02-00, Brussels, April 2008.
56. The Foresight Commission of Air and Space Academy, *Flying in 2050, Initial Report*, Air and Airspace Academy, November 2011.
57. Transrapid, *High-Tech for "Flying on the Ground"*, May 2002.
58. TRB 92nd Annual Meeting 2013, *Operational and environmental assessment of the electric taxi based on fast-time simulation*, Washington, USA, January 13-17, 2013.
59. Verbeek, R. J. D., *Landing capacity of a dual threshold runway*, M-857, 1998.
60. Website: http://www.munich-airport.de/en/company/umwelt/ressourcen/index.jsp, as given on 26th August 2013.
61. Website: http://www.airportcarbonaccreditation.org, as given on September 15th 2013.
62. Website: http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10471/#gallery/4786, as given on September 20th 2013.
63. Website: http://science1.nasa.gov, as given on September 20th 2013.
64. Website: http://www.airbus.com/innovation/future-by-airbus, as given on September 20th 2013.

65. Workshop report, AP2050, June 2013.
66. Wyllie, T., *Parachute recovery for UAV systems*, Aircraft Engineering and Aerospace Technology 73.6 (2001): 542-551.
67. Young, D. and P. Cauwenbergh, *Mitigating the Challenges for Air Transport*, 2030, EUROCONTROL, Brussels, December 2009.