STARGATE
CONCEPTUAL FRAMEWORK FOR CIRCULARITY

MAY 2023

Stargate
within EU Green Deal

CONTENTS

1. EXECUTIVE SUMMARY

In March 2020, the European Commission adopted a new Circular Economy Action Plan (CEAP), one of the main building blocks of the European Green Deal (European Commission, 2021). The circular economy, which promotes the elimination of waste and the continual safe use of natural resources, offers an alternative that can yield up to $4.5 trillion in global economic benefits by 2030 (Franco et al., 2021).

Applying circular economy concepts has significant potential for the aviation sector due to several factors. First, the industry expects substantial growth, increasing resource use and waste and emissions generation in the coming years. Next, passengers are increasingly becoming aware of adverse environmental impacts, presenting an opportunity to increase customer satisfaction in the aviation industry. Lastly, governments may impose taxes to regulate emission rates and waste generation.

This report develops a conceptual framework for modelling resource circularity at airport terminals. The report starts by explaining the project context (see chapter 3) and the framework's methodology (see chapter 4). Chapter 5's framework is built for five important sectors: construction and demolition, energy management, (waste) water management, material and resource management and transport. Chapter 6 focusses on identifying Key Performance Indicators (KPIs) for all energy and material flows identified in the framework. Chapter 7 checks the framework's validity by investigating its applicability for various circular actions implemented at international airports. Chapter 8 suggests a step-by-step approach for successful implementation, thereby considering the organizational change management necessary to transform an organization towards increased circularity.

The framework suggests using the KPIs identified here but simultaneously allows for a large degree of individual customization due to the distinction between primary and secondary indicators. Primary indicators are derived from measurements at the airport. In contrast, secondary indicators can be derived from primary indicators by calculation, e.g. (currencies, % or CO2 equivalents). The relevant indicators were selected from existing frameworks, e.g. i) the circular city implementation framework (UNECE, 2020) and ii) the European Commissions' categorisation system for the circular economy (European Commission, 2020) and adjusted if needed to fit the context of airport terminals.

It is advised to perform baseline measurements before the start of circularity actions, thereby deciding the frequency of measurement and, in doing so, guaranteeing a relevant monitoring process able to assess and evaluate the goals towards increased circularity that are set.

Finally, the framework is validated using a dual approach whereby circularity actions at international airports and a diverse set of airport partners' circularity actions are checked for their applicability within the framework.

2. LIST OF ABBREVIATIONS

Table 1: list of abbreviations

APOC	Airport Planning and Operations Centre
ATAG	Air Transport Action Group
ATM	Air Traffic Management
BAC	Brussels Airport Company
CAPSA	Collaborative Arrangement for the Prevention and Management of Public Health Events in Civil Aviation
CDW	Construction and Demolition Waste
CHP	Combined Heat and Power
CPPA	Corporate Power Purchasing Agreements
EC	European Commission
EV	Electric Vehicle
FOD	Foreign Object Debris
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICT	Information and Communication Technologies
ICW	International Catering Waste
MRO	Maintenance, Repair and Overhaul
OECD	Organization for Economic Co-operation and Development
PRM	Passengers with Reduced Mobility
PAX	Passengers
SAMP	Strategic Airport Mobility Plan
SEAC	Sustainability and Environment Advisory Council
SUPs	Single Use Plastics
U4SCC	United 4 Smart Sustainable Cities
UHA	University Hasselt

3. Introduction

A circular economy aims to maintain the value of products, materials and resources for as long as possible by returning them into the product cycle at the end of their use while minimizing the generation of waste (Eurostat). Food and water waste are explicitly identified as a high potential intervention, as is the overall strategy to decouple waste production from economic growth (i.e., Less Waste, More Value). The transition to a circular economy, promoting the elimination of waste and the continual safe use of natural resources, requires unprecedented collaboration given that today, only 8.6% of the world economy follows these circularity principles.

In its 2019 environmental report, the International Civil Aviation Organization states that "*at airports, the application of circular economy has also demonstrated great potential for environmental and economic benefits*." (ICAO, 2019). For the aviation sector, the circular economy is an emerging concept. While its application is still not widespread, the utilization of circular economy concepts could provide valuable learning opportunities for the future (ICAO, 2019). The sector is expecting significant growth rates in the coming years. "*Aviation is a sector expecting annual world air traffic to double by 2035, with an average annual growth rate of 4.4 per cent*", thereby expecting increasing resource use and waste and emissions generation.

Here, the framework for resource circularity at airport terminals is built for five important sectors: construction and demolition, energy management, (waste)water management, material and resource management and ground transportation for personnel and passengers.

3.1 PROJECT CONTEXT

Airports offer a unique opportunity to design, test, and deploy innovative circularity concepts, given their nature as a nexus of human, resources and goods flows. In one of its most cutting-edge initiatives, the STARGATE project seeks to define a practical framework to model and evaluate resource circularity in airport terminals, supported by the airport's Digital Twin.

One of the five main STARGATE pillars is the optimization of terminal operations, a novel approach to circular resource management and the minimization of resources and waste generated. Within this pillar, a conceptual framework for modelling resource circularity at airport terminals is developed as an integrated approach to enable circular resource economy management.

3.2 PROJECT OBJECTIVE

The objective of the conceptual framework is to provide a theoretical framework that can guide and support the implementation process, measure relevant actions, and evaluate circularity initiatives at airport terminals. It is built from conceptual analysis and integration of existing frameworks, e.g. i) the circular city implementation framework (UNECE, 2020) and ii) the European Commission's categorisation system for the circular economy (2020) to provide a step-by-step guideline able to successfully measure and evaluate circularity initiatives at airport terminals.

4. METHODOLOGY

4.1 PROCESS METHODOLOGY

The process is initiated by inventorising all possible terminal resources and assets to ease the identification of resources and assets for which potential circularity actions can be developed (see section 4.3). Next, a quick scan identifies potential circularity actions that could be applied to airport terminals (see section 4.4). An overview of the process methodology is represented in Figure 1.

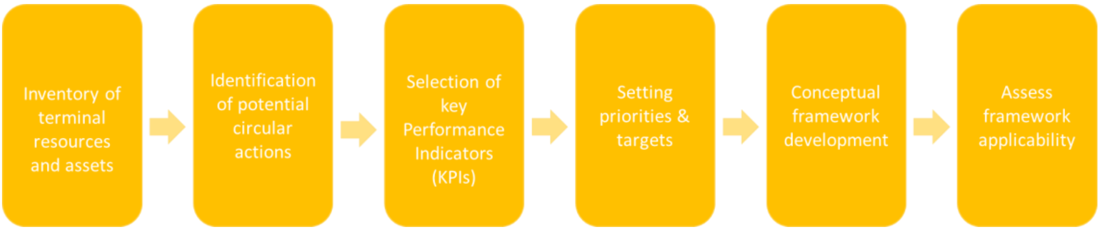

Figure 1: An overview of process methodology.

The baseline measurement is executed before implementing circularity actions, after which targets are monitored and evaluated. The measurement frequency depends on the type of respective indicators and the data generation and/or collection specifications. The conceptual framework visually represents i) the different sectors (construction and demolition, energy management, water management, materials and resources management and transportation) ii) the indicators linked to these flows and iii) the interlinkages between the KPIs (See chapter 5).

KPIs for the different flows and sectors are identified and, if needed, adapted for the context of airport terminals (chapter 6). In chapter 7, validation is executed on two different levels. First, the application of the conceptual framework is tested with circularity actions generated at STARGATE partner's airport terminals to test its applicability (see section 7.1). Second, the framework's applicability is tested using case studies implemented at airport terminals worldwide (see section 7.2).

Last, a step-by-step guide towards implementing circularity is proposed in chapter 8, considering the organisational change management required to transform an organization towards circularity.

4.2 BOUNDARIES AND SCOPE

The airport terminals are considered small cities due to the large flow of individuals, suppliers, and customers and the availability of assets such as infrastructure, resources, and goods and services. Businesses and shops located at the terminals are considered customers of airport terminals when they collectively contract for energy, water, waste management, and wastewater treatment. Airlines are generally outside the scope of the circularity actions initiated at airport terminals, except when airline operations overlap with circular actions for terminal operations.

In line with the EC's Monitoring Framework for the Circular Economy (Eurostat), the indicators identified here will take account of the focus areas in the EC's circular economy action plan, stressing interlinkages between circularity, climate neutrality and zero pollution ambition. In this regard, indicators relating to sustainability (e.g. sustainable energy consumption and production and sustainable transportation) are included in this framework.

4.3 INVENTORY OF TERMINAL ASSETS AND PRODUCTS

The United 4 Smart Sustainable Cities (U4SCC) initiative (UNECE, 2020) contains a circular city implementation framework designed to improve city circularity and support stakeholders in implementing circular actions. It identifies critical components of circular cities. One of these components is the "*city assets and products (i.e. various city infrastructures, city resources)".*

The airport terminal assets and products are identified in line with the U4SCC guide for circular cities. This identification facilitates the identification of potential circular actions that can be developed for these resources and assets. **Error! Reference source not found.** represents a generic overview of the airport terminal assets and products (adapted from the U4SCC guide to circular cities).

Figure 2: generic overview of airport terminal assets and products (adapted from U4SSC guide for circular cities).

Further specifications of terminal infrastructure, terminal resources and terminal services are represented in Figure 2, figure 4 and figure 5 respectively.

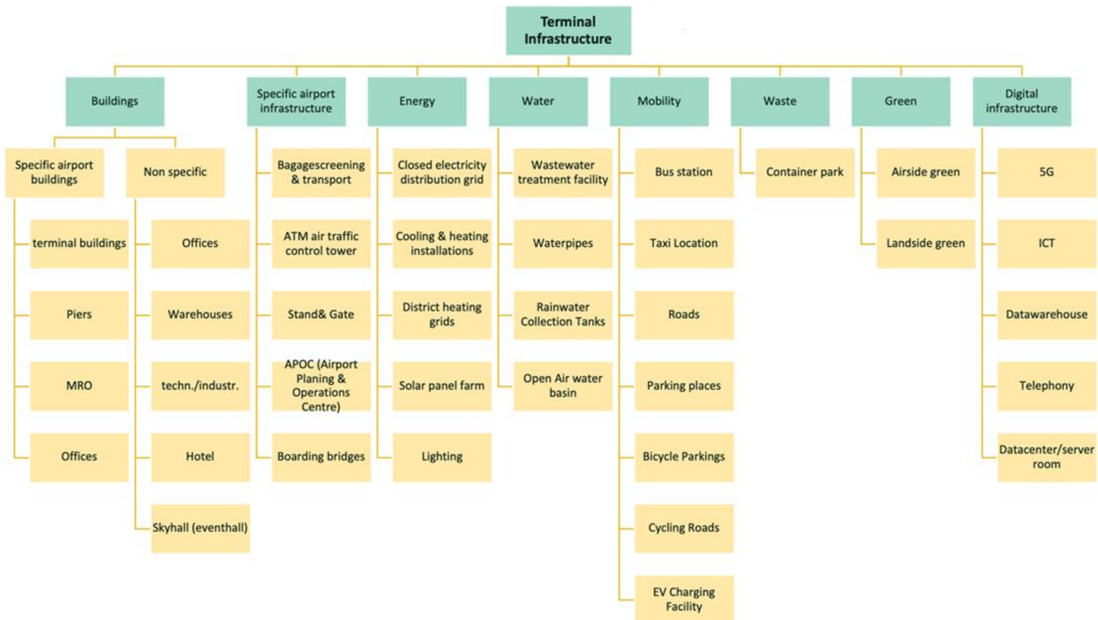

Figure 2: Example of terminal infrastructure inventory for identification of terminal assets and products

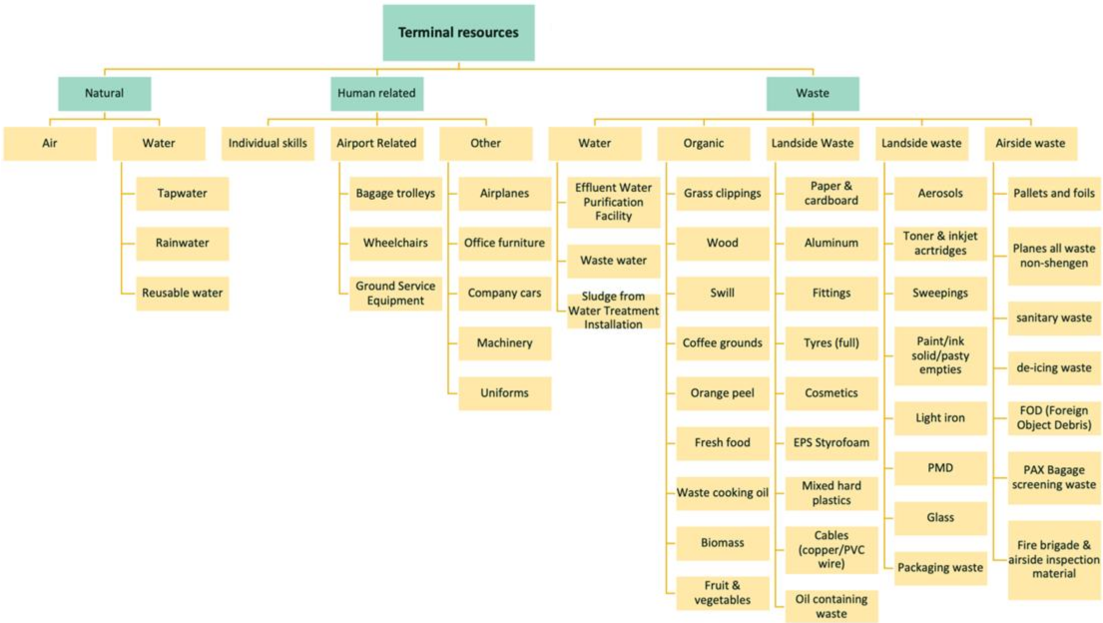

Figure 3: Example of terminal resources inventory for identification of terminal assets and products

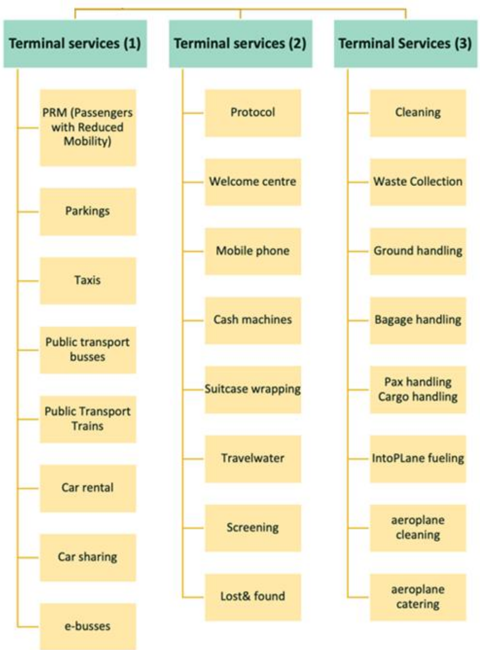

Figure 5: Examples of terminal services inventory for identification of terminal assets and products.

4.4 QUICK-SCAN OF POTENTIAL AIRPORT TERMINAL CIRCULARITY ACTIONS

A collection of circular actions has been compiled to serve as inspiration for setting up concrete circular actions at the airport terminal. These case studies, found in Annex 1, are not intended to be a comprehensive overview of all potential circular actions, but rather a source of inspiration. More examples of best practices regarding cabin waste management can be found in the IATA cabin waste handbook (IATA, 2019), and in Sebastian et al., 2021.

5. CONCEPTUAL FRAMEWORK

The section discusses the creation of a conceptual framework for measuring and evaluating circularity initiatives at airport terminals. The framework is based on existing frameworks and consists of five interconnected individual frameworks for building construction and demolition, energy management, water management, materials and resources management, and transportation. The framework's goal is to guide and support implementation while also measuring relevant actions to achieve circularity goals. In Chapter 6, the passage also mentions the identification of relevant Key Performance Indicators (KPIs).

5.1 CONSTRUCTION AND DEMOLITION

There are two parts to the framework for evaluating circularity in construction and demolition as shown in Figure 6. The combination of numbers and letters (e.g. C1., C11.) represents a specific KPI. The upper section identifies the flows of demolition material, and waste is divided into three categories: reused construction material (upcycling), recyclable waste (selective waste recycling), and non-recyclable waste. Upcycled materials are redeployed at the same or higher quality level, whereas recycled materials are degraded and eventually become waste. Non-recyclable waste is either incinerated or buried. Some materials can be reused internally in new construction projects, while others can be made externally available for reuse through recovery or reuse inventories.

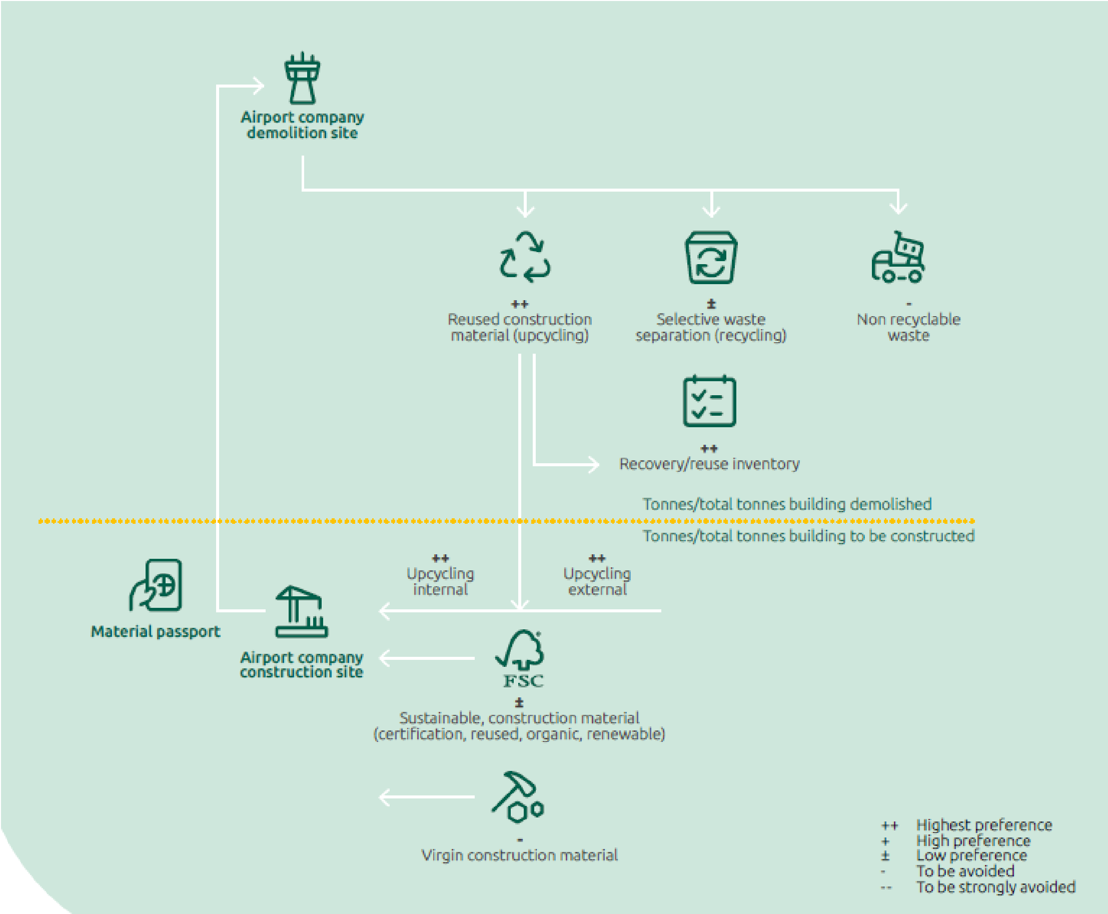

Figure 4: conceptual framework for measuring circularity performance in construction and demolition. Color gradings indicate preferred flows (green: high preference, yellow: low preference, red: to be avoided) based on environmental performance and impact.

The bottom section of the construction circularity framework evaluates the source of materials used in building construction. There are three sources of construction materials identified: reusing construction materials, environmentally friendly sustainable construction materials, and virgin construction materials with a negative environmental impact. The framework aims to promote component recovery and reuse by utilizing material passports, which contain data describing defined characteristics of materials in products ensuring the right information is easily accessible, and reducing legal and engineering uncertainty during the construction phase.

5.2 ENERGY MANAGEMENT

The framework developed here will take account of the focus areas in the EC's circular economy action plan, stressing interlinkages between circularity, climate neutrality and the zero pollution ambition. It is in this regard that the framework for assessing sustainable energy consumption and production is included here.

According to the framework (figure 7) , the total energy used by an airport terminal includes energy used by partners and the airport company. This energy can be derived from either renewable or nonrenewable sources. Corporate Power Purchasing Agreements (CPPAs) are a type of procurement strategy that enables airports to obtain renewable energy with transparent value chains. As an intermediate energy source, combined heat and power (CHP) generation is also included. Solar energy, biogas production, heat generation, and other sources of renewable energy can be generated on-site. Excess renewable energy can be stored or transmitted to the grid.

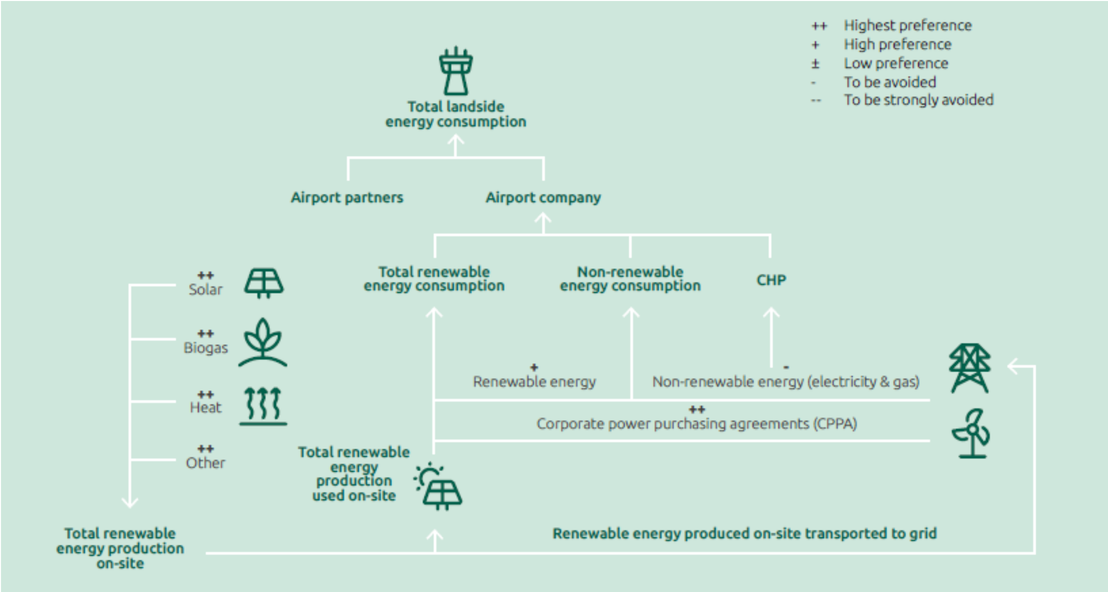

Figure 5: conceptual framework for measuring circularity and sustainability performance in energy management at airport terminals. Color gradings indicate preferred flows (dark green: highest preference, green: high preference, yellow: low preference, red: to be avoided)

5.3 WATER MANAGEMENT

Measuring circular actions in water management entails both the use and disposal of water, including wastewater. There are four water sources identified: tap water, ground and/or surface water, rainwater collection, and recycled water that can be reused internally. Figure 8 shows four methods for disposing of wastewater, including capturing it in on-site treatment facilities to recover energy and nutrients, sending it to external wastewater treatment companies, separating it from rainwater, and discharging it into rivers and streams. In ideal situation water is first recycled internally, then purified on-site for reuse, including capturing wastewater from outside sources. The figure additionally incorporates the disposal of sanitary waste from airlines and glycol from de-icing aircraft by terminal infrastructure.

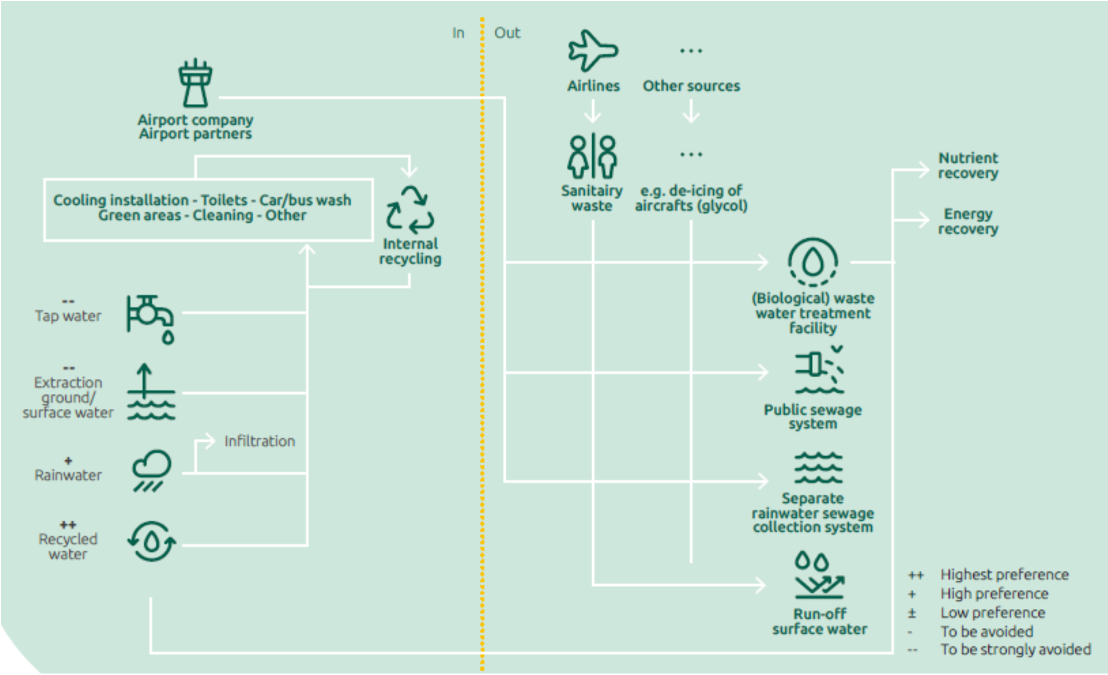

Figure 8: Conceptual framework for measuring circularity and sustainability performance in the water management of at airport terminals.

5.4 MATERIAL AND RESOURCES MANAGEMENT

For the management of materials and resources, the well-known and established framework by Potting et al. (2017) is adopted. It contains a set of ten strategies for product circularity (R-strategies). Usually, they are grouped around three main circularity strategies, namely: (i) smarter product use and manufacture; (ii) extended product and its parts' lifespan; and (iii) useful application of materials. The ten R-strategies are:

- Refuse (R0): Make product redundant by abandoning its function or by offering the same function with a radically different product
- Rethink (R1): Make product use more intensive (e.g., through sharing products or putting multifunctional products on the market)
- Reduce (R2): Increase efficiency in product manufacturing or use by consuming fewer natural resources or materials
- Reuse (R3): Reuse by another consumer of discarded product which is still in good condition and fulfils its original function (and is not waste) for the same purpose for which it was conceived
- Repair (R4): Repair and maintenance of defective product so it can be used with its original function
- Refurbish (R5): Restore an old product and bring it up to date
- Remanufacture (R6): Use parts of discarded product in a new product with the same function
- Repurpose (R7): Use discarded product or its parts in a new product with a different function

- Recycle (R8): Process materials to obtain the same (high grade) or lower (low grade) quality
- Recovery (R9): Incineration of materials with energy recovery

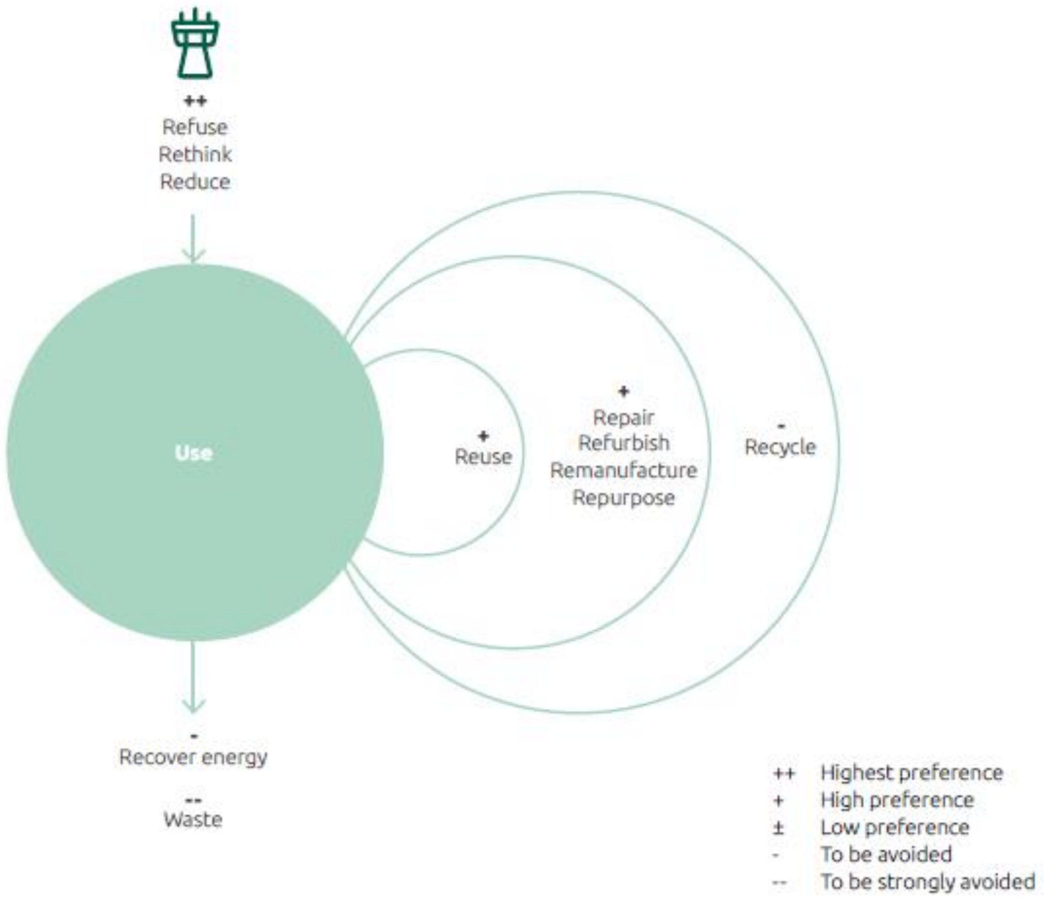

Figure 9: Potting's conceptual framework for measuring circularity and sustainability performance in the material and resources management at airport terminals.

5.4 TRANSPORTATION

For transportation management, only KPIs are identified and no separate visual framework is developed due to the lack of added value and the parallel sustainability initiatives focusing on sustainable transportation: the Strategic Airport Mobility Plan (SAMP), 'Mobility week' (campaign and awareness raising), the bicycle parking airport community and development of a mobility dashboard. KPIs for measuring transportation management are included below (see chapter 6).

6. SELECTION AND MEASUREMENT OF KEY PERFORMANCE INDICATORS

Relevant indicators were selected from existing frameworks, e.g. i) the circular city implementation framework (UNECE, 2020) and ii) the European Commissions' categorisation system for the circular economy (European Commission, 2020) and adjusted if needed in order to fit the context of airport terminals.

The indicators have been divided into two sets of indicators: primary indicators (see 6.1) and secondary indicators (see 6.2). Primary indicators are derived from measurements at the airport, whereas secondary indicators can be derived from primary indicators by means of calculation, e.g. (currencies, % or CO_2 equivalents), therefore allowing a considerable degree of individual customization.

Each primary indicator is linked to a specific flow of resource/energy as indicated in the visual representation of the framework (see figure 6-9). The coding and numbering of indicators is as follows: indicators related to Construction and demolition (C), Energy management (E), Water management (W), Material and resources management (M), and transportation (T). Each code is followed by a number (e.g.the KPI code C1. Aligns with KPI name 'Demolition Total' which is then further defined. Also a methodology for the measurement as well as the units of measurement are listed for all KPIs.

The secondary indicators that can be derived from these primary indicators include a wide variety of ratios and/or percentages that can be derived, as well as different currencies or the derivation of CO_2 equivalents, as desired by the terminal mangement board. A set of secondary indicators for construction and material management are listed in 6.2 as an example of which indicators can be derived.

6.1 PRIMARY KPIS

Table 2: primary indicator set for the measurement and evaluation of circularity actions in construction and demolition with KPI no. (KPI code), KPI name and definition, methodology for measurement and unit.

Construction and Demolition KPIs (C.)				
KPI No.	**KPI name**	**Definition**	**Methodology**	**Unit**
C1.	Demolition Total	Total amount of building materials released upon demolition	Tons of demolished material	Tons
C2.	Total Upcycling Material from demolition	Total amount of demolished building material collected for upcycling	Tons of demolished material	Tons
C3.	Total Recycling Material from demolition	Total amount of demolished building material with selective waste collection used for recycling	Tons of demolished material	Tons
C4.	Total non-recyclable waste from demolition	Total amount of demolished building material identified as non-recyclable waste	Tons of demolished material	Tons
C5.	Upcycling promotion effort	Total upcycling material to be included in reuse inventories	Tons of demolished material	Tons

C6.	Upcycling internal	Total amount of demolished building material collected for upcycling on site and reused internally	Tons of demolished material	Tons
C7.	Upcycling external	Total amount of demolished building material collected for upcycling externally and used on site	Tons of demolished material	Tons
C8.	Sustainable construction material	Total amount of sustainable construction material used on site	Tons of building material	Tons
C9.	Virgin construction material	Total amount of virgin construction material used on site	Tons of building material	Tons
C10.	Material passports	Number of material passports registered for construction	Number of material passports registered for construction	Number
C11.	Public Building Sustainability	Percentage area of public buildings with recognized sustainability certifications for ongoing operations	Numerator: Floor area of public buildings with certification to a recognized standard for ongoing building operations (m2). Denominator: Total floor area of public buildings (m2). Multiply by 100. Report by Certification Scheme	%

Table 3: primary indicator set for the measurement and evaluation of circularity actions and/or sustainability actions in energy consumption and production with KPI no. (KPI code), KPI name and definition, methodology for measurement and unit.

Energy Management KPIs (E.)				
KPI No.	**KPI name**	**Definition**	**Methodology**	**Unit**
E1.	Total Landside Energy Consumption	Total amount of electricity and gas used for heating and powering of buildings (transport not included) for Airport Company and Airport Partners		PetaJ or MWh
E2.	Total Airport Company Energy Consumption	Total Airport Company Energy Consumption		PetaJ or MWh
E3.	Total Airport Partners Energy Consumption	Total Airport Partners Energy Consumption	See Energy Management Overview for Airport Partners	PetaJ or MWh
E4.	Total Renewable Consumption	Total Airport Company (or Airport Partner) Renewable Energy Consumption from all sources (on-site and off-site)		PetaJ or MWh
E5.	Total Non-renewable Consumption	Total Airport Company (or Airport Partner) Non-renewable Energy Consumption		PetaJ or MWh

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E6.	CHP	Total Airport Company (or Airport Partner) Combined Heat and Power (CHP) generation		PetaJ or MWh
E7.	Renewable Consumed off-site	Total Airport Company (or Airport Partner) Renewable Energy Consumed from off-site or grid		PetaJ or MWh
E8.	CPPA	Airport Company (or Airport Partner) Renewable Energy from Corporate Purchasing Power Agreements		PetaJ or MWh
E9.	Renewable Production	Total Airport Company (or Airport Partner) Renewable Energy Production on Site		PetaJ or MWh
E10.	Renewable Production used	Share of Airport Company (or Airport Partner) Renewable Energy Production that is used on site		PetaJ or MWh
E11.	Renewable production not used	Total Airport Company (or Airport Partner) Renewable Energy Production on site transported to grid or other off-site sources		PetaJ or MWh
E12.	Solar	Total Airport Company (or Airport Partner) Renewable Solar Energy Production on site		PetaJ or MWh
E13.	Biogas	Total Airport Company (or Airport Partner) Renewable Biogas Energy Production on site		m^3
E14.	Heat	Total Airport Company (or Airport Partner) Heat Generation on site		J
E15.	Other Renewable	Total Airport Company (or Airport Partner) Other Renewable Energy Production on site		PetaJ or MWh
E16.	Energy Efficiency		Primary Energy Consumption (Total Landside Energy Consumption E1.)/m^2	PetaJ or MWh
E17.	Energy Intensity		Nominator: Total Landside Energy Consumption (E1.) Denominator: Total number of passengers	PetaJ

E18.	Smart Electricity Meters		Numerator: Number of smart electricity meters installed. Denominator: Total number of electricity meters installed. Multiply by 100	%
E19.	Demand Response Penetration		Numerator: Number of demand response enabled electricity installations. Denominator: Total number of electricity installations. Multiply by 100	%

Table 4: primary indicator set for the measurement and evaluation of circularity actions in water management with KPI no. (KPI code), KPI name and definition, methodology for measurement and unit.

Water Management KPIs (W.)				
KPI No.	**KPI name**	**Definition**	**Methodology**	**Unit**
W1.	Total water consumption	Landside total water consumption		l/year
W2.	Water intensity	Total water consumption in function of the total number of passengers (pax) and employees		ratio
W3.	Tap water consumption	Landside Total Tap water usage		l/year
W4.	Freshwater consumption	Extraction of ground-or surface water		l/year
W5.	Rainwater consumption	Landside Total Rainwater Usage on site or to third parties		l/year
W6.	Recycled water consumption	Landside Total Recycled Water Usage		l/year
W7.	Internal recycling of wastewater	Total amount of water used more than once without purification treatment		l/year
W8.	Water Supply loss	Percentage of water loss in the water distribution system	Numerator: Volume of water supplied minus the volume of utilized water (l/year). Denominator: Total volume of water supplied (l/year). Multiply by 100	%
W9.	Wastewater collection	Percentage of Total Water Consumption served by wastewater collection	Numerator: Sum of Total Water Treated and Total Water Sewage Denominator: Total Water Consumption. Multiplied by 100	%

W10.	Total Water Treated	Total Wastewater Treated in on-site facility		l/year
W11.	Total Water Sewage	Total Wastewater diverted to sewage system with treatment off-site		l/year
W12.	Total Water Rainwater Sewage	Total Wastewater to communal rainwater sewage collection		l/year
W13.	Total Water Run Off	Total Water Not collected in Sewage or treatment facility		l/year
W14.	Airside Sanitary wastewater collection			l/year
W15.	Wastewater other			l/year
W16.	Nutrient Recovery from Wastewater Treatment			ton/year
W17.	Energy Recovery from Wastewater Treatment		To be included with E.15	MWh
W18.	Recycled water on-site water treatment facility	Recycled water usage stemming from on-site water treatment facility		

Table 5: primary indicator set for the measurement and evaluation of circularity actions in material and resource management with KPI no. (KPI code), KPI name and definition, methodology for measurement and unit.

Material and Resources Management KPIs (M.)				
KPI No.	**KPI name**	**Definition**	**Methodology**	**Unit**
M1.	Total amount of solid waste		Total amount of solid waste produced (Tons).	Tons
M2.	R0 Refuse	make a product redundant: abandon function or use different product	Total amount of materials that are refused	Tons
M3.	R1 Rethink	Make a product use more intensive: sharing or multifunctional products	Total amount of materials that are shared or used multifunctionally	Tons
M4.	R2 Reduce	Consume less through efficient manufacturing or use	Total amount of materials that is reduced	Tons
M5.	R3 Reuse	Re-use of functioning discarded products by another use	Total amount of materials that are reused	Tons

M6.	R4 Repair	Repair and maintain of defects to keep original function	Total amount of materials that are repaired	Tons
M7.	R5 Refurbish	Restore and update	Total amount of materials that are refurbished	Tons
M8.	R6 Remanufacture	Use part in new product with the same function	Total amount of materials that are remanufactured	Tons
M9.	R7 Repurpose	Use products or parts in new product with a different function	Total amount of materials that are repurposed	Tons
M10.	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality	Total amount of waste/materials that are recycled	Tons
M11.	R9 Recover Energy	Incineration of materials with energy recovery	Total amount of solid waste that is incinerated with the recuperation of energy.	Tons
M12.	R10 Waste disposal	Solid waste that is disposed to landfills/burnt in an open area/disposed in an open dump/other).	Total amount of solid waste that is disposed to landfills/burnt in an open area/disposed in an open dump/other) (Tons).	Tons

Table 6: primary indicator set for the measurement and evaluation of circularity and/or sustainability actions in transportation management with KPI no. (KPI code), KPI name and definition, methodology for measurement and unit.

Transportation Management KPIs (T.)				
KPI No.	**KPI name**	**Definition**	**Methodology**	**Unit**
T1.	Dynamic Public Transport Penetration	Percentage of urban public transport stops for which traveler information is dynamically available to the public in real time	Numerator: Number of stops and stations with dynamic information available. Denominator: Total number of stops and stations. Multiply by 100	%
T2.	Public Transport Network	Length of public transport network per 100,000 travelers	Numerator: length of public transport lines within terminal boundaries (km) (one-way length). Denominator: 100,000 travelers	kilometers/ 100.000 travelers
T3.	Bicycle Network	Length of bicycle paths and lanes per 100,000 travelers	Numerator: km of bicycle paths/lanes. Denominator: 100,000 travelers.	kilometers/ 100.000 travelers

T4.	Transportation Mode share	The percentage of people using various forms of transportation to travel to work	Numerator: Number of travelers using a specific transportation mode. Denominator: Total number of travelers. Multiply by 100. Report on modes: public transportation, personal vehicles, bicycles, walking, paratransit.	%
T5.	Travel Time Index	Ratio of travel time during the peak periods to travel time at free flow periods	Numerator: Travel time during peak periods (min). Denominator: Travel time during free-flow periods (min). The following should be taken into consideration for this indicator: ▪ TTI <= 1.5 is "Good"; ▪ TTI between 1.5 and 2.5 is "Potentially Acceptable"; and ▪ TTIs > 2.5 is "Less Desirable".	Ratio
T6.	Shared bicycles	Number of shared bicycles per 100,000 inhabitants	Numerator: Number of shared bicycles available. Denominator: One 100,000th of the city's population.	number/100.000 travelers
T7.	Shared vehicles	Number of shared vehicles per 100,000 inhabitants	Numerator: Number of shared vehicles. Denominator: One 100,000th of the city's population.	number/100.000 travelers
T8.	Zero emission vehicles	Percentage of zero emission passenger vehicles	Numerator: Number of zero emission vehicles registered (hydrogen & EV). Denominator: Number of total vehicles. Multiply by 100	%

6.2 SECONDARY KPIS

The secondary KPIs that can be derived from the primary indicators by means of calculation allow for a wide variety of ratios and/or percentages, as well as different currencies or the derivation of CO_2 equivalents, as desired by the terminal management board. Since including all potential secondary indicators in this report would become quite extensive, it is opted here to present a set of examples of secondary indicators for one sector, being construction and material management.

Table 7: secondary indicator set exemplifying secondary KPIs for the measurement and evaluation of circularity and/or sustainability actions in in construction and demolition with KPI no. (KPI code), KPI name and definition, methodology for measurement and unit

Construction and Material Management secondary KPIs (W.)				
KPI No.	**KPI name**	**Definition**	**Methodology**	**Unit**
C12.	% Upcycling Material	Percentage of demolished building material collected for upcyling	Tons/ total Tons of demolished material	%
C13.	% Recycling	Percentage of demolished building material with selective waste collection used for recycling	Tons/ total Tons of demolished material	%
C14.	% non-recyclable	Percentage of demolished building material identified as non-recyclable waste	Tons/ total Tons of demolished material	%
C15.	Upcycling promotion effort %	Percentage of upcycled material to be included in reuse inventories to be used off site	Tons/ total Tons of demolished material	%
C16.	Upcycling internal %	Total amount of demolished building material collected for upcyling on site and reused internally	Tons/ total Tons of construction material	%
C17.	Upcycling external %	Total amount of demolished building material collected for upcyling externally and used on site	Tons/ total Tons of demolished material	%
C18.	Sustainable construction material %	Total amount of sustainable construction material used on site	Tons/ total Tons of construction material per building	%
C19.	Virgin construction material %	Total amount of virgin construction material used on site	Tons/ total Tons of construction material	%
C20.	CO2 reduction upcycling	CO2 reduction from Upcycling Material from demolition		CO2 eq.
C21.	CO2 reduction Recycling	CO2 reduction from Recycling material from demolition		CO2 eq.

C22.	CO2 reduction promotion	CO2 reduction from upcycling material to be included in reuse inventories		CO2 eq.
C23.	CO2 reduction upcycling on site	CO2 reduction from Upcycling Material from demolition on site		CO2 eq.
C24.	CO2 reduction upcycling off site	CO2 reduction from Upcycling Material from demolition off site		CO2 eq.
C25.	CO2 Reduction Sustainable construction material	CO2 reduction from total amount of sustainable construction material used on site		CO2 eq.
C26.	€ waste diversion	€ saved from diverting material from waste disposal to upcycling	Reduced cost of waste collection services	€
C27.	€ upcycling	net € saved from the use of upcycling material (on-site & off-site collection)	Cost of purchasing virgin material minus de costs incurred for upcycling and the purchase of upcycled material off site	€

7. FRAMEWORK VALIDATION

7.1 VALIDATION PART I: ASSESSMENT OF AIRPORT PARTNERS' CIRCULARITY ACTIONS

The conceptualisation of this framework and KPIs is based on the case of Brussels Airport Company. In order to assess the applicability of the framework in a wider context, potential circularity actions at the partner airports of Athens, Toulouse Blagnac and Budapest are listed here and assessed according to the frameworks capability of integrating a variety of actions and the relevance of the indicators.

CIRCULARITY ACTIONS IN PROGRESS AT ATHENS INTERNATIONAL AIRPORT

- Strong involvement of all airport users for at source separation and recycling of waste. Currently, at least 70% of solid non-hazardous waste produced on-site is recycled
    - M10: total amount of waste or materials that are recycled (Tons)
    - M10 secondary indicator: total amount of waste or materials that are recycled (% and/or € and/or CO_2 equivalents)
- Program for advanced mechanical separation- in an advanced Materials Recovery Facility (MRF plant) - of waste not separated at source. Depending on the previous waste disposal with or without energy recovery, and the final destination of waste materials (repurposed or not) this action could impact respectively:
    - M11: Total amount of solid waste that is incinerated with the recuperation of energy (Tons)
    - M11 secondary indicator: Total amount of solid waste that is incinerated with the recuperation of energy (% and/or € and or CO_2 equivalents)
    - M12: Total amount of solid waste that is disposed to landfills/burnt in an open area/disposed in an open dump/other) (Tons)
    - M12 secondary indicator: Total amount of solid waste that is disposed to landfills/burnt in an open area/disposed in an open dump/other) (% and/or € and/or CO_2 equivalents)
    - M9: Total amount of materials that are repurposed (Tons)
    - M9 secondary indicator: Total amount of materials that are repurposed (% and/or € and/or CO_2 equivalents)
- All CDW (Construction/Demolition Waste) is separated and recycled off-site. Non-recyclable CDW is not produced
    - C3: Total amount of CDW with selective waste collection used for recycling (Tons)
    - C3 secondary indicator: Percentage of CDW with selective waste collection used for recycling (see C13) (% and/or €), or CO_2 reduction from Recycling material from demolition (CO_2 equivalents) (see C21)
- Certain CDW (such as milled asphalt or remains of antiskid inert produced during RWY pavement works) is not recycled but reused at the airport to pave certain areas.

- C2: Total amount of CDW collected for upcyling (Tons)
- C2 secondary indicators: Total amount of demolished building material collected for upcyling (% (C12), and/or CO_2 equivalents(C20), and/or €

- Certain CDW (mainly doors/windows/support beams/metallic staircases etc) is not disposed but rather stored and if not used in future construction projects, then recycled. In the case of reuse of CDW materials:
    - C2: Total amount of CDW collected for upcyling (Tons)
    - C2 secondary indicators: Total amount of demolished building material collected for upcyling (% (C12), and/or CO_2 equivalents(C20), and/or €

  In the case of recycling of CDW materials:

    - C3: Total amount of CDW with selective waste collection used for recycling (Tons)
    - C13 secondary indicator: Percentage of CDW with selective waste collection used for recycling (see C13) (% and/or €), or CO_2 reduction from Recycling material from demolition (CO_2 equivalents) (see C21)
- Small scale upcycling projects (e.g. construction of fences/recreation tables using wood/metallic items by the existing waste contractor, production of souvenirs made by expired life jackets of by local air carrier)
    - M9: Total amount of materials that are repurposed (Tons)
    - M9 secondary indicator: Total amount of materials that are repurposed (% and/or € and/or CO_2 equivalents)
- Excavated soil not disposed of-site rather on-site at certain areas requiring filling in light of future construction projects
    - C2: Total amount of demolished building material collected for upcyling (Tons)
    - C2 secondary indicators: Total amount of demolished building material collected for upcyling (% (see C12), and/or CO_2 equivalents (see C20), and/or €)

CIRCULARITY ACTIONS IN PROGRESS AT TOULOUSE BLAGNAC AIRPORT

- Setting up sorting bins for cans and bottles in the canteens
    - M10 Recycle: Total amount of waste/materials that are recycled
- Partnerships with organizations that refurbish and reuse used computer equipment for solidarity reuse, recondition and reuse professional furniture and old damaged armchairs into boarding seats, donations of uniforms for reuse
    - M5 Re-use of functioning discarded products by another use: Total amount of materials that are reused
    - M7 Refurbish: Total amount of materials that are refurbished
- 20% of asphalt used comes from recycled materials
    - C6 upcycling internal (or C7 upcycling external, depending on the source): Total amount of demolished building material collected for upcycling on site

  - and reused internally (or Total amount of demolished building material collected for upcycling externally and used on site)
  - C23 CO_2 reduction from Upcycling Material from demolition on site (or C24 CO2 reduction from Upcycling Material from demolition off site, depending on the source of the material)
- Recycling demolition waste
  - C3: Total amount of demolished building material with selective waste collection used for recycling (Tons)
  - C13 secondary indicator: Percentage of demolished building material with selective waste collection used for recycling (see C13) (% and/or €), or CO_2 reduction from Recycling material from demolition (CO_2 equivalents) (see C21)
  - C6 upcycling internal: Total amount of demolished building material collected for upcycling on site and reused internally
  - C23 CO_2 reduction from Upcycling Material from demolition on site

CIRCULARITY ACTIONS IN PROGRESS AT BUDAPEST INTERNATIONAL AIRPORT

- Planned: organic waste used at the terminal (food waste and coffee grounds) composting off-site by a partner; Security collected/lost items: most items cannot be reused due to Hungarian legislation and smaller items are offered for employees' auction, charity actions: some unused terminal items offered to Ukrainian airports or child playgrounds to nurseries, glycol recycling
  - M5 Re-use of functioning discarded products by another use: Total amount of materials that are reused
- Waste pre-sorting facility to maximize the recycling ratio of the whole airport (paper, PET/plastic, glass, cardboards are recycled by 3rd party partner)
  - M10 Recycle: Total amount of waste/materials that are recycled
- Office furniture refurbished
  - M7 Refurbish: Total amount of materials that are refurbished
- New hotel construction planned grey water collection for watering plants around the hotel
  - W7 internal recycling of wastewater: Total amount of water used more than once without purification treatment
- Water: Total Organic Carbon monitor to direct clean apron water to natural creeks
  - W13 Total water run-off to surface water
- waterless car-wash to save water, drinking fountains at the terminal to reduce plastic bottles
  - W3 Total Tap water usage
- Landside transport: internal bicycle lane connecting terminals
  - T3 Length of bicycle paths and lanes per 100,000 travelers

- Landside transportation zero emission (electric) vehicles increase
  - T8 Percentage of zero emission vehicles
- Recycling demolition waste: mostly broken concrete from the runway and taxiway refurbishments are used within the airport territory
  - C3: Total amount of demolished building material with selective waste collection used for recycling (Tons)
  - C13 secondary indicator: Percentage of demolished building material with selective waste collection used for recycling (see C13) (% and/or €), or CO_2 reduction from Recycling material from demolition (CO_2 equivalents) (see C21)
  - C6 upcycling internal: Total amount of demolished building material collected for upcycling on site and reused internally
  - C23 CO_2 reduction from Upcycling Material from demolition on site

7.2 VALIDATION PART II: ASSESSMENT OF OTHER AIRPORT TERMINAL CIRCULARITY ACTIONS

In order to extend the applicability of the framework to a wider context, potential circularity actions taken by airports worldwide are assessed here according to the frameworks capability of integrating a variety of actions and the relevance of the indicators.

EXAMPLE 1: PHILIPS LIGHTING SOLUTIONS (SCHIPHOL AIRPORT)

In its 2019 environmental report, ICAO reports on the iconic example of the partnership that was developed between Schiphol Airport and Philips in providing a circular lighting solution for airports (ICAO, 2019). In this light service solution, Philips remains the owner of the lamps and fittings. It is possible to replace separate components with ease, thus extending the service life of the lighting fixtures. When lamps reach the end of their service life, Philips will collect and recycle them. In terms of measuring progress, KPIs involved here are:

- Material and waste management
  - M3: R1 Rethink - Make a product use more intensive: sharing or multifunctional products (Tons)

This circular solution not only reduces 50 per cent energy consumption by energy-efficient LED lighting and extends 75 per cent service life of the fittings, but also reduces maintenance costs and raw material consumption. KPIs used could involve:

- Energy management:
  - E16: Energy efficiency – PetaJ or MWh
  - E17: Energy intensity - PetaJ or MWh
  - E16 and E17 secondary indicator: cost reduction and/or CO_2 emission reductions (€ and/or CO_2 equivalents)

EXAMPLE 2: SUSTAINABLE WASTE MANAGEMENT SYSTEMS (VANCOUVER INTERNATIONAL AIRPORT, GENEVA AIRPORT, PORTLAND INTERNATIONAL JETPORT, QUEENSTOWN AIPORT)

The commercial aviation industry body Air Transport Action Group (ATAG), representing all sectors of the air transport industry, including airports, airlines, airframe and engine manufacturers, air navigation service providers, and tourism and trade partners released the website 'Aviation: benefits beyond borders' (https://aviationbenefits.org/) to promote "*aviation's sustainable growth for the benefit of global society*" and to "… *provide clear information on the many measures and initiatives taken by the industry to limit the environmental impact of aviation*". The site displays a wide variety of circular initiatives undertaken both by airlines and airports. In the paragraphs below, three examples featured on the site are used as an example of how the KPIs constructed here can be used to measure a variety of circular actions taken at airport terminals.

"Vancouver International Airport surpassed its ambitious target of diverting half the waste produced at the terminal from going to landfill by 2020, achieving 51% terminal waste diversion in 2016 and 2017. The airport supplemented long-standing recycling programmes with community engagement initiatives and installed a centralized food court sorting station. This organic waste recycling programme dramatically increased their waste diversion." The following KPIs could be used:

- KPIs from Material and Waste management that could be used:
    - M12: Total amount of solid waste that is disposed to landfills/burnt in an open area/disposed in an open dump/other) (Tons).
    - M12 secondary indicator: Total amount of solid waste that is disposed to landfills/burnt in an open area/disposed in an open dump/other) (% and/or € and/or CO2 equivalents

"At Geneva Airport, the recycling rate in the main terminal increased from 49% to 53% between 2016 and 2017, thanks to the installation of new sorting centers in front of the new check-in hall façade, and the implementation of a new process enabling passengers to keep their bottles by emptying them before passing through security."

"A different type of recycling programme was developed by Portland International Jetport in collaboration with Inland Technologies. Together, they created a recycling programme to recapture the superfluous aircraft de-icing fluid after it is sprayed on planes and turn it back into de-icing fluid. It is the first recycling programme of its kind in the United States and Portland Jetport became the first airport in the country to use 100% recycled aircraft de-icing fluid."

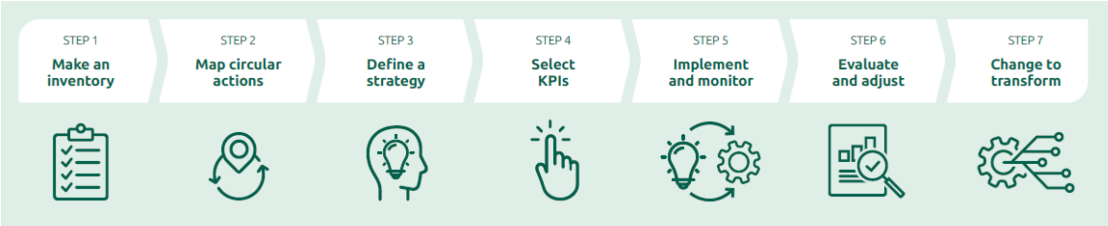
- KPIs from Material and Waste management that could be used:
    - M10: total amount of waste or materials that are recycled (Tons)
    - M10 secondary indicator: total amount of waste or materials that are recycled (% and/or € and/or CO_2 equivalents)

“*Queenstown Airport* turned trash to treasure for its latest resurfacing project by using a new lower carbon asphalt which incorporates waste printer toner and recycled glass to resurface its aircraft parking area beside the terminal building.”

- KPIs from Material and Waste management that could be used:
  - M9: Repurpose – use products or parts in new product with a different function (Tons)
  - M9 secondary indicator: Repurpose – use products or parts in new product with a different function (% and/or € and/or CO_2 equivalents)
  - M6: Repair (resurfacing of the aircraft parking) - Repair and maintain of defects to keep original function (Tons)
  - M6 secondary indicators: Repair (resurfacing of the aircraft parking) - Repair and maintain of defects to keep original function (% and/or € and/or CO_2 equivalents

8. FRAMEWORK APPLICATION

In order to successfully implement circular strategies at airport terminals, a step-by-step strategy is formulated here, based on the conceptual framework and development of KPIs as elaborated above. Considerable attention is also given here to the organisational change management that is required in order to successfully implement a transformation process in the organisation towards better resource circularity.



STEP 1

Make an inventory of airport resources and assets. This identification facilitates the identification of potential circularity actions that can be developed (see 4.3 for more information or **Error! Reference source not found.**) representing a generic overview of the airport terminal assets and products (adapted from U4SCC guide to circular cities).

STEP 2

Collect examples of circular actions that have the potential to be applied at the terminal. A non-exhaustive list of potential circular actions is provided in Annex1. More case studies can be found at the Ellen Mac Arthur Foundation (https://ellenmacarthurfoundation.org), in the scientific literature (see examples of waste management practices in Sebastian et al., 2021), websites reporting on sustainable aviation (https://aviationbenefits.org/), circular city initiatives or dedicated reports from the European and International Organizations (https://unece.org/sites/default/files/2021-01/2020_A-Guide-to-Circular-Cities.pdf).

STEP 3

In order to identify, implement and monitor circular actions, a clear strategy is needed, whereby priorities are identified (e.g. food waste reduction), targets and goals for actions are set (e.g. 30% reduction by 2030) and a monitoring process is developed. Development of the monitoring process also involves determining the frequency of measurement, which depends on the type of action and the measuring instruments in place.

STEP 4

Before the circular action is implemented, baseline measurements are performed, through selecting and measuring the KPIs as developed in this framework. The baseline measurement enables a calculation of selected KPIs for the baseline scenario and serves as the reference point towards which action progress can be measured to track the impact from a future implementation of identified circular actions.

STEP 5

Implementation and monitoring of circular actions.

STEP 6

Circular action evaluation and adjustment.

STEP 7

Last, in order to facilitate the transition to resource circularity, organizational change management as a transformation process to resource circularity is needed. Organizational change can be defined as '*the process of continually renewing an organization's direction, structure, and capabilities to serve the everchanging needs of external and internal customers*'(Moran & Brightman, 2000). It requires *'establishing a sense of urgency to change, forming leading teams, then building a vision with clear goals and rules, communicating the vision, involving all stakeholders and finally monitoring progress, adjusting and scaling up'* (Klein et al.). It is an internal process that devotes considerable time, efforts and resource to prepare for an organizational structural change.

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10. Annex 1

Examples of potential circularity actions

Terminal assets and products			Location	Strategy	Details	Source
Terminal Resources	Natural	Energy	Various airports	Production of biogas from organic materials	Some airports like Cochin International Airport adopt anaerobic digestion to divert their organic wastes on-site, instead of composting, in turn generating biogas [99] Gatwick airport is one of the first airports in the world to have a waste processing and conversion facility on-site. Food wastes, meal plates, cups, etc. are dried, pelletised, and fed to an incinerator, and the recovered energy is used to heat part of the terminal. The recycling rate at the airport is stipulated to jump to 85%, within 5 years of operation of this facility. The facility has a capacity of 10 TPD [100] and can generate about 1 MW renewable energy [37].	Sebastian 2021
Terminal Resources	Natural	Energy	Various airports	Production of heat from waste	Kansai International Airport also relies on a fluidized bed furnace to incinerate the combustible wastes. The heat recovered is used for air heaters, while hot water generated is used for room heating or tap water heating [101].	Sebastian et al., 2021
Terminal Resources	Natural	Energy	Schiphol Airport	Energy efficiency	Schiphol Airport in collaboration with Philips transitioned to an energy-efficient lighting system that allows 75% longer service life, and a 50% reduction in energy consumption by the lighting system. Philips collects and recycles the lighting systems at the end of the service period. The system reduces maintenance costs, allows easy servicing and replacement, and minimized raw material consumption.	Sebastian et al., 2021
Terminal Resources	Natural	Land & soil	Portland Airport (USA)	Planting of native plant species	We've planted 100,000 native plants to enhance wetlands at Troutdale Reynolds Industrial Park. Site development will close 3 gaps in the 40-mile loop trail.	

Terminal Resources	**Waste**	**All organic**	Various airports	Valorization of organic waste to compost and fertilizer	Looking at the composting operations at airports, it was observed that food wastes, green wastes from landscaping activities, coffee grounds, paper towels, etc. were mostly diverted to either in-house or regional composting units. The implementation of composting activities involve placing separate collection bins for segregated collection and subsequent hauling to composting facilities. For instance, SeattleTacoma International Airport composts food wastes like coffee grounds along with yard wastes. The Metropolitan Airports Commission (MAC) uses the compost produced along with topsoil for landscaping activities at Minneapolis St Paul International Airport [21]. Denver International Airport along with some restaurants in the airport composts organic wastes and paper towels diverting more than 72 tonnes from landfills during the initial stages [97]. Detroit Metropolitan Airport also has a coffee grounds composting program as a part of its diversion efforts [98]. Treatment of green waste or landscaping waste also plays a major role in increasing the diversion rates at airports. Grass cuttings, trimmings, etc. are composted at composting facilities within the airport or Table 4 Waste diversion initiatives by airports. Airport Waste diversion initiative Reference Atlanta International Airport Leases to tenants restrict the use of single-use plastics and encourage compostable alternatives. Lease is suspended after a third violation of the clause. Styrofoam and number 5 plastics banned. Collected plastic bottles repurposed into the fabric for clothing post-processing. Constructing Green Acres, an in-house recycling and composting unit to divert 30,000 TPY of wastes. [82] Shanghai Pudong Airport Oil-water separators and dedicated garbage containers used for kitchen wastes. [29]	Sebastian et al., 2021

Terminal resources	**Waste**	**All organic**	Various airports		Changi Airport Use of recycled materials for on-site construction, including runways, roadways, and drains [32,74] Vancouver International Airport 51% diversion in 2016–17. Organic waste reduction through Metro Vancouver's regional organic waste van. [68,72] Geneva Airport Recycling rate increased from, 49–53% in 2016–2017. [72] Gatwick Airport Constructing an in-house material sorting facility to enhance diversion. Zero Waste to Landfill certification acquired in 2018 from Carbon Trust. [82] Queenstown Airport Use of waste printer toner and recycled glass in developing low carbon asphalt for resurfacing operations [72] Galapagos Airport Terminal construction through the use of 80% of recycled materials from demolished buildings, recycled petroleum exploration pipes, etc. [74] Denver International Airport Zero waste airport by 2020 [34] Munich Airport Recycling rate of 79%. 11% of the remaining portion was sent to the biogas plant and the remaining 10% ended up in landfills. [83] Goodyear And Deer Valley Airport 50% diversion by 2020. [84] Indianapolis International Airport Reused/recycled 87% of the C &D wastes from terminal demolition. [48] Cincinnati/Northern Kentucky International Airport Recycling of old concrete and asphalt from the airfield. Light bulbs and batteries are also recycled at the airport. [85] San Diego International Airport 90% diversion of C& D wastes. 50,832 tonnes of C & D wastes diverted in 2018. [62] Victoria International Airport On-site composting facility for the landscaping waste and has generated more than 27 tonnes of compost. [81] Sunshine Coast Airport Use of solar-powered On-Site Compositing Apparatus (OSCA) and use of compostable packing and cutlery. [86] Naples International Airport Segregated collection implemented in 2017, by which 62% was recycled and the rest sent for energy recovery. Doorto-door waste collection in airport buildings; stakeholder engagement through campaigns to reduce the use of plastics. [46]	Sebastian et al., 2021

Terminal Resources	Waste	All organic			Tulsa Airport Diversion rate of 82%. C&D wastes from runway reconstruction used for pavement modeling diverting 170,000 tonnes of wastes. [87] Abu Dhabi International Airport Recycled materials in all structural and reinforcing steel. Only recycled aggregate used for backfilling. 96% waste diversion rate. [88] Delhi International Airport Elimination of single-use plastics within the airport. To be replaced with green and sustainable alternatives. [89] Adelaide Airport Over 95% of C&D wastes recovered in 2018. [90] Table 4 (continued) Airport Waste diversion initiative Reference Oakland International Airport Pillow recycling program to collect airline pillows for use as an insulation material or in furniture. Diverts over 75 tonnes of food wastes for use as high nutrient fertilizer in organic food production. Diverts over 340 tonnes of recyclables from landfills. [91] Toronto Pearson International Airport 72% waste diversion, excluding cabin wastes. Program to recycle C&D and organics wastes. Initiatives like Paper Cut, collaboration with Partners in Project Green, Diabetes Canada, etc. to achieve waste reduction. [92,93]. Sydney Airport Elimination of single-use plastic bags, plastic straws, etc., and recycling of organics on groundside of terminals. Water fountains reduce 1400 plastic bottles daily. 43% waste diversion, excluding quarantine wastes. [35] Portland International Jetport The first airport in the US to use 100% recycled aircraft de-icing fluid. Diverted 2350 tonnes of food wastes since 2003. Aims to get a net waste diversion of 90%. [61,72] Dallas/Fort Worth International Airport Eliminating single-use plastic straws gradually, to achieve a reduction of 4 million straws from the waste stream, on the complete ban. Washed out concrete recycling diverted 1000 tonnes of concrete from landfills. [82] R.M. Sebastian and J. Louis Renewable and Sustainable Energy Reviews 147 (2021) 111229 10 off-site, wherever applicable. London Stansted airport, for instance, composts about 600–800 tonnes of green waste annually and projects it as a part of their recycling targets [28].	
Terminal Resources	Waste	All organic	Victoria Airport Authority	On-site composting	Victoria Airport Authority also employs recycling and on-site composting of organics including coffee grounds. The composting facility has generated 27 tonnes of soil, which has been used as fill material. 21% diversion was achieved through these activities by the Victoria Airport Authority (VAA) [81].	Sebastian et al., 2021
Terminal resources	Waste	Food waste	Various airports	Donation of food to local shelters	Another successful practice for airport waste reduction include the implementation of food donation drives, to donate consumable food from various businesses in the airport vicinity to local shelters. Some of the food wastes like cooking oils are also recycled by some airports. Seattle-Tacoma International Airport is one such example where unused food is donated to local food banks to reduce wastage. It has also been reported to divert reclaimed cooking oils for biodiesel production [21]. San Diego International Airport through US Food Loss and Waste 2030 Champions [57], Austin-Bergstrom International through Food Rescue. Program [64], Denver International Airport through Metro Caring [65] are examples of other airports which donate food to minimize wastes.	Sebastian et al., 2021

Terminal Resources	Waste	Cargo operations waste	Various airports		Cargo operations at the airport are a major point of generation of recyclable materials like wooden pallets, plastic, cardboard, paper, etc. If the cargo handling and shipping companies can reuse the wooden pallets or minimize the paper and cardboard packaging, it can significantly reduce the associated wastes being generated. San Diego International Airport has introduced terms into contract agreements with the stakeholders to achieve sustainability and zero waste targets [62]. London Stansted airport also encourages its delivery partners to reduce the packing like metal cages and pallets and returns abandoned packing material to owners or interested third parties [28]. Old staff uniforms are also donated to charity for making quilts.	Sebastian et al., 2021
Terminal Resources	Waste	Beverages	Various airports	Beverage collection services before security screening	Some of the measures commonly adopted by airports to minimize wastes include a liquid collection and disposal system on the groundside to dispose of the liquids before the security screening and in turn, reduce the energy consumption in waste management processes. This practice is evident at San Francisco International Airport (SFO), Oakland International Airport, etc. [5]. Portland International Airport was reported to have saved 30,000 USD in labour costs through beverage collection stations (Portland State University, 2019). Similarly, the San Diego County Regional Airport Authority targets a reduction of 5% in the per capita generation by 2025, from the rate of 0.26 kg/cap in 2018 [62]. Waste minimization at Christchurch Airport, NZ, on the other hand, was mostly through reduction of surplus stock procurement and on-site storage [63].	Sebastian et al., 2021
Terminal Resources	Waste	Other waste	Various airports	Airport waste reduction actions	Some of the other potential actions which can reduce the wastes at the airport include: • Contractual agreements to use refillable containers for cleaners and other fluids • Use of compostable and durable serving ware for foodservice operations • Agreement to reduce the packaging in cargo transport services • Passengers encouraged to carry fewer liquids, gels, aerosols, etc. as carry-on items. Employing Green Concessions Program and other incentive-driven programs will encourage the airport tenants and surrounding businesses to reduce the use of non-biodegradable packaging and switch to sustainable compostable alternatives. A typical Green Concessions Program encourages airport concessionaires to adopt sustainable practices for business and the environment. Use of recyclable food packaging, and serve ware, elimination of single-use plastics by choosing alternative materials, source-segregation of recyclables, compostables, and disposables, elimination of Styrofoam use in daily operations, use of biodegradable trash bags, etc. are some of the green initiatives specific to waste management. Airport concessionaires who adopt such sustainable practices get certified as 'Green Concessions', and receive exclusive marketing support from the airport authorities [66,67]. Some airport authorities also rely on incentive-driven programs to encourage compliance by the airport businesses. Vancouver Airport Authorities were exploring such programs for eliminating plastic bags and encouraging the use of compostable tableware in the food courts [68]. Incentive-driven programs have also been employed by some airports to reduce waste generation and disposal.	Sebastian et al., 2021

Terminal resources	Waste	Non-recyclable waste	Heathrow Airport	Conversion of non-recyclable plastic to furniture, fuel & uniforms	A new technology to convert non-recyclable plastic wastes including food packing and plastic films into airport furniture, renewable fuels, uniforms, etc. is also being initiated by Heathrow airport. The plan, which is stipulated to divert 5000 tonnes of plastic waste annually from incineration, can recycle 100% of plastic wastes at Heathrow. The plastic is converted into oil, which is upgraded using renewable hydrogen to low-carbon products [103].	Sebastian et al., 2021
Terminal Resources	Services	Commercial waste from airport	Various airports	Commercial waste reduction incentives for tenants	Specific initiatives and targets set by airport authorities to deal with wastes generated by airport businesses and tenants and airport operations.	Sebastian et al., 2021
Terminal Resources	Services	All waste	Gatwick Airport	Redesigning waste collection	The waste management system at Gatwick was hence, redesigned to allow efficient waste collection, segregation, and on-site utilisation. The resultant reduction in the consumption of energy, and water, and offsite processing and disposal costs, combined with the financial benefits of increased recycling have led to a net reduction of 1 million USD in the annual operation costs [127]	Sebastian et al., 2021

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